Soybean Response to Phosphorus and Potassium Fertilization

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soybean [Glycine max (L.) Merr.] production on silt- and sandy-loam soils in Arkansas often requires that phosphorus (P) and potassium (K) fertilizers be applied to maximize yield potential. Fertilizer use surveys conducted by the USDA show that Arkansas soybean growers typically apply P and K fertilizers to about 33% of the soybean acreage at average rates of 51 lb P₂O₅ and 68 lb K₂O/acre (USDA-NASS, 2005). Phosphorus and K fertilizer application rates and state average soybean yields have increased gradually across time while the planted acreage has declined. The average yields for irrigated soybean are commonly >40 bu/acre, which is 10 bu/acre or more higher than non-irrigated soybean yields (AASS, 2005). These data plus other changes in soybean production practices (i.e., herbicide technology, earlier seeding dates, and production of early-maturing cultivars) all indicate that the management of soybean is being intensified to maximize yields and profits.

Fertilization of soybean grown on soils with low cation exchange capacity is important and can represent a significant expense to growers. For example, in the South Central U.S. the average prices of muriate of potash and triple superphosphate in 2007 were approximately $566/ton ($0.46/lb K₂O) and $887/ton ($0.96/lb P₂O₅), respectively (USDA-NASS, 2008). Based on these prices, the cost of 0-40-60, a relatively low rate of fertilizer, is $66.00/acre, which requires a 6 to 9 bu/acre yield increase to recover fertilizer costs when soybean prices range from $8.00 to 10.00/ bu.

Many growers and consultants have questioned whether existing P and K fertilizer recommendations for soybean, developed from research in the 1970’s and 1980’s, are adequate to maximize and sustain high crop yields or are economical. The overall research goals were to i) correlate Mehlich-3 soil-test P and K with soybean yield and ii) calibrate the appropriate P and K fertilizer rates needed to produce optimum soybean yields for irrigated soybean production.

PROCEDURES

Phosphorus and K fertilization trials with soybean were established at three Agricultural Experiment Stations (Cotton Branch Experiment Station, CBES; Pine Tree Branch Station, PTBS; and Rice Research Extension Center, RREC) and two commercial production fields during 2008. Specific soil and agronomic information for each site are listed in Table 1. Each location will be referred to by the site name listed in Table 1. In the commercial fields, P and K fertilizers were applied to the surrounding field but not to the area where research plots were established.

A maturity group IV or V soybean cultivar was grown at each site. For the study conducted in the commercial fields, cultivar selection, planting, and management were performed by the cooperating grower. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas Cooperative Extension Service.

At each site, individual plots were 16- to 25-ft long by 10-to 24-ft wide with each nutrient trial positioned in adjacent plot areas. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (n = 4-6) for each nutrient study area. Soil samples were oven-dried at 55°C, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil weight:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in the extracts were determined using inductively coupled plasma spectroscopy (ICPS). Selected soil chemical property means are listed in Tables 2 and 3.

Potassium trials included five rates (0, 40, 80, 120, and 160 lb K₂O/acre) of muriate of potash, which were broadcast to the soil surface shortly before or after planting. Triple superphosphate (~60 lb P₂O₅/acre) was broadcast to the soil surface to ensure that P was not yield limiting. Granular B fertilizer (1.0 lb B/acre) was applied to all sites except CBES and RREC. Each trial was a randomized complete block design with four to six replications.

Phosphorus fertilization trials were established adjacent to each K-rate trial. Triple superphosphate fertilizer was broadcast to the soil surface shortly after planting at rates equal to 0, 40, 80, 120, and 160 lb P₂O₅/acre. Muriate of potash (60 to 120 lb K₂O/acre) was broadcast to the soil surface to ensure that K was not yield limiting. Granular B fertilizer (1.0 lb B/acre) was applied to all sites except CBES and RREC. Each trial was a randomized complete block design with six or seven replications.
The P and K rate trials at the RREC were established and cropped to rice in 2007 with designated plots receiving the same P and K rates in both 2007 and 2008. The PTBS-39 and -40 trials were established in 2001 and have been cropped to rice (Oryza sativa L., odd years) and soybean (even years) with the same K rates being applied annually to designated plots. Thus, these sites represent cumulative crop responses to annual P and K fertilization rate. In contrast, all other sites represent soil that has been fertilized uniformly across time.

Trifoliate leaves (15) were collected from each plot at the R2 growth stage, dried to a constant moisture, ground to pass a 1-mm sieve, digested, and analyzed for elemental concentrations by ICPS. A 12- to 20-ft long section of the middle of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations. For all studies, analysis of variance was conducted by site with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher’s Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

K-Rate Trials

The University of Arkansas soil-test guidelines for soybean showed that soil-test K (Table 2) at the Poinsett-2 was ‘Low’ (61 to 90 ppm); Poinsett-1, PTBS-40, and PTBS trials were ‘Medium’ (91 to 130 ppm); and PTBS-39, RREC, and CBES were ‘Optimum’ (131 to 175 ppm). Little or no positive yield response to K fertilization was expected at sites having medium or optimum soil-test K, but 50 lb K₂O/acre are suggested to maintain soil K fertility.

Soil-test K at the long-term K trials, PTBS-39 and -40, has been affected by annual K application rate following 7 years of K fertilization (Table 4). However, soil-test K in both PTBS-39 and -40 was unexpectedly high compared to values in previous years (Slaton et al., 2008). In 2007, rice yields were increased significantly from K fertilization in both trials and soil-test K was <60 ppm. Despite the high 2008 soil-test K values, K-deficiency symptoms were visible within weeks after emergence on soybean that received 0 lb K₂O/acre/year. The soil-test K results may be from sampling error or other poorly understood mechanisms that influence extractable K at the time of sampling, but not K availability to the subsequent soybean crop.

The second year of the K-rate trials at the RREC showed soil-test K increased as K-fertilizer rate increased. Soil receiving 0 and 40 lb K₂O/acre/year showed a slight decline from samples collected before rice was planted in 2007, while soil receiving >40 lb K₂O/acre/year showed a numerical increase in soil-test K. Rice grown in 2007 showed no positive yield response to K fertilization.

Potassium concentrations in recently matured trifoliate leaves at the R2 growth stage were affected by K fertilization at 6 of 7 sites (Tables 4 to 6). Trifoliate K concentrations were not affected significantly by K-fertilizer rate at the CBES, the site with the greatest soil-test K (Table 2), but did show a trend to increase as K rate increased (Table 6). Trifoliate-leaf K concentrations in soybean receiving no K were <1.5%, the established critical K concentration, at all sites except CBES and RREC (Tables 4 to 6). The low K concentrations in soybean receiving no K suggest that soybean yields should have been increased from K fertilization at 5 of the 7 sites. Potassium fertilization increased trifoliate leaf K concentrations above 1.5% at all sites except Poinsett-1.

Soil-test K was increased significantly from K fertilization at PTBS-39 and -40 were not surprising since the same K-fertilizer rates have been applied to these plots since 2002 (Table 4). The significant yield increases to K fertilization coupled with the higher than expected soil-test K at PTBS-39 and -40 are of concern. Reasons why the soil-test K was higher than expected are unknown at this time. The positive yield response at PTBS (Table 6) was also somewhat surprising because the soil-test K was 125 ppm (Medium) and near the low boundary of the Optimum level (131 to 175 ppm). Although soybean yields among K rates at each of the two Poinsett sites were not significantly different (P>0.10) using the LSD test, a single-degree-of-freedom comparison of soybean yields receiving K against no K showed the overall response to K fertilization was significant at Poinsett-2. Potassium fertilization was not expected to increase soybean yields at RREC and CBES as soil at these sites contained Optimum levels of soil-test K.

P-Rate Trials

The University of Arkansas soil-test guidelines for soybean showed that soil-test P (Table 3) was ‘Very Low’ (<16 ppm) at Poinsett-2; ‘Low’ at Poinsett-1, PTBS, and RREC (16 to 25 ppm); and ‘Optimum’ (36 to 50 ppm) at CBES. The second year of the long-term P-fertilization trial at the RREC showed soil-test P changed by ±4 ppm from samples collected in spring 2007 despite having P-application rates up to 160 lb P₂O₅/acre applied in 2007 (Table 5).

Phosphorus concentrations in recently matured trifoliate leaves at the R2 growth stage were significantly affected by P application rate at 2 of 5 sites including Poinsett-2 (Table 8) and RREC (Table 5), which had the lowest soil-test P values. Soil-test P was ≤22 ppm at Poinsett-1 and PTBS (Tables 3 and 5) and trifoliate leaf P concentrations of the unfertilized controls were 0.30 and 0.24%, respectively, but concentrations did not increase significantly as P rate increased (Tables 5 and 8).

Soybean yields were not significantly affected by P fertilization at any site during 2008 (Tables 5 and 9). Based on soil-test P, P fertilization was expected to benefit soybean yields at Poinsett-2, PTBS, and RREC, which had the lowest soil-test P values (Table 3). Previous P-fertilization trial results have suggested that soybean is most likely to respond positively to P fertilization when soil-test P is <20 ppm. Closer examination of the soil properties of responsive sites also shows that soil pH...
is usually <6.5, suggesting that soybean grown on soils with low Mehlich-3 soil P and high pH may be less responsive to P fertilization. Soil pH was >7.0 at all 2008 sites except the RREC and CBES. Soil at CBES had an ‘Optimum’ soil-test P level and a pH of 5.7. Soil-test P at the RREC was ‘Low’ and had a pH of 5.4 when soil samples were collected several months before planting. Due to the low pH at the RREC, 1 ton lime/acre was applied in March to raise pH and may have affected the response of soybean to P fertilization.

**PRACTICAL APPLICATION**

Soybean response to K fertilization was predicted with good accuracy by the Mehlich-3 soil test method, but Mehlich-3 P does not appear to accurately differentiate between P-deficient and sufficient soils cropped to soybean. Additional research is needed to identify whether other soil-test parameters, such as pH, or soil-test methods can be used with soil-test P to improve the accuracy of identifying soils that require P to produce near maximum soybean yields. Phosphorus-fertilization trials with soybean have been conducted on 26 sites since 2004 with yields responding positively to P fertilization at only five sites (19%). The five responsive sites had soil-test P <20 ppm, but eight other trial sites having soil-test P <20 ppm failed to respond to P fertilization. The frequency of positive responses to P fertilization suggests that many Arkansas silt loams do not currently need supplemental P to maximize soybean yields or, alternatively, broadcasting P fertilizer to the soil surface, even at relatively high rates, is not an effective method of fertilization. In contrast, K-fertilization trials on many of the same soils show positive yield responses have occurred in 20 of 36 field trials, making K fertilization a critical component for maximizing soybean yield potential.

**ACKNOWLEDGMENT**

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**LITERATURE CITED**


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**Table 1.** Selected soil and agronomic management information for P and K fertilization trials conducted in 2008.

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Soil series</th>
<th>Cultivar</th>
<th>Tillage - previous crop</th>
<th>Row spacing</th>
<th>Plant date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(inches)</td>
<td>(month/day)</td>
</tr>
<tr>
<td>CBES</td>
<td>Lee</td>
<td>Convent</td>
<td>Schillinger 495</td>
<td>Conv./Soybean</td>
<td>38</td>
<td>May 30</td>
</tr>
<tr>
<td>PTBS</td>
<td>St. Francis</td>
<td>Calhoun</td>
<td>Armor 47G7</td>
<td>Conv./Soybean</td>
<td>15</td>
<td>May 21</td>
</tr>
<tr>
<td>PTBS39</td>
<td>St. Francis</td>
<td>Calhoun</td>
<td>Armor 47G7</td>
<td>No-till/Rice</td>
<td>15</td>
<td>May 21</td>
</tr>
<tr>
<td>PTBS40</td>
<td>St. Francis</td>
<td>Calhoun</td>
<td>Armor 47G7</td>
<td>No-till/Rice</td>
<td>15</td>
<td>May 21</td>
</tr>
<tr>
<td>RREC</td>
<td>Arkansas</td>
<td>Dewitt</td>
<td>Armor 47G7</td>
<td>Conv./Rice</td>
<td>7.5</td>
<td>May 21</td>
</tr>
<tr>
<td>Poinsett-1</td>
<td>Poinsett</td>
<td>Hillemann</td>
<td>UA4805</td>
<td>Conv./Rice</td>
<td>7.5</td>
<td>May 24</td>
</tr>
<tr>
<td>Poinsett-2</td>
<td>Poinsett</td>
<td>Hillemann</td>
<td>Agrow 5501</td>
<td>Conv./Rice</td>
<td>7.5</td>
<td>May 31</td>
</tr>
</tbody>
</table>

* Conv., conventional tillage.
Table 4. Soil-test K, trifoliate-leaf K (at R2 stage), and seed yield data means from tests 39 and 40 at PTBS in 2008 as affected by annual soil-test K rate (same K rates applied since 2001).

<table>
<thead>
<tr>
<th>Annual K rate</th>
<th>Soil-test K$^a$</th>
<th>HNO$_3$ K$^a$</th>
<th>R2 Trifoliate</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>(lb K$_2$O/acre/yr)</td>
<td>-----------------</td>
<td>---------------</td>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>PTBS 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>131</td>
<td>405</td>
<td>1.23</td>
<td>53</td>
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<tr>
<td>40</td>
<td>130</td>
<td>392</td>
<td>1.50</td>
<td>64</td>
</tr>
<tr>
<td>80</td>
<td>138</td>
<td>426</td>
<td>1.65</td>
<td>68</td>
</tr>
<tr>
<td>120</td>
<td>145</td>
<td>453</td>
<td>1.80</td>
<td>70</td>
</tr>
<tr>
<td>160</td>
<td>159</td>
<td>487</td>
<td>1.85</td>
<td>72</td>
</tr>
<tr>
<td>LSD(0.10)</td>
<td>18</td>
<td>37</td>
<td>0.17</td>
<td>7</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0121</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0022</td>
</tr>
<tr>
<td>C.V., %</td>
<td>10.8</td>
<td>6.9</td>
<td>9.7</td>
<td>10.1</td>
</tr>
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<td>PTBS 40</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>110</td>
<td>362</td>
<td>1.32</td>
<td>55</td>
</tr>
<tr>
<td>40</td>
<td>113</td>
<td>430</td>
<td>1.59</td>
<td>68</td>
</tr>
<tr>
<td>80</td>
<td>113</td>
<td>383</td>
<td>1.68</td>
<td>68</td>
</tr>
<tr>
<td>120</td>
<td>133</td>
<td>411</td>
<td>1.72</td>
<td>66</td>
</tr>
<tr>
<td>160</td>
<td>147</td>
<td>511</td>
<td>1.93</td>
<td>68</td>
</tr>
<tr>
<td>LSD(0.10)</td>
<td>13</td>
<td>107</td>
<td>0.16</td>
<td>8</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0001</td>
<td>0.0775</td>
<td>0.0003</td>
<td>0.0508</td>
</tr>
<tr>
<td>C.V., %</td>
<td>6.8</td>
<td>16.5</td>
<td>7.5</td>
<td>9.3</td>
</tr>
</tbody>
</table>

$^a$ Soil K extracted with Mehlich-3.

$^b$ Soil K extracted with $1 M$ HNO$_3$. 
Table 5. Soil-test P and K (Mehlich-3), trifoliate leaf P and K (at R2 stage) concentration, and seed yield means from the second year of long-term P and K fertilization trials at the Rice Research and Extension Center in 2008 as affected by annual P and K rate (same rates applied since 2007).

<table>
<thead>
<tr>
<th>Annual nutrient rate</th>
<th>2007 Soil-test K</th>
<th>2008 Soil-test K</th>
<th>R2 Trifoliate</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>(lb K₂O/acre/yr)</td>
<td>------------------</td>
<td>------------------</td>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>0</td>
<td>148</td>
<td>139</td>
<td>1.56</td>
<td>74</td>
</tr>
<tr>
<td>40</td>
<td>150</td>
<td>144</td>
<td>1.72</td>
<td>71</td>
</tr>
<tr>
<td>80</td>
<td>152</td>
<td>167</td>
<td>1.71</td>
<td>74</td>
</tr>
<tr>
<td>120</td>
<td>148</td>
<td>160</td>
<td>1.71</td>
<td>74</td>
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<tr>
<td>160</td>
<td>150</td>
<td>167</td>
<td>1.74</td>
<td>73</td>
</tr>
<tr>
<td>LSD(0.10)</td>
<td>NS^a</td>
<td>12</td>
<td>0.09</td>
<td>NS</td>
</tr>
<tr>
<td>P-value</td>
<td>0.9867</td>
<td>0.0006</td>
<td>0.0182</td>
<td>0.7571</td>
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<tr>
<td>C.V., %</td>
<td>8.3</td>
<td>7.4</td>
<td>5.4</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Table 6. Trifoliate-leaf K concentration of soybean at the R2 stage response to K-fertilizer rate at four sites during 2008.

<table>
<thead>
<tr>
<th>K rate (lb K₂O/acre)</th>
<th>CBES (%)</th>
<th>PTBS (%)</th>
<th>Poinsett-1 (%)</th>
<th>Poinsett-2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.71</td>
<td>1.26</td>
<td>1.12</td>
<td>1.14</td>
</tr>
<tr>
<td>40</td>
<td>1.76</td>
<td>1.36</td>
<td>1.26</td>
<td>1.53</td>
</tr>
<tr>
<td>80</td>
<td>1.78</td>
<td>1.42</td>
<td>1.22</td>
<td>1.45</td>
</tr>
<tr>
<td>120</td>
<td>1.80</td>
<td>1.43</td>
<td>1.38</td>
<td>1.63</td>
</tr>
<tr>
<td>160</td>
<td>1.83</td>
<td>1.52</td>
<td>1.41</td>
<td>1.72</td>
</tr>
<tr>
<td>LSD(0.10)</td>
<td>NS^a</td>
<td>0.09</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>P-value</td>
<td>0.2842</td>
<td>0.0012</td>
<td>0.0026</td>
<td>0.0004</td>
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<tr>
<td>C.V., %</td>
<td>5.3</td>
<td>6.5</td>
<td>8.3</td>
<td>8.8</td>
</tr>
</tbody>
</table>

^a NS, not significant (P>0.10).

Table 7. Soybean seed yield response to K-fertilizer rate at four sites during 2008.

<table>
<thead>
<tr>
<th>K rate (lb K₂O/acre)</th>
<th>CBES (bu/acre)</th>
<th>PTBS (bu/acre)</th>
<th>Poinsett-1 (bu/acre)</th>
<th>Poinsett-2 (bu/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>58</td>
<td>67</td>
<td>66</td>
<td>64</td>
</tr>
<tr>
<td>40</td>
<td>58</td>
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<td>67</td>
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<td>80</td>
<td>57</td>
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<td>160</td>
<td>57</td>
<td>74</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>LSD(0.10)</td>
<td>NS^a</td>
<td>3</td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>P-value</td>
<td>0.8729</td>
<td>0.0020</td>
<td>0.1449</td>
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<tr>
<td>C.V., %</td>
<td>3.9</td>
<td>4.2</td>
<td>9.4</td>
<td>8.5</td>
</tr>
</tbody>
</table>

^a NS, not significant (P>0.10).
### Table 8. Trifoliate-leaf P concentration of soybean at the R2 stage response to P-fertilizer rate at four sites during 2008.

<table>
<thead>
<tr>
<th>P rate (lb P₂O₅/acre)</th>
<th>CBES</th>
<th>PTBS</th>
<th>Poinsett-1</th>
<th>Poinsett-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.42</td>
<td>0.30</td>
<td>0.24</td>
<td>0.28</td>
</tr>
<tr>
<td>40</td>
<td>0.44</td>
<td>0.31</td>
<td>0.24</td>
<td>0.29</td>
</tr>
<tr>
<td>80</td>
<td>0.44</td>
<td>0.29</td>
<td>0.23</td>
<td>0.31</td>
</tr>
<tr>
<td>120</td>
<td>0.42</td>
<td>0.31</td>
<td>0.25</td>
<td>0.34</td>
</tr>
<tr>
<td>160</td>
<td>0.44</td>
<td>0.31</td>
<td>0.23</td>
<td>0.35</td>
</tr>
</tbody>
</table>

LSD(0.10) NS

P-value 0.1086 0.4661 0.1387 0.0007

C.V., % 4.2 5.9 6.7 9.7

NS = not significant (P > 0.10).

### Table 9. Soybean yield response to P-fertilizer rate at four sites during 2008.

<table>
<thead>
<tr>
<th>P rate (lb P₂O₅/acre)</th>
<th>CBES</th>
<th>PTBS</th>
<th>Poinsett-1</th>
<th>Poinsett-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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</tbody>
</table>

LSD(0.10) NS

P-value 0.9935 0.8273 0.3879 0.7333

C.V., % 7.3 6.1 9.6 10.1

NS = not significant (P > 0.10).