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Potassium Requirements and Fertilization of Rice and Irrigated Soybeans

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Potassium (K) is a macronutrient taken up by plants in large quantities with total aboveground uptake in mature crops approaching or exceeding the equivalent of 200 lb K_2O/acre. Potassium performs important roles in enzyme activation, photosynthesis, photosynthate translocation, protein synthesis (i.e., nitrogen use) and plant water relations and is known to play an important role in the plant's ability to resist disease. Potassium fertilizer use in Arkansas has declined since 2007 when fertilizer prices increased and is cause for concern regarding soil K fertility in Arkansas soils with low cation exchange capacity. Use of insufficient K fertilizer rates on silt and sandy loam soils for several years will lead to K deficiency and yield loss. The objectives of this fact sheet are to (1) provide the most up-to-date information regarding K fertilization of rice and soybeans, (2) provide guidelines for diagnosing K deficiency and (3) aid growers in interpreting and using soil test information.

Potassium Deficiency Symptoms

Potassium deficiency of rice is most frequently observed between beginning internode elongation and heading. Deficiency symptoms may be most dramatic in levee ditches because the rice is growing in a deep flood and is rooted in subsoil low in K. The most prominent visual symptom of rice K deficiency is yellowing of the leaf tip margins beginning with the oldest leaves. In severe cases, the yellowing begins at internode elongation and becomes increasingly worse as rice progresses toward heading. Fields often take on a brownish-red appearance as leaf tips turn brown. Discoloration may be due in part to increased severity of brown spot disease on leaves or stem rot on infected tillers. Potassium-deficient rice may also be shorter and respond less vigorously to preflood and midseason nitrogen (N). Rice that is K deficient may fail to "green up" after application of midseason N. A study conducted in 2010 showed that rice yield failed to increase from N fertilization when no (0 lb K_2O/acre/year) or suboptimal (40 lb K_2O/acre/year) K fertilizer rates had been applied for the previous 10 years (Table 1).

Potassium deficiency can be diagnosed by analysis of the whole aboveground portion of the rice plant. Rice whole-plant concentrations <1.7% K are deficient, and a range of 1.7% to 2.3% K is considered low at internode elongation. At late boot to early heading, whole-plant concentrations of 1.1% to 1.3% K are considered low, and <1.1% K is deficient. Whole-plant sodium (Na) concentrations also tend to be very high (>2,000-3,000 ppm) when K is low or deficient.

Soybeans show symptoms similar to those described for rice with yellowing beginning on the margins of the lower and middle leaves. Symptoms on soybeans usually appear near or

TABLE 1. Rice yield response to nitrogen (N) and potassium (K) fertilizer after 10 years of cropping and applying different K fertilizer rates to the same plots.

Annual K Rate	Preflood Nitrogen Rate (lb N/acre)			
	80	120	160	200
lb K_2O/ acre	- - - - - - - - Rice Yield (bu/acre) - - - - - - - -			
0	88	87	87	79
40	106	108	105	109
80	110	118	117	118
120	116	122	128	131
160	116	124	134	136
LSD0.10	5 bu/acre (compare N rate means within a K rate)			
LSD0.10	7 bu/acre (compare two means across K rates)			

after blooming (on determinate varieties) when the demand for K uptake by soybeans increases. However, K deficiency may be observed as early as the V3-V4 growth stage when soil moisture is low, soil is compacted and/or soil K availability is extremely low. Potassium deficiency of soybeans can be diagnosed by sampling mature trifoliate leaves (no petioles) at the R2 growth stage. Arkansas research suggests that soybean leaves with >1.9% K are sufficient, 1.5% to 1.9% K are low and <1.5% K are deficient. The growth stage and the plant part sampled are both important aspects of interpreting tissue analysis results.

Dramatic visual symptoms of K deficiency are usually expressed only when K is very limited. Observations in K-fertilization trials indicate that soybean and rice plants may show no visual symptoms of K deficiency (hidden hunger) but produce significantly greater yields when sufficient K is applied. In soybeans, symptoms resulting from cyst nematode damage and K deficiency may be similar, making it important to properly examine soybean root systems when troubleshooting fields.

Rice and soybeans are more susceptible to many plant diseases when K nutrition is low or deficient, which can cause yield and/or quality losses beyond that caused from the physiological effects of insufficient K nutrition. High incidence of brown leaf spot (*Bipolaris oryzae*), stem rot (*Sclerotium oryzae*) and other opportunistic diseases are important signs of potential K deficiency in rice. Increased incidence of seed decay caused by *Diaporthe*/*Phomopsis* spp. and purple seed stain (*Cercospora kikuchii*) have been associated with K deficiency of soybeans. Generally, on soils with suboptimal soil K availability, rice and soybean yields are maximized and disease susceptibility minimized when sufficient K is applied preplant or early postemergence. Mid- and late-season K fertilizer applications of granular fertilizer to K-deficient rice and soybeans can produce significant yield increases, but the magnitude of yield increase usually declines as K fertilization is delayed. Although foliar feeding may reduce yield loss from K deficiency, only small amounts of K can be applied in a single application without significantly burning plant leaves. Since K is a macronutrient and is taken up in large amounts, application of granular K fertilizer followed by irrigation or a timely rainfall is the salvage practice most commonly recommended.

Soil Sampling for K

Proper soil sampling and testing are critical components for developing K-fertilization programs for rice and soybean production on silt and sandy loam soils. Fertilizer recommendations for rice and soybean production are based on soil samples collected from the 0-4 inch depth between January and May. Sampling to depths greater than 4 inches usually results in lower soil-test K values because K is stratified in most silt and sandy loam soils. Soil samples collected from the 0-4 and 0-6 inch depths of seven silt loam soils showed the average difference in soil-test K was 13 parts per million (ppm) between the 0-4 (109 ppm) and 0-6 (96 ppm) inch depths, a 12% decrease, with a range of 3 to 24 ppm, depending on the site. While this difference seems small, it is enough to significantly change the recommended fertilizer rate. Collecting samples from depths less or greater than 4 inches may under- or over-estimate, respectively, the recommended rate of K fertilizer.

The time of year soil samples are collected can also influence soil-test K. In general, soil samples collected in the early fall (September) following crop harvest have lower soil-test K than soil samples taken from November through May. Thus, K fertilizer recommendations are apt to be higher for samples collected in the early fall. The change in soil-test K across time following crop harvest varies somewhat among soils as it is affected by the previous crop grown (and how it was managed), soil-buffering capacity, initial soil-test K and environment (soil moisture), among other factors, making it difficult to predict how much soil-test K will change in every situation. For these reasons, soil samples should be collected at similar times of the year, crop rotation cycle (e.g., following soybeans) and field conditions (soil moisture status). Growers are encouraged to sample once every two or three years and retain a history of field-specific soil test results. In some years, soil-test K may be unusually higher or lower than normal and may require that soil test results from previous years be referenced and possibly used to make fertilizer recommendations.

TABLE 2. Descriptive statistics for soil-test potassium (K) from five silt loam fields in eastern Arkansas that were grid sampled.

Field Site	Field Size	Sample No.	Soil-Test K				Soil-Test K Level[3] Distribution			
			Maximum	Minimum	Mean	Std. Dev.[1]	Very Low	Low	Medium	Optimum
	acres	#[2]	ppm	ppm	ppm	ppm	- - - - - - - % of samples - - - - - - -			
St. Francis[4]	68	27	138	73	94	14	0	44	52	4
St. Francis[4]	68	27	150	47	96	30	7	44	30	19
Poinsett	163	67	114	32	63	16	51	42	7	0
Greene[5]	81	28	142	66	98	19	0	39	54	7
Craighead[5]	24	9	85	46	64	13	33	67	0	0

[1]Std. Dev. – Standard deviation of mean soil-test K.
[2]Number of grid samples collected in each field using the grid intersection sampling method.
[3]Soil test levels: Very Low, <61 ppm; Low, 61-90 ppm; Medium, 91-130 ppm; and Optimum, 131-175 ppm.
[4]The St. Francis county field was grid sampled in consecutive years.
[5]Soil test information from Arkansas Soybean Research Verification Program fields.

Soil K levels vary within a single field. Soil samples are usually collected by (1) some form of grid sampling, (2) zone sampling based on soil characteristics or crop performance or (3) the field average sampling method, where one or more composite samples are collected from areas representing ≥20 acres per sample. The typical row-crop soil sample collected using the field average technique in Arkansas represents about 45 acres. Collecting a sufficient number of soil cores across a single field (15-25 cores) provides the average soil test level within a field. Information from grid-sampled fields indicates the typical range of soil-test K within single fields (Table 2). This is especially useful for understanding the field average soil-test K from samples that represent ≥20 acres. The range (minimum to maximum) of soil-test K for the grid-sampled fields shown in Table 2 was 39 to 103 ppm. The standard deviation of each field's mean soil-test K simply indicates that the majority of grid samples would have a soil-test K within one standard deviation above and below the field mean. In most fields, a properly collected composite soil sample provides a good estimate of K availability for the majority of the field. University of Arkansas K-fertilizer recommendations are based on stepwise soil-test K levels that encompass a range of soil-test K concentrations of 30 to 40 ppm to help account for slight variations in K availability within a field.

Interpreting Soil-Test K

Soil-test K, as determined by the Mehlich-3 soil test method, is a good indicator of soil K availability. Research focused on correlating and calibrating soil-test K for these crops with the goal of verifying or refining K-fertilization recommendations was conducted between 2004 and 2010. The basic concept of soil testing is that (1) crop growth/yield benefits from fertilization occur frequently in soils that have low nutrient availability, (2) the probability and magnitude of yield increases decrease as soil nutrient availability increases and (3) eventually soil nutrient availability is great enough (Optimum) that crop yields do not show immediate benefits from fertilizer application.

Research results show that rice and soybean yields were increased by application of optimal rates of K fertilizer in 86% to 100% of the field trials conducted on soils having soil-test K values that averaged ≤90 ppm (Table 3) and, therefore, were categorized as having "Very Low" or "Low" soil-test K levels. Soils possessing Low or Very Low soil K availability had yield losses that averaged 18% to 21% for rice and 22% to 37% for soybeans. Of the soils classified as having a "Medium" soil-test K, significant yield increases from K fertilization occurred on 0% to 55% of these fields, with the average yield loss ranging from 4% to 11%. Rice and soybean yields are not likely to be increased by K fertilization on soils that have "Optimum" soil-test K levels, but application of some K fertilizer will help maintain the Optimum K availability level by replacing some K that is removed by the harvested crop. This approach is currently used in soybean K recommendations. A nominal amount of K fertilizer is recommended for soybeans grown on soils that have an Optimum soil-test K level

TABLE 3. The influence of potassium (K) fertilization on the frequency and magnitude of rice and soybean yield for selected soil-test K (Mehlich-3) ranges as determined in K-fertilization research in Arkansas.

Soil-Test K		Sites Tested		Average Yield (across all sites)†		
Level	**Range**	**Total**	**Responsive**	**No K**	**Fertilized**	**Loss**
	ppm	n	% of Total	bu	bu	bu (%)
RICE						
Very Low	<61	5	100%	143	180	37 (21%)
Low	61-75	8	88%	147	184	37 (20%)
Low	76-90	10	90%	152	185	33 (18%)
Medium	91-110	11	55%	171	184	13 (7%)
Medium	111-130	3	0%	160	166	6 (4%)
Optimum	>130	8	0%	181	183	2 (1%)
SOYBEANS						
Very Low	<61	4	100%	29	46	17 (37%)
Low	61-75	6	100%	44	61	17 (28%)
Low	76-90	7	86%	46	59	13 (22%)
Medium	91-110	16	44%	51	57	6 (11%)
Medium	111-130	6	33%	50	55	5 (9%)
Optimum	>130	6	0%	62	64	2 (3%)

† Within each row, the “No K” column indicates the average yield of rice or soybeans receiving no K fertilizer compared to the average maximum yield fertilized (column heading “Fertilized”) with K. The column labeled “Loss” gives the average yield difference and percent yield loss when no K was applied.

(Table 4). Arkansas research has defined the critical soil-test K values as 103 ppm (± 9 ppm) for rice and 108 ppm (±5 ppm) for soybeans, which would be included in the lower half (91-110 ppm K) of the Medium soil test level. These critical soil test values can be interpreted as fields that have lower values typically respond to K fertilization and fields that have higher values do not usually respond to K fertilization.

K-Fertilizer Rate Recommendations

Results from over 40 K-fertilization trials (Table 3) with rice and soybeans were used to calibrate K-fertilizer rates to soil-test K and crop yield potential. The relationships between selected K-fertilizer rates and soil-test K are shown in Table 5. Information contained in Table 5 can be used to estimate the general benefit of different K-fertilizer rates at different soil-test K values. For example, if a soybean field has an average soil-test K of 75 ppm, Table 4 indicates that the recommended K rate is 120 lb K_2O/acre. Table 5 shows that a maximal soybean yield would be expected if 120 lb K_2O/acre were applied, but yield losses of 6%, 11% or 21% could occur if less-than-recommended K-fertilizer rates of 100, 60 or 0 lb K_2O/acre were applied, respectively.

TABLE 4. Soil-test potassium (K; Mehlich-3) concentrations, soil-test K levels and the associated K-fertilizer rates recommended for rice and soybeans.

Soil-Test K		Recommended K-Fertilizer Rate	
		Rice	**Soybeans**
Level	ppm	lb K_2O/acre	
Very Low	<61	120	160
Low	61-90	90	120
Medium	91-130	60	60
Optimum	131-175	0	50
Above Optimum	>175	0	0

TABLE 5. Predicted yield loss at selected soil-test potassium (K) values and different K-fertilizer rates. The shaded area of the table indicates that near maximum or maximum yields (95%-100% of yield potential or <5% yield loss) will be produced by the associated K rate. Note: Yield loss estimates were rounded and expressed as whole numbers for simplicity.

Soil-Test K	K-Fertilizer Rate (lb K_2O/acre)							
	0	40	60	80	100	120	140	160
	Estimated % yield loss at selected soil-test K and K-fertilizer rates							
RICE								
45 ppm	22	16	13	11	8	6		
60 ppm	17	12	10	7	5			
75 ppm	13	9	7	5				
90 ppm	10	6						
105 ppm	7							
120 ppm								
135 ppm								
SOYBEANS								
45 ppm	32	23	19	15	12	9	6	
60 ppm	27	18	15	11	9	6		
75 ppm	21	14	11	8	6			
90 ppm	17	10	8	6				
105 ppm	12	7	5					
120 ppm	9	5						
135 ppm	5							

The mathematical relationships that were defined by research, used to correlate and calibrate K-fertilizer recommendations and to develop the information given in Table 5, were simplified to develop an equation for variable rate fertilizer applications. The simplified (linear) equations for calculating the K-fertilizer rate to produce 95% to 100% of maximum yield for rice and soybeans are given in Equations 1 and 2 below (where x = Mehlich-3 soil-test K in ppm):

[Equation 1 – Rice] $\text{lb } K_2O\text{/acre} = 223 - 1.825x$

[Equation 2 – Soybean] $\text{lb } K_2O\text{/acre} = 237 - 1.609x$

Potassium-fertilizer rate recommendations provided on University of Arkansas Soil Test Reports are based on the soil-test K levels listed in Table 4. These stepwise recommendations are based on satisfying the amount of K to produce maximum crop yields and to gradually build soil-test K levels over time. Recommendations were based on this philosophy to accommodate the field average soil-sampling strategy. The equations listed above can also be used to determine a more specific K fertilizer rate for field average samples. For soils having a "Medium" soil-test K level, this approach may result in a very low K rate recommendation. Uniform distribution of very low rates of granular fertilizer may be difficult, especially if the fertilizer spreader is not properly calibrated.

Concern has been expressed over the potential for inducing chloride injury from the application of high K rates using muriate of potash fertilizer. The maximum K_2O rate applied preplant as muriate of potash evaluated in rice and soybean research has been 160 lb K_2O/acre. We have noticed no injury or adverse effects on yield from K rates >120 lb K_2O/acre in research trials conducted on silt loam soils. Although the amount of chloride applied with high rates of muriate of potash is significant and crop injury is possible, chloride toxicity will not likely be caused exclusively by the application of K fertilizer. In many fields, irrigation water is the single greatest contributor to chloride injury of crops. Fields having a history of salt injury or chloride toxicity should be managed using a number of practices that may reduce chloride injury risk. Such practices include but are not limited to growing a chloride excluder soybean cultivar, application of K fertilizer far in advance of planting (fall or winter), split applications of K fertilizer, use of K-fertilizer sources that do not contain chloride and eliminating potholes or low spots in fields where salts may accumulate.

Rice and Soybean Grain Nutrient Content

Arkansas research shows that harvested rough rice, on average, contains 0.28% K and 0.30% phosphorus (P) and soybean contains 1.71% K and 0.51% P. On average, rough rice seed contains the equivalent of 0.15 lb K_2O and 0.31 lb P_2O_5/bu. A rice yield of 180 bu/acre removes 27 lb K_2O and 56 lb P_2O_5/acre, which is equivalent to 45 lb/acre of muriate of potash (60% K_2O) and 122 lb/acre of triple superphosphate (46% P_2O_5). Soybean seed contains the equivalent of 1.2 lb K_2O and 0.70 lb P_2O_5/bu. A soybean yield of 60 bu/acre removes a total of 66 lb K_2O and 46 lb P_2O_5/acre, which is equivalent to 110 lb of muriate of potash and 100 lb of triple superphosphate/acre, respectively. The average values for soybean nutrient content in Arkansas are comparable to the commonly cited values of 0.8 lb P_2O_5/bu and 1.4 lb K_2O/bu. Seed nutrient concentrations may vary among cultivars, environments, fertilization practices and soils. The amount of K removed by harvested grain typically accounts for <20% of total aboveground K uptake by rice and about 55% of total aboveground K uptake by soybeans. In addition to crop removal of nutrients, some soil and fertilizer P and K may also be lost from fields via runoff, leaching, erosion and removal of crop residues. When crop residues are burned following harvest, P and K are not lost from the field unless the ash is removed by wind or runoff water. However, a large proportion of the nitrogen, sulfur and carbon in crop residue is lost during burning.

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