DIVISION OF AGRICULTURE
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Fertilization and Liming Practices

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Soybeans have long been considered the "other crop" grown in crop rotation systems in Arkansas. Proper fertilization programs for soybeans have long been ignored. However, high soybean prices and interest in the production of ultra-high (>100 bu/acre) soybean yields have stimulated interest in maximizing soybean yields via proper fertilization. The soybean crop is very nutrient-intensive with total aboveground uptake of 5.0 lb N, 1.0 lb P_2O_5 and 3.8 lb K_2O required to produce each bushel of soybeans. For perspective, the aboveground phosphorus (P) and potassium (K) uptake needed to produce one bushel of soybeans is 1.5 to 3.0 times greater than the amounts of P_2O_5 and K_2O equivalent needed to produce one bushel of corn or rice. Just like any other crop, sufficient soil fertility coupled with a well-planned fertilization program is only one component of producing high soybean yields. Identifying and correcting other soil-associated yield limitations (e.g., slope, poor drainage, excessive drainage, etc.) that are potentially greater yield-limiting factors than soil fertility is important for fertilization to be an economical practice. This chapter's objectives are to (1) review soil test-based fertilizer recommendations, (2) describe the symptoms of nutrient deficiencies or toxicities and (3) provide research- and/or experience-based insight on nutrient management strategies.

Soil Testing

Fertilizer and lime applications should be made using the most recent soil test results, the field's history of soil test results and an examination of the field's crop yield and fertilization history. The field's most recent soil test results provide a current assessment of the field's nutrient availability status and pH suitability for soybeans and crops that may be grown in the rotation. The history of soil test results will provide an indication of how consistent the soil nutrient availability information has been across time and may provide insight about nutrient depletion or accumulation as a result of the balance between the amounts of nutrients removed by the harvested crop and added via annual fertilization practices. In some years, abnormal soil test results can occur from sampling error or short-term environmental influences (e.g., extremely dry weather conditions). Should the most recent soil test results differ substantially from previous years' results, we would recommend using the old soil test results to make fertilization decisions if resampling fields is not an option.

Monitoring a field's soil test P and K fertility history can be done quite easily in most spreadsheet programs (Fig. 5-1). Making a graph of soil test P and K values across time is an excellent way of monitoring soil test trends. Note that the use of soil test results from different labs or even the same lab can be tricky. Be sure that the soil test information for P and K is compared using the same soil test methods and units. For example, the University of Arkansas Soil Test Laboratory made slight adjustments to the soil test methodology in January 2006 which affected the amount of soil nutrients that were extracted and reported on the soil test. The University of Arkansas uses the Mehlich-3 soil test method and shows soil test information with units of both lb/acre and parts per million (ppm, which is one-half of lb/acre). Units reported as lb/acre assume that the soil sample was collected from an acre furrow slice that weighs 2 million pounds. For most Arkansas silt loam soils, this

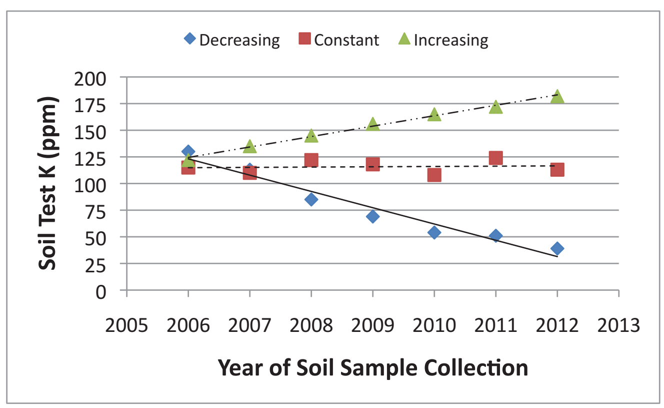


Figure 5-1. Example of graph showing trends for soil test K to increase, decrease or remain constant across time.

would require that soil samples be collected to a 7-inch depth. The University of Arkansas recommends a 4-inch soil sample depth for soybeans because the presence of a hard pan makes sampling deeper than 4 inches impractical. All University of Arkansas soil test-based P and K recommendations are correlated and calibrated for a 4-inch sample depth. Due to nutrient stratification (e.g., soil nutrient concentrations decline with increasing soil depth), collecting samples from a greater depth usually decreases the soil test values and may result in greater fertilizer rates being recommended. Collecting samples from less than a 4-inch depth would cause soil test values to be greater and would potentially reduce the amount of P and K fertilizer that would be recommended and potentially lead to under-fertilization.

As a general rule, soil samples should be collected following the same crop in a crop rotation sequence and at approximately the same time (month) each year. This is especially important in fields rotated with rice because the soils may be flooded for two or three months during the summer and the anaerobic/flooded soil conditions can influence soil nutrient availability. Soil test P values tend to be lower following rice compared with samples taken following soybeans in a 1:1 rice:soybean rotation. Other than this exception, research suggests that soil test P is consistent across the fall, winter and spring months, but pH and soil test K can fluctuate substantially (Table 5-1). Soil samples collected in the fall (October to November), late winter (February to March) and spring (April) showed the soil test K was always slightly higher when samples were collected in the fall.

The University of Arkansas fertilizer recommendations are sufficient to produce high soybean yields as nutrient availability is only one component influencing yield potential. Fertilizer recommendations for soybeans are a combination of research trial data and soil nutrient management logic (e.g., building the fertility levels of depleted soils). Fertilizer recommendations provide an indication of the magnitude of yield response that can be expected and the probability that a significant yield increase will occur. Phosphorus and K fertilizer recommendations should be based on yield goals only when one is trying to replace the nutrients removed by the harvested crop. Soil test results are simply a nutrient availability index and not an absolute amount of total nutrients or plant-available nutrients in the soil. The nutrient removal rate used in University of Arkansas recommendations is calculated based on a 50 bu/acre soybean yield, although yields >50 bu/acre may be produced with these recommendations.

Lime

Economic yield reductions due to soil acidity generally occur on sandy and silt loam soils at pH values less than 5.5. Fields with pH values below 5.3 require close attention. If soil pH values are 5.0 or less, liming should take priority over P and K fertilization. Soybeans may tolerate pH values as low as 5.2 on many alluvial clayey soils without significant yield loss (Table 5-2). However, crops grown in rotation with soybeans, such as wheat and corn, may suffer from aluminum (Al) and manganese (Mn) toxicities.

The University of Arkansas Soil Test Laboratory makes lime recommendations based on the soil pH and soil calcium (Ca) content (an indicator of soil texture, Table 5-3). Other laboratories typically use what is called a buffer pH to determine lime rate. It should be noted that soil pH is not a static soil property. Soil pH can fluctuate by approximately 1.0 unit (±0.5 from the true mean pH) during the calendar

Table 5-1. Effect of soil sample collection time on soil test P, K and soil pH (values are the average of 12 to 24 composite soil samples with each sample representing a 150 ft^2 plot at each sample time) in five silt loam soils.

Site	Soil pH			P			K		
	Fall†	Winter‡	Spring§	Fall	Winter	Spring	Fall	Winter	Spring
	- - - - - - - pH - - - - - - -			- - - - - - - ppm P - - - - - - -			- - - - - - - ppm K - - - - - - -		
Convent	6.1	6.7	6.1	43	39	38	138	123	108
Convent	6.4	6.7	6.4	39	35	41	138	126	115
Calloway	6.8	6.6	6.6	12	11	10	118	108	103
Calloway	6.6	6.7	6.8	6	6	6	105	86	79
Calloway	7.1	7.2	6.9	15	14	14	115	89	90

†Fall, late October to mid-November
‡Winter, mid-February to early March
§Spring, mid-April

Table 5-2. Expected yield reductions due to soil acidity.

Soil pH	Expected Yield Reduction†	
	Sandy and Silt Loams	Clayey or Alluvial Soils Along Streams and Rivers
	%	%
4.6 – 5.0	30 – 50	15 – 20
5.1 – 5.4	20 – 30	10 – 15
5.5 – 5.7	10 – 20	5 – 10
5.8 – 6.0	0	0

†Reduction in yield relative to an optimum pH level of approximately 6.0 to 6.5. Expressed as a percentage of potential yield.

Table 5-3. Arkansas lime recommendations for soybeans.

Soil Texture	Soil Test Ca	Below Optimum			Medium	Optimum
		<5.0	5.0 – 5.3	5.4 – 5.7	5.8 – 6.2	6.2 – 6.9
	- - - ppm Ca - - -	- - - - - - - - - - - - - - - - - - - lb ag lime/acre - - - - - - - - - - - - - - - - - - -				
Sandy loam	≤500	4,000	3,000	2,000	0	0
Silt loam	501 – 1,500	5,000	4,000	2,500	0	0
Clay loam	1,501 – 2,500	6,000	5,000	3,000	0	0
Clay	≥2,501	7,000	6,000	4,000	0	0

year with the highest pH values typically occurring in the winter months and the lowest pHs occurring in the hot, dry summer months. During fall and winter months (the time that most soil samples are collected) with abnormally low amounts of rainfall, soil pH values may be lower (e.g., 0.5 lower) than normally observed. However, these lower pH values may be representative of what the crop will endure during the summer months.

Rice, the crop grown in rotation with soybeans on the greatest number of acres, is quite tolerant of low pH and sensitive to alkaline pH. When fields used for rice and soybean production must be limed, lime should be applied following the rice crop, and uniform application of lime is critical. In the rice-soybean rotation, growers may want to apply lower rates of lime more frequently to avoid the likelihood of over-liming and inducing Zn and P deficiencies in the rice crop.

When lime is needed, it is best applied in the fall following rice harvest, but benefits can still be realized when lime must be applied shortly before planting. Mechanically incorporating the lime (e.g., before soybeans are planted) will help distribute lime particles in the topsoil. When the soil has adequate moisture, the fine lime particles in agricultural lime will begin reacting to neutralize soil acidity immediately, and the maximum pH increase may be attained within one to six months, depending on the lime source. Based on 715 lime samples evaluated by the Arkansas State Plant Board between 2006 and 2009, the typical agricultural lime in Arkansas has a calcium carbonate equivalent (CCE) of 91.5% (4.1% standard deviation), an average fineness factor of 59.5 (9.5% standard deviation) and an overall lime quality score, referred to as Effective Calcium Carbonate Equivalent (ECCE), of 54%.

Pelletized lime is commonly sold in Arkansas because it is easy to handle and spread. Pelletized lime is usually composed of a binding agent and fine lime particles (<100 mesh) that may be calcitic (Ca based) or dolomitic (contains Ca and Mg). Unfortunately, pelletized lime is reportedly and inappropriately marketed as being four or five times more effective than agricultural lime (i.e., requiring only 200 to 500 lb/acre to provide the same soil pH adjustment as one ton of agricultural lime). Research suggests that the time required for pelletized lime to increase soil pH is similar to, but not faster than, agricultural lime when rates with equivalent ECCE are applied. The amount of pelletized lime needed to neutralize the same amount of acidity as agricultural lime can be calculated using the CCE and fineness factors of two lime sources (see Example 5-1). If pelletized lime is used, it should be applied to the soil surface and the pellets allowed to “weather” (or disintegrate following several rainfall events) before it is mechanically incorporated. Droughty conditions following lime application, regardless of the source, can delay lime reaction or the time required to neutralize acidity.

Example 5-1. Lime source comparison example (hypothetical data).

Lime Source	CCE†	Fineness Factor Information‡			ECCE§	Equal Rates¶
		10 mesh	60 mesh	Fineness Factor		
						- - - lb/acre - - -
Ag lime	90%	92%	38%	59.6	53.6	2,000
Pelletized lime	80%	100%	100%	100.0	80.0	1,340

†CCE, calcium carbonate equivalent.
‡The values in each column represent the percentage of material passing through a 10- and 60-mesh sieve. Fineness factor coefficients of 0, 0.4 and 1.0 multiplied by the percentage of lime having a diameter of >10-mesh (8%), <10-mesh and >60-mesh (54%), and <60-mesh (38%) were used to calculate the fineness factor for ag lime.
§ECCE, effective calcium carbonate equivalent, is the product of [fineness factor x (CCE/100)].
¶Equivalent rates, the amount of lime needed from each source to neutralize the same amount of acidity. Calculated by [((Ag lime ECCE/pelletized lime ECCE) × 2,000 lb ag lime/acre) = lb pelletized lime/acre]

Molybdenum

Molybdenum (Mo) is an essential micronutrient that is especially important for legumes and required by the bacteria (rhizobia) that form nodules on soybean roots and fix atmospheric N_2 gas into a form that can be used by the plant (biological N fixation). Unlike most other micronutrients, the availability of Mo increases as soil pH increases. Molybdenum deficiencies are most likely to occur on acidic soils. On low fertility, acidic soils, soybean yield response to recommended P and K fertilizer may be limited if Mo is not applied. With adequate Mo, recommended rates of P and K fertilizer have a greater chance of increasing soybean yields.

When lime cannot be applied to sandy or silt loam soils with pH values below 5.8, treating seed with Mo is recommended. Treating seed with Mo is a low-cost practice that may be beneficial whenever the pH is ≤7.0, if lime has been applied within the last year or in fields with a wide range of soil pH values. On some clayey soils with a pH below 5.8, responses to Mo have been nearly as good as response to lime alone or a lime and Mo combination. The application of Mo to soybean seed should not be used as a substitute for maintaining the soil at an optimal pH using a proper liming program. When needed, the application of 0.2 to 0.4 oz Mo/acre is recommended. These Mo sources can also be sprayed onto the soil if application to the soybean seed is not feasible. Some fungicide seed treatments used on soybean contain Mo.

A Mo deficiency will cause stunted soybeans with leaves that are pale green or yellow, giving the same appearance as nitrogen (N) deficiency (Fig. 5-2 and 5-3). Molybdenum-deficient plants will have few or no nodules on the root system. Determining the soil pH will help differentiate between the possibility of N deficiency caused by insufficient Mo or lack of the N-fixing rhizobia in the soil. Ammonium and sodium molybdate are water-soluble fertilizers that can be foliar applied in the case that a Mo deficiency is diagnosed.

Figure 5-2. Nitrogen deficiency – closeup of N-deficient soybeans.

Figure 5-3. Nitrogen deficiency – non-nodulating soybeans receiving no N surrounded by nodulating soybeans.

Nitrogen and Seed Inoculation With Rhizobia Bacteria

Soybean seed should be inoculated with the proper rhizobia on land where soybeans have not been grown in the previous three to five years or where previous soybean crops have had poor nodulation. Some states recommend that inoculant be added to seed that will be planted in fields that were previously flooded. Limited research in Arkansas reported no benefit from inoculation following two years of flood-irrigated rice production. There is no effective means of delivering inoculum to soybean roots after soybeans have been planted. Failure to apply the proper or viable inoculum to soybeans planted on soils that have not recently been used for soybean production (e.g., fields used for continuous cotton production) may result in N deficiency. If poor nodulation results in N deficiency, application of N may be warranted. If soybeans are determined to be N deficient due to lack of nodulation, application of a minimum of 40 to 60 lb N/acre can stimulate growth and increase yield. Additional N applications may be needed.

Nodules should be present on soybean root systems and fixing N by the V2 to V3 growth stage. In fields where proper nodulation occurs, neither soil- nor foliar-applied fertilizer N has increased soybean yields consistently or economically in hundreds of experiments conducted in Arkansas and other soybean-producing states. Therefore, applying N fertilizer to soybeans is not a recommended practice.

Phosphorus and Potassium

The current University of Arkansas phosphate (P_2O_5) and potash (K_2O) fertilizer recommendations for full-season and double-cropped soybeans are shown in Table 5-4. The recommendations are specific for the Mehlich-3 soil test and soil samples collected from a 4-inch depth. The use of results from different soil test methods or soil samples from different depths may influence the accuracy of the results. Field experiments show that soybean yield responses to K fertilization (Table 5-5) are larger and more frequent than yield responses to P fertilization (Table 5-6).

Table 5-4. University of Arkansas phosphorus and potassium fertilizer recommendations for full-season and double-cropped soybeans based on Mehlich-3 soil test P (as determined by ICAP) and K.

Nutrient	Soil Test Level	Soil Test Value	Production System	
			Full-Season Soybeans	Wheat and Double-Crop Soybeans†
		- - - ppm P - - -	- - - - - - - - lb P_2O_5/acre - - - - - - - -	
Phosphorus	Very Low	≤15	80	120
	Low	16 – 25	60	90
	Medium	26 – 35	40	50
	Optimum	36 – 50	0	0
	Above Optimum	≥51	0	0
		- - - ppm K - - -	- - - - - - - - lb K_2O/acre - - - - - - - -	
Potassium	Very Low	≤60	160	180
	Low	61 – 90	120	120
	Medium	91 – 130	60	80
	Optimum	131 – 175	50	60
	Above Optimum	≥176	0	0

†Double-crop soybean P and K fertilizer recommendations include the recommendations for winter wheat. The cumulative fertilizer rate can be applied in the fall.

Table 5-5. Summary of trials conducted between 2004 and 2008 describing soybean yield response to K fertilization by soil test level.

Potassium Level	Range	Sites Tested		Average Yield (Unresponsive Sites)		Average Yield (Responsive Sites)			
		Total	Responsive	No K	Fertilized	No K	Fertilized	Loss	
	ppm K†	#	% of total	- - - - - - - - - - - - bushels/acre				- - - - - - - - - - - -	%
Very Low	≤60	4	100%	--‡	--	29	46	17	37
Low	61 – 90	13	92%	55	64	44	60	16	27
Medium	91 – 130	22	41%	51	55	51	59	8	14
Optimum	131 – 175	6	0%	62	64	--	--	--	--
Above Optimum	≥175	2	0%	48	51	--	--	--	--

†Soil test units are listed as parts per million (ppm or mg/kg) and may be converted to pounds per acre by multiplying the ppm value by 2 (ppm × 2 = lb/acre) assuming an acre furrow slice of soil weighs 2 million pounds.
‡Cells with no values had no observations (responsive or unresponsive sites) in this soil test level.

Table 5-6. Summary of trials conducted between 2004 and 2012 describing soybean yield response to P fertilization by soil test level.

Phosphorus Level	Range	Sites Tested		Average Yield (Unresponsive Sites)		Average Yield (Responsive Sites)			
		Total	Responsive	No P	Fertilized	No P	Fertilized	Loss	
	ppm P†	#	% of total	- - - - - - - - - - - - bushels/acre				- - - - - - - - - - - -	%
Very Low	≤15	18	56	60	63	52	59	7	12
Low	16 – 25	14	21	63	65	53	61	8	13
Medium	26 – 35	11	0	54	55	--‡	--	--	--
Optimum	36 – 50	4	25§	60	62	54	62	8	13
Above Optimum	≥51	3	0	49	49	--	--	--	--

†Soil test units are listed as parts per million (ppm or mg/kg) and may be converted to pounds per acre by multiplying the ppm value by 2 (ppm × 2 = lb/acre) assuming an acre furrow slice of soil weighs 2 million pounds.
‡Cells with no values had no observations (responsive sites) in this soil test level.
§The one trial that responded to phosphorus fertilization had a mean soil test P of 39 ppm, but the soil test P within the research area was highly variable. Positive responses to phosphorus fertilization on soils with an Optimum soil test P level are not likely.

Soil test K tends to be a more accurate predictor of soybean response to K fertilization than soil test P is for predicting yield response to P fertilization. The recommendations for K fertilization fit the soil test level definitions and exhibit the concept of soil testing very well. The concept of soil testing is that plant growth or yield increases to fertilization are highly probable when soil nutrient availability is very low or low, improbable when soil nutrient availability is optimum or above optimum and somewhat unpredictable in the middle. By definition, the Medium soil test level, as interpreted in the University of Arkansas recommendations, is the soil test level of uncertainty regarding the potential yield benefit from fertilization. The soil test K recommendations for soybeans fit these soil test level definitions quite well (Table 5-5), whereas soil test P recommendations do not follow these concepts as closely (Table 5-6). Nominal K fertilizer rates are recommended for soils with nutrient availability indices in the Medium level (Table 5-4) for numerous reasons, including yield increases may occur less than 50% of the time, actual soil test values within a field or grid are variable, fertilization aids in maintaining the Medium level and soils with values in the lower range of the Medium level tend to be more responsive than when soil test values are in the upper half of the level, especially values near the lower boundary (e.g., 91 to 100 ppm). Yield potential may also be a factor influencing whether a yield increase results from fertilization on soils having Medium nutrient levels. Growers should note that a nominal rate of K fertilizer is recommended for soils having an Optimum soil test K level. This recommendation should simply be viewed as a grower option as no significant yield benefit is expected (during the year of application), but applying some potash will help maintain adequate soil K fertility for high-yielding soybeans in future years.

Potassium-depleted soils usually test Low or Very Low and receive recommendations for 120 or 160 lb K_2O/acre. The most common and economical K fertilizer is muriate of potash or potassium chloride (KCl). Muriate of potash (60% K_2O) is 52.5% K and 47.5% Cl. Application of 120 to 160 lb K_2O/acre also supplies about 95 to 125 lb Cl/acre. Although Cl toxicity is a concern in many poorly drained soils, the amount of Cl in these high K fertilizer rates alone will not likely cause Cl toxicity. Applying high rates of K fertilizer in the fall or early spring may allow rainfall to flush the Cl laterally (i.e., runoff) or vertically (i.e., leaching) from the field. Potassium sulfate (K_2SO_4, which is 50% K_2O) or potassium-magnesium sulfate (K_2SO_4 and $MgSO_4$, which is 22% K_2O, also sold as Sul-Po-Mag and K-Mag) are alternative K fertilizers that may be used in place of muriate of potash if chlorides are a significant concern. In most areas of Arkansas, K deficiency is more likely to be a greater yield-limiting factor for soybeans than Cl toxicity.

For variable rate fertilizer application, K fertilizer rates can be calculated using Equation 1. An equation for applying variable P fertilizer rates has not been developed, due in large part because soil test P has been a less reliable indicator of yield response than soil test K. For example, an area or grid with a Mehlich-3 soil test K of 75 ppm (150 lb/acre) would have a calculated fertilizer rate of 116 lb K_2O/acre [237 – (75 × 1.61) = 116.25].

Equation 1:

lb K_2O/acre = 237 – 1.61 x (where x = soil test with units in ppm)

Arkansas research shows that significant soybean yield increases to P fertilization may occur in the Low and Very Low soil test levels (Table 5-6). When soybean yields are increased by P fertilization, the yield increase tends to range from 10% to 15%. Results show that soil test P is highly accurate at predicting that soybean yields will not be increased by P fertilization on soils with Medium or greater soil test P levels. Phosphorus recommended for the Medium soil test level (Table 5-4) is not expected to increase soybean yields (Table 5-6) but serves to help maintain soil test P by replacing a portion of the P that will be removed by the harvested grain.

Triple superphosphate (46% P_2O_5) is the most commonly used P fertilizer in Arkansas and is appropriate for soybeans. Diammonium phosphate (18-46-0), monoammonium phosphate (11-52-0) and MicroEssentials® (10-40-0-10S-1Zn) are alternative P fertilizers sold in Arkansas that can be used for soybean fertilization, but their N content has not been shown to increase soybean yields compared to triple superphosphate. Purchase the P fertilizer that provides the recommended amount of P at the most economical price.

Poultry litter can be applied as a P and K source for soybeans. High-quality litter will contain 50 to 70 lb P_2O_5 and K_2O/moist ton, but because litter nutrient and moisture contents vary considerably, subsamples of litter should be analyzed for total nutrient content to determine its P and K fertilizer value. The P and K in poultry litter should be considered equivalent in availability as commercial fertilizer sources. Research on undisturbed soils (i.e., not recently precision graded) in Arkansas has shown no yield benefit from litter applied to soils with Optimum or Above Optimum soil nutrient availability, suggesting that poultry litter alone does not increase crop yield potential. However, on low-fertility soils, soybeans fertilized exclusively with poultry litter have produced equal to slightly higher yields than soybeans receiving equivalent rates of P_2O_5 and K_2O as commercial fertilizer. The most significant concern in using poultry litter or other animal manures as a fertilizer source is uniform distribution of nutrients.

The recommendations for double-cropped soybean should be used in conjunction with the recommendations for small grain (winter wheat or oats). The cumulative (small grain + double-crop soybean rate) fertilizer rate can be applied in the fall or split applied (Table 5-4).

Research has shown that fertilizer application rate rather than application time (e.g., fall vs. spring) is the most important factor influencing full-season and double-crop soybean response to fertilization. Although field research has shown no difference in soybean yields between fall and spring P and K fertilizer application, several factors should be considered in making this decision. As a general rule, a soil's capacity to rapidly fix P and K fertilizer into unavailable forms increases as soil test index value decreases. Therefore, to ensure maximum nutrient availability, spring fertilizer application may be best on soils with Very Low soil test levels. The exception to this rule may be in fields with a history of chloride toxicity problems, in which case K fertilizer might best be applied in the fall or late winter. Fall application of fertilizer on soils with Medium or Optimum soil test levels is appropriate since fertilization is largely intended to maintain soil nutrient levels by replacing nutrients removed in the harvested portion of the crop. Fall application of P and K fertilizer should also be avoided on sandy loam soils with very low cation exchange capacity, fields where erosion is a concern and fields where nutrient deficiencies have been previously observed. In fields that will be flooded for waterfowl habitat (or are located in a flood-prone area), fertilizer should always be applied as close to planting as possible as the alternating flooded (anaerobic)-nonflooded (aerobic) conditions can influence soil and fertilizer nutrient availability and loss.

The potential benefit of foliar feeding soybeans with liquid solutions containing N, P, K and other nutrients has been well researched in the United States. The University of Arkansas recommends that macronutrients like P and K be supplied to the soil preplant. Foliar feeding may be used at the grower's discretion as a supplement to an agronomically and economically sound soil fertilization program. Research has shown no consistent benefit from supplemental foliar feeding, especially on soils with sufficient fertility. Exclusive use of foliar feeding may eventually deplete soil nutrient levels, especially on low CEC soils, and lead to nutrient deficiencies and reduced crop yields. Numerous foliar applications of K fertilizer would be needed to supply enough K to produce maximum yields on K-deficient soils. On silt loam soils with Medium soil test K levels, crop yields may decline significantly within three or four years after a soil fertilization program is abandoned (Fig. 5-4).

Potassium is mobile within the plant, indicating that deficiency symptoms should first appear on the older (bottom) leaves as a chlorosis or yellowing

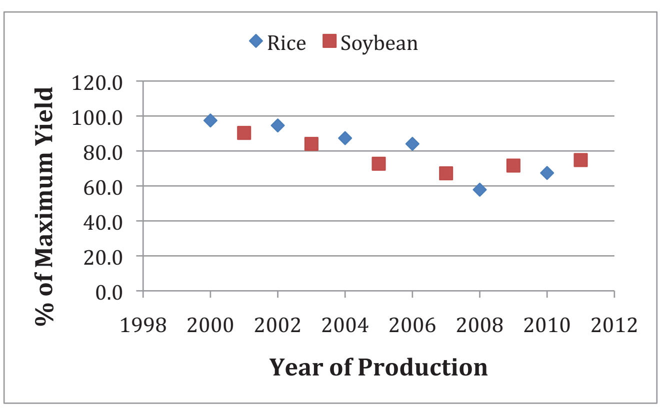


Figure 5-4. The percentage of the maximum yield (relative yield) produced by rice and soybeans that received no potassium fertilizer compared to rice and soybeans that received an annual application of potassium fertilizer. ***(Slaton, unpublished data)***

along the leaf margin (Fig. 5-5 and 5-6). The amount of the leaf that is chlorotic increases as the duration and severity of K deficiency increases. Potassium deficiency symptoms are often present on leaves in the middle and top of the plant. Observations made in commercial fields and research trials indicate that K deficiency symptoms in the youngest leaves are common. Symptoms that appear in the early season may indicate very low soil K availability, problems involving uptake of soil K (e.g., drought) or both. Early-season symptoms are common when soils become very dry or in areas with significant soil compaction.

Figure 5-5. Potassium deficiency – early-season symptoms on double-cropped soybeans (note dry soil condition).

Figure 5-6. Potassium deficiency – advanced symptoms.

If K deficiencies occur prior to early seed development (before R5) or if K fertilizer was not applied, K fertilizer may still be applied and watered in with prompt irrigation or a timely rain. Significant yield increases can be achieved from mid- to late-season K fertilization. The trifoliolate leaf nutrient concentrations shown in Table 5-7 can be used as a guide to interpret soybean leaf analysis. Arkansas research shows that leaf K concentrations >1.80% at the

R1-R2 growth stage are sufficient for optimum yield, 1.50% to 1.80% can be considered low (probable deficiency) and <1.50% indicates K deficiency. These guidelines tend to work best on varieties with a determinate growth habit. The growth stage that soybeans are sampled is important because leaf K concentrations tend to decline as pod and seed development progresses beyond the R2 stage. Limited research suggests that trifoliate leaf K concentrations decline by 0.015% per day (or 0.10% per week) after the R2 growth stage. Additional information on sampling soybeans for leaf tissue analysis is given in a later section.

Phosphorus deficiency of soybeans occurs much less frequently than K deficiency. The deficiency symptoms exhibited by P-deficient soybean plants are usually subtle in that the plants have small leaves and an overall unthrifty appearance. In some instances, P-deficient plants may exhibit an interveinal reddening on the lower leaves (Fig. 5-7).

Figure 5-7. Phosphorus deficiency – stunted plant with reddish interveinal coloration of lower leaves. ***(Photo by Bryan Stobaugh)***

Phosphorus is mobile in the plant, and symptoms should be more severe on the lower leaves, but growth of the whole plant is usually affected. The most recently mature trifoliate leaves are considered P deficient when P concentrations are <0.25% at the R2 growth stage, but concentrations of 0.25% to 0.30% P should be considered low. Similar to K, leaf P concentrations decline quite rapidly following the R2 stage as P is translocated to the developing pods and seeds, making the growth stage at the time of sampling an important consideration for interpreting leaf P concentrations. There has been very little research regarding the management of P-deficient soybeans to indicate whether foliar or soil application of a P-containing fertilizer will produce a significant yield increase.

The average amount of nutrients removed by harvested soybean seed is shown in Table 5-8 on a per-bushel basis and for an average yield of 50 bu/acre. Soybean stalks are sometimes baled following harvest and also contain nutrients. On average, one ton of soybean stalks (following harvest) contains 4 to 5 lb P_2O_5 and 10 to 15 lb K_2O/ton. If pods (without the seed) and/or leaves remain on the stalks following harvest, the nutrient content of the soybean residue will be greater than the listed values. The nutrient content of soybean stover following grain harvest is dependent on a number of factors, including initial soil fertility levels, the amount of fertilizer applied and how soon after harvest the stover is baled. If the unharvested stover will be baled and sold, samples should be collected and submitted to a laboratory for nutrient analysis to determine its average nutrient content. This will allow the fertilizer value of the stover to be calculated.

Table 5-7. Suggested sufficiency ranges of nutrients in the most recently fully expanded trifoliolate leaves (top three or four nodes) of soybeans at the flowering stage (R1-R2). ***(Sabbe et al., 2000)***

Range	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	- - - - - - - - - - - - - - - - - - - % - - - - - - - - - - - - - - - - - - -						- - - - - - - - - - - - - - - ppm - - - - - - - - - - - - - -				
Low†	3.25	0.25	1.50	0.80	0.25	0.25	25	17	21	4	20
High	5.00	0.60	2.30	1.40	0.70	0.60	300	200	80	30	60
†Values below the Low boundary are considered deficient.											

Table 5-8. Nutrient removal (grain content) for 50 bu/acre soybean yield. Values based on analysis of soybean seed from various research studies or grower fields in Arkansas from 2004-2011. ***(Slaton, unpublished data)***

Yield	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	- lb nutrient/bushel (or 50 bushels) -										
1 bu/acre	3.6	0.79	1.19	0.18	0.13	0.20	--	--	--	--	--
50 bu/acre	178	39	60	9	7	10	0.23	0.12	0.13	0.03	0.07

Boron

Soybeans are generally not considered to be highly susceptible to boron (B) deficiency, but B deficiency of soybeans is widespread in northeast Arkansas, making it the most common micronutrient deficiency of soybeans in Arkansas. Boron deficiency was diagnosed in northeast Arkansas in the early 2000s on silt loam soils. Fields that are likely to show B deficiency have been irrigated long-term with groundwater high in calcium (Ca) and magnesium (Mg) bicarbonate, soil pH >7.0, silt and sandy loam texture and are located north of Interstate 40 to the Missouri line and west of Crowley's Ridge. Boron deficiency has also been observed after liming acidic silt loam soils in Prairie and Arkansas counties.

Symptoms of B deficiency may be evident shortly after emergence or in the late reproductive growth stages, but symptoms are most commonly observed during mid- to late-vegetative growth (e.g., V6 to early bloom) after the first irrigation (Figure 5-8 through 5-15). The symptoms of B deficiency may include leaf cupping, stunting (i.e., short internodes), swollen nodes, leaf malformation that may resemble phenoxy herbicide injury, leaf chlorosis and, when severe, death of the terminal growing point. In its later stages, B-deficient soybean plants are short, the leaves become thick and dark green, retain their leaves longer than soybeans with sufficient B nutrition, have few pods and maturity is delayed.

Figure 5-9. Boron deficiency – stunted plant with regrowth (branching) from lower node.

Figure 5-10. Boron deficiency – plant recovering from deficiency (note multiple branches from lower node).

Figure 5-8. Boron deficiency – leaf appearance after prolonged boron deficiency.

Figure 5-11. Boron deficiency – delayed maturity (leaf retention) as a result of boron deficiency.

Figure 5-12. Boron deficiency – normal growth from previous year's rice levees with deficient plants between.

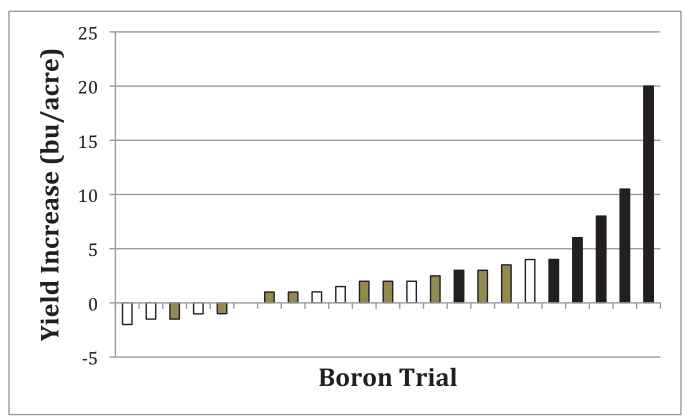
Figure 5-13. Boron deficiency – small soybean plant with dead growing point.

Figure 5-14. Boron deficiency – dead growing points after falling off plant.

Figure 5-15. Boron deficiency – healthy leaf (left) compared to leaf from boron-deficient plant (right).

Boron deficiency tends to be more widespread in years with below-normal rainfall (Fig. 5-16) and on shallow or compacted soils that restrict rooting depth.

Figure 5-16. Summary of soybean yield increase attributed to boron fertilization in 23 trials conducted on silt loam soils in Arkansas. [Sites with white bars had soil pH <7.0, and soybean yield was not expected to increase from boron fertilization. Sites with black bars had soil pH >7.0, and boron-fertilized soybeans produced greater yields than the no-boron control. All other sites (tan-colored bars) had pH >7.0, and soybean yield was not significantly (i.e., statistically) affected by boron fertilization.] *(DeLong et al., 2007)*



Toxicity is also a concern with boron. Boron toxicity symptoms initially appear as chlorotic leaf margins that develop into necrotic areas that make the leaf margins ragged (Figure 5-17). Very limited field experience with this problem in Arkansas suggests that only subtle symptoms are expressed on plants with B concentrations of 100 to 150 ppm B and the severity of symptoms increase when plants have greater leaf B concentrations. Boron toxicity is most likely to occur on soils with below optimal pH (<6.0) and moderate to high soil test B (Mehlich 3 > 2.5 ppm).

Figure 5-17. Boron toxicity – symptoms of boron toxicity on lower soybean leaves.

Identifying B-deficient soils from routine soil analysis has not been highly successful in Arkansas. Soil test (Mehlich 3) results commonly show soil test B values of <0.5 ppm (<1.0 lb/acre) and are not sensitive enough to differentiate between B-sufficient and B-deficient soils in eastern Arkansas. However, soil test results with high amounts of B may accurately indicate high availability from an accumulation of B.

Boron deficiency can usually be diagnosed using tissue analysis. During the growing season, the B nutritional status of soybeans can be evaluated by collecting 10 to 20 fully expanded (e.g., mature) trifoliolate leaves (no petiole) from the top three or four nodes. If a deficiency is suspected, samples from plants with and without visual symptoms should be collected and submitted to an analytical lab for analysis. Trifoliolate leaf B concentrations <20 ppm indicate probable B deficiency, and concentrations <10 ppm indicate definite B deficiency. Experience and research suggest that these leaf analysis guidelines are accurate for soybeans at the R1 to R2 growth stage but may not accurately reflect the B status of small soybean plants with a poorly developed root system. Soybean seed can also be used as an indicator of B deficiency. Soybean seed B concentrations <5 ppm indicate severe B deficiency, and B concentrations of 6 to 10 ppm suggest B deficiency is probable.

Prevention of B deficiency is the recommended fertilization strategy in the geographic area (NE Arkansas) where it is commonly observed, because severe B deficiency can cause near complete yield loss and B application following the expression of symptoms does not always result in a positive growth response. Granular B fertilizer (1 lb B/acre) may be blended with P and K granular fertilizers and applied preplant. Most granular B fertilizers marketed in Arkansas contain 15% B, and 6.7 lb of fertilizer is needed to supply 1 lb of elemental B per acre. While this method of application is typically effective, B deficiency may occur when dry conditions persist following fertilizer application. Application of granular B weeks in advance of planting and mechanically incorporating the fertilizer are recommended practices. The alternative to granular fertilizer is to apply 0.2 to 0.5 lb B/acre as a solution usually tank-mixed with pre- or post-emergence herbicides. The higher rate (0.5 lb B) should be used pre-emergence and the lower rate used post-emergence. Post-emergence or foliar-applied B may cause some leaf burn, which is cosmetic. The amount of leaf injury is affected by the product applied (in addition to tank mix components), environmental or climatic factors and B rate – minimal leaf injury usually occurs when B rates are <0.25 lb B/acre. Ten years of field observations suggest that B should be applied each year that soybeans are grown in the rotation. Growers are cautioned that B toxicity is also a potential problem. Application of B fertilizer on acidic soils may result in elevated plant uptake of B.

Sulfur

Research in Arkansas has not shown a significant soybean yield response to sulfur (S) addition. On deep sandy soils, 10 to 20 lb of sulfate (sulfur) per acre may be beneficial. Deficiencies may show up initially as pale green to yellow leaves in the top of the plant. As deficiency progresses, the entire plant may turn green to yellow. Prolonged S deficiency results in plant symptoms similar to prolonged N deficiency.

Magnesium

Most of the soils used for soybean production in eastern Arkansas contain adequate magnesium (Mg) because Mg is present in groundwater used for crop irrigation. Fields irrigated from surface water sources that are sandy and/or highly weathered soils located in northwest Arkansas may contain low Mg concentrations that require attention. If soil tests indicate exchangeable Mg levels below 35 to 40 ppm (70 to 80 lb/acre), providing Mg from resources such as sulfate of potash magnesia (Sul-Po-Mag or K-Mag), magnesium sulfate (epsom salts) or dolomitic limestone, when lime is recommended to correct low soil pH, may be beneficial. Poultry litter usually contains about 0.50% to 0.70% Mg (10-14 lb Mg/ton).

Manganese, Copper, Iron and Zinc

Copper (Cu), iron (Fe) and zinc (Zn) deficiency have not been diagnosed or recognized as nutrients limiting soybean yields in Arkansas. Ensuring that the soil Zn level is optimal for corn and rice that may be grown in the rotation sequence will ensure adequate Zn is available for soybeans.

Limited soybean growth/yield response to Mn fertilization has been reported on some eastern Arkansas silty clay soils where soil-test Mn levels were below 10 ppm (20 lb/acre). Trifoliolate leaf Mn concentrations less than 20 ppm are considered deficient and have reliably confirmed foliar symptoms. The most common Mn deficiency symptom is an interveinal chlorosis of the uppermost leaves while the leaf veins remain green (Figure 5-18). Localized Mn-deficient areas in soybean fields will often have a yellow cast that is visible from a distance (e.g., edge of field, Figure 5-19). In states where Mn deficiency of soybean is a consistent problem, the standard recommendation is to apply 0.25 to 0.5 lb Mn/acre to soybean foliage. Manganese fertilizer should not be tank-mixed with glyphosate as the efficacy of the glyphosate may be substantially reduced. The amount of antagonism that occurs in a tank-mixture of Mn fertilizer and glyphosate varies among Mn fertilizers, but as a general rule, fertilizers containing Mn-EDTA are least antagonistic. When Mn is actually deficient, 0.2 to 0.5 lb Mn/acre should be applied 7 to 10 days after the glyphosate.

Figure 5-18. Manganese deficiency – interveinal chlorosis.

Figure 5-19. Manganese deficiency – hot spot (chlorotic area) in middle of field.

Glyphosate-resistant soybean varieties (following treatment with glyphosate) may be more sensitive to Mn and possibly other micronutrient deficiencies than conventional soybean varieties. Glyphosate is capable of forming complexes (e.g., chelating) with Mn and other metal cations in the plant and soil, which can temporarily reduce nutrient availability. The Mn deficiency problems with glyphosate-resistant soybeans are most pronounced in areas where Mn deficiency was also a problem with conventional soybean varieties. While this topic is actively being researched, there are no glyphosate-resistant variety-specific nutrient management recommendations. In Arkansas, symptoms similar to Mn deficiency are sometimes observed in young soybeans following a glyphosate application (a.k.a., glyphosate flash). The glyphosate flash symptoms look very similar to Mn deficiency with symptoms including interveinal chlorosis (veins remain green) of the young or upper leaves. The "yellow flash" has been attributed to either Mn deficiency or the accumulation of a degradation product of glyphosate. In Arkansas, a limited number of tissue analyses of young plants exhibiting the "yellow flash" show tissue Mn concentrations are usually more than adequate. The yellow-flash symptoms tend to be most pronounced and prolonged when less-than-optimal growing conditions exist (e.g., hot, dry weather). Although these soybean fields can look very unthrifty, observations in grower fields and limited research suggest that foliar application of Mn and/or Fe fertilizers have little or no effect on improving the physical appearance, growth or yield of soybeans. The symptoms are usually alleviated when soil moisture availability improves from a timely rain or irrigation. Unless plant tissue analyses indicate deficiencies of these nutrients (Table 5-7), foliar application of nutrients is likely an unnecessary expense and is not recommended.

Poultry Litter on Leveled and Salt-Affected Soils

Response of soybeans to poultry litter on soils that have been recently cut or leveled to facilitate irrigation has been similar to responses by rice. The use of poultry litter to supply recommended rates of P and K on recently leveled soils is recommended. Rates of fresh or pelleted litter, ranging from 1,000 to 2,000 lb/per acre, may help restore soil productivity and increase crop yields. Repeated applications of litter for several years may be necessary to fully restore soil productivity. Research on the interaction between phosphate and potash fertilizer and poultry litter rate indicates that the response from litter is not entirely from the litter's fertilizer value as some other factors are also involved (e.g., microbial). Many growers continue to apply recommended rates of commercial fertilizer on leveled fields that are treated with poultry litter to help rebuild soil fertility. Subsoils with low soil pH or that are high in sodium (Na) may be exposed in fields with deep cuts (>6-8 inches) and may benefit from lime. When time allows, collecting soil samples by zones based on cut and fill areas or crop growth may be helpful in making decisions involving the need for lime, commercial fertilizer and/or poultry litter. The cause for poor crop growth, especially soybean, in many deep cuts is due to a combination of factors that may include soil physical properties (e.g., compaction/restricted rooting depth) and fertility-related maladies (salt injury or P and micronutrient deficiencies). Following land leveling, rice rather than soybeans is most often grown because the continuous flood irrigation eliminates the added effect of periodic water-stress (for soybeans) and its interaction with nutrient stress. Rice is much less sensitive to soil acidity than soybeans and produces more biomass than soybeans to help build soil organic matter.

Chloride Toxicity

Significant amounts of chloride (Cl) can be delivered in the irrigation water and/or exist in the rooting zone of poorly drained soils. Soybean plants may show leaf scorching symptoms, and yields may be reduced by chloride toxicity. At present, the most practical way to reduce problems from Cl toxicity is to select a "chloride-excluding" variety. Chloride-excluding varieties do not readily translocate Cl from plant roots to the shoots. Information regarding soybean variety classification as either a Cl "includer" or "excluder" is available in University of Arkansas variety performance summaries and from literature provided by many seed companies.

Chloride toxicity may occur in localized field areas or be present across most of a field's acreage. Hot spots may occur in plants located in (1) "potholes or low spots" where water pools and salts become more concentrated as the water evaporates, (2) points where subsurface, lateral water flow emerges at the soil surface and deposits salt and/or (3) plants located in the center of beds. Use of poor-quality irrigation water that contains excessive chloride (>70 to 100 ppm Cl or 2 to 3 mmol or meq/L) coupled with poor soil drainage may cause field-wide problems. Application of 10 acre-inches of irrigation water (per acre) that contains 3 mmol or meq Cl/L during a growing season results in the deposition of 240 lb Cl/acre/season.

Plants affected by Cl toxicity will have leaves that appear scorched along the edges, and the scorching will generally be worse on the lower leaves of large plants or relatively uniform on small soybeans (Figures 20-25). The petioles will eventually detach from the stem of chloride-affected plants, but once this occurs the plants are usually dead. To our knowledge there are no published leaf concentrations for diagnosing Cl toxicity of soybeans. Analysis of tissue from soybean plants (usually includer varieties) suffering from Cl toxicity indicate Cl concentrations range from 20,000 to 40,000 ppm Cl (2.0% to 4.0% Cl) in the lower leaves and >10,000 ppm (>1.0% Cl) in the most recently matured trifoliolate leaves. Chloride concentrations in recently matured trifoliate soybean leaves at the R2 stage ranging from 2,000 to 4,000 ppm have been measured in plants showing no symptoms of Cl injury and are therefore considered normal until more specific information becomes available. If soil tests show the need for K, muriate of potash (which is potassium chloride) or another suitable K source may still need to be applied to provide adequate K nutrition.

Diagnostic Sampling

Plant tissue analysis is a valuable tool for diagnosing plant nutritional problems. For best results, collect the most recently matured trifoliolate leaves (no petiole) from one of the top three or four nodes of 15 to 20 plants. For plants in early vegetative growth, collecting the whole aboveground plant may be warranted. Samples should be placed in labeled paper bags and shipped to an appropriate laboratory. Plant and soil samples taken for diagnostic purposes should include separate samples from the "normal or healthy" and "abnormal or problem" areas of the field. Plants that are severely stunted and have been nutrient deficient for a long period are not always the most informative samples. The plants that

Figure 5-20. Chloride Injury – damage in low area.

Figure 5-21. Chloride injury – scorching on margin of older leaves.

Figure 5-22. Chloride injury – dead soybean plant with detached petiole.

Figure 5-23. Chloride injury – Poor stand caused by chloride injury.

Figure 5-24. Chloride injury – mottled and scorched leaves.

Figure 5-25. Chloride injury – middle rows of soybeans planted on beds suffering from Cl toxicity.

look healthy sometimes provide a better assessment of plant nutrition problems as they may be suffering from hidden hunger. When possible, a third sample of plants showing slight or intermediate symptoms should be sampled too. This sampling procedure allows for an in-field comparison plus comparison to published nutrient levels. If the leaves or whole plants are dirty/dusty, they should be rinsed briefly, albeit thoroughly, in clean water while the leaves are still fresh.

The sufficient ranges of nutrient levels at bloom (R1-R2) for soybeans are shown in Table 5-7. Even though a nutrient level drops below the desirable range, this does not necessarily imply a need for that plant nutrient. Other factors such as drought, nematodes, herbicide damage, diseases and insect damage may be the problem or contribute to the problem. Follow a thorough diagnostic procedure that includes soil, plant and irrigation water analyses, along with detailed observations of field conditions and history, crop management practices, crops in adjacent fields, and plant root and shoot observations (nodules, plant growth stage, leaf color, etc.) for accurate diagnosis of plant nutrition problems.

Tissue analyses during the early vegetative growth or late reproductive stages, while helpful, do not have good predictive values for assessing nutrient limitations. As much as 60% or more of a soybean's total nutrient uptake occurs after bloom (R2). The desired nutrient levels (Table 5-7) may be used before bloom but only as a general reference to detect gross nutrient imbalances. It should also be recognized that not all of the sufficiency levels listed in Table 5-7 were developed from research and may represent the outer limits of leaf concentrations from a survey. Consulting someone with extensive experience in interpreting soybean leaf analysis is encouraged. More specific information for interpreting leaf nutrient concentrations is often included in the chapter sections covering specific nutrients.

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