FOLIAR APPLICATION OF K ON SOYBEANS

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Abstract

Use of foliar K fertilization has been extensively researched starting in the 1970's with relatively variable and inconsistent soybean yield response. However, recent developments which have increased the observed incidence of K deficiency in soybeans and the growing acreage planted to glyphosate-resistant soybeans may make foliar K fertilization more cost-effective. Moreover, this fertilization practice may improve the flexibility of growers to respond to decreased K availability during the growing season because of changes in environmental and management conditions. This paper details the results of a sequence of soybean foliar K fertilization field experiments which have been conducted in Missouri since 2001 which have investigated the use of foliar K applications at different soybean growth stages and evaluated crop response and weed control after application of several foliar K sources with and without glyphosate. In an initial two-year field experiment at a low to medium soil test K site with a claypan soil, soybean grain yield increased an average of 703 kg ha^{-1} when foliar K was applied at a rate of 18 kg K ha^{-1} at three vegetative and reproductive growth stages. Further research has been conducted starting in 2003 to compare use of seven possible foliar K sources (potassium chloride, potassium sulfate, potassium nitrate, potassium thiosulfate, potassium carbonate, Trisert K+ and NACHURS 3-18-18) mixed with and without glyphosate. Foliar injury, crop grain yields and weed control were the primary factors evaluated after foliar application of the K fertilizer sources mixed with glyphosate. Among the conclusions reached by this research is that foliar K fertilization will only possibly be a supplemental practice to long-term K fertilization practices that build up and maintain soil test K levels. However, foliar K fertilization may become a useful management tool if further research can be conducted to determine the soil and environmental conditions that promote soybean crop response to foliar K fertilization and if methods can be developed to assist growers to make rapid assessments of soil K availability during the growing season to decide if and when foliar K fertilization may be profitable.

Introduction

Soybean response to foliar fertilization at several times over the growing season has been extensively examined by researchers starting in the 1970's (Garcia and Hanway, 1976; Parker and Boswell, 1980; Vasilas et al., 1980; Poole et al., 1983; Haq and Mallarino, 1998; Haq and Mallarino, 2000). Some research has examined foliar applications at early vegetative growth stages (Haq and Mallarino, 1998; Haq and Mallarino, 2000) or during late reproductive growth stages (Garcia and Hanway, 1976; Parker and Boswell, 1980; Vasilas et al., 1980). However, these studies evaluated mixed N, P, K, and sometimes S fertilizer sources (Garcia and Hanway, 1976; Parker and Boswell, 1980; Poole et al., 1983; Haq and Mallarino, 1998) and several studies were conducted when soil test fertility levels were optimal (Parker and Boswell, 1980; Haq and Mallarino, 1998; Haq and Mallarino, 2000). Most of the reported responses to foliar fertilizer applications have been variable and inconsistent, especially when tested over a wide range of farm fields (Boote et al., 1978; Haq and Mallarino, 1998; Parker and Boswell, 1980; Poole et al., 1983). Therefore, the practice of foliar fertilization of soybeans with macronutrients has not been widely adopted.

However, recent changes in agricultural management practices and other developments justify additional research into use of foliar K applications for improved soybean production. The incidence of K deficiency in agronomic crops has increased in recent years in Missouri and other Midwestern states due to the effects of drought conditions and soil compaction on decreasing K availability, reduced amounts of applied K fertilizer and lower frequency of soil testing by producers due to low commodity prices, and higher K fertilizer requirements because of increasing corn yields and larger soybean acreage (Reetz and Murrell, 1998; Fixen, 2000). Moreover, 83% of the soybean varieties produced on over 5 million acres in Missouri were Roundup Ready® or contained another form of transgenic herbicide resistance in 2003 (MASS, 2003). Widespread use of glyphosate for postemergence weed control in soybeans opens up the possibility of making foliar K fertilization more cost-effective by combining foliar fertilization with post-emergence herbicide applications. Finally, the goal of recent developments in soil fertility management practices, such as the management practices being developed for site-specific corn N management, has been to provide tools to growers to allow them to have the flexibility to assess and respond to changes and spatial variation in soil nutrient availability over a longer portion of the growing season. If effective, postemergence application of foliar K fertilizer would have the advantage of increased flexibility for growers to more rapidly respond to observed K deficiency due to the effects of variable soil properties, management practices or climatic conditions.

Research Objectives and Information

The research discussed in this paper was initiated in 2001 and includes a sequence of several field experiments with different research objectives. An initial exploratory field experiment was conducted from 2001 to 2002 on a farmer's field in northeastern Missouri with low to medium soil text K. The objectives of that experiment were 1) to determine soybean response to foliar-applied K fertilizer applied at several growth stages compared to a preplant K fertilizer application, and 2) to evaluate the cost-effectiveness of these different timings and methods of K fertilizer applications for soybean growth in claypan soils. Progressing from our initial findings, a second set of field experiments was initiated in 2003 on both low to medium and high soil text K field sites in northeastern Missouri with the objectives of: 1) determining soybean yield response and salt injury from different foliar-applied K fertilizer sources, 2) assessing if the K fertilizer source affects weed control when mixed with a glyphosate-based herbicide, and 3) evaluating the cost-effectiveness of applying K fertilization with glyphosate-based herbicides for soybean production. A final set of field experiments were initiated in 2004 on field sites in northeastern and southeastern Missouri. These field experiments reduce the number of K fertilizer sources being evaluated for foliar K fertilization and compare the effects of uniform application rates of foliar K fertilizer with and without glyphosate. The results of the final set of experiments will not be presented in this paper but some information on the experimental setup is included.

2001 to 2002 Initial Field Experiment

Field research was conducted in a farmer cooperator's field near the University of Missouri Greenley Research Center at Novelty in 2001 and 2002 at adjacent areas in the field each year. The claypan soil at the site was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) and had been in continuous soybeans. The initial exchangeable soil test K level of the field was 74 ± 10 mg K kg^{-1} soil which is in the low to medium range based on University of Missouri soil test interpretations.

The experiment was arranged as a randomized complete block design with four replications in plots 3 by 15.2 m. 'Asgrow 3701' soybeans were no-till planted on 13 June 2001 and 2 June 2002 in 19 cm rows at 494,000 seeds ha^{-1}. Potassium fertilizer was either preplant, broadcast-applied at 140, 280, and 560 kg K ha^{-1} (as K_2SO_4) or foliar applied at 9, 18, and 36 kg K ha^{-1} (as K_2SO_4) at the V4, R1-R2, and R3-R4 stages of soybean development. Potassium sulfate (K_2SO_4) was selected as the K fertilizer source because it had a low salt index and minimal crop injury was expected. Magnesium sulfate ($MgSO_4$) was applied at 15 kg ha^{-1} at V4, R1-R2, and R3-R4 stages of development as a foliar control. Foliar treatments were applied with a CO_2-propelled hand-boom calibrated to deliver 39, 78, 156 L ha^{-1} for the 9, 18, and 36 kg K ha^{-1} rates, respectively, due to the solubility of K_2SO_4. The sprayer was calibrated at 124 kPa, and equipped with 8003 flat-fan nozzles spaced 51 cm apart and 48 cm above the soybean canopy. The entire field was fertilized with 81 and 33 kg P ha^{-1} (as triple superphosphate) in 2001 and 2002, respectively, based on University of Missouri fertilizer recommendations for soybean. A burndown application of glyphosate (*N*-(phosphonomethyl)glycine) (formulated as Roundup Ultra®, Monsanto Co., St. Louis, MO) at 840 g ae ha^{-1} followed by two postemergence applications was used to maintain the plot area weed-free throughout the season.

Soybean injury from 0 (no visual crop injury) to 100% (complete crop death) was evaluated 3 and 7 days after treatment based on the combined visual effects of the foliar fertilizer on necrosis, chlorosis, and stunting. Soil samples were collected on July 2001, June 2002, and October 2002 to 15 cm. Exchangeable soil test K was determined by extraction with 1 M NH_4OAc and K in the extractant was measured using atomic absorption/emission spectrometry. A composite sample of the most recently mature trifoliolate from 20 plants in each plot was removed before the V4, R1 to R2, and R3 to R4 application timings and K in the leaf was determined using atomic absorption/emission spectrometry after dry ashing and extraction with 6 M HCl. Soybean grain was harvested with a small plot combine and moisture adjusted to 13%. Grain samples were collected and K in the grain was determined with the same procedure used for leaf tissue analysis.

An economic analysis evaluated gross margins for the foliar treatments. The gross margin was calculated as the difference between the gross receipts and foliar K fertilizer plus application cost. Foliar fertilizer and application costs were estimated at \$0.08 kg^{-1} and \$12.30 ha^{-1}, respectively, while dry fertilizer application cost was estimated at \$9.88 ha^{-1}. Gross receipts were the product of crop grain yield and market price of \$0.04/kg.

2003 to 2004 Glyphosate-Foliar K Field Experiments

Research was initiated in 2003 at the University of Missouri Greenley Research Center near Novelty, MO on a Putnam silt loam soil with a high soil test K (228 ± 56 mg K kg^{-1}) and a diverse, high population of weeds. An additional field site on a cooperator's field was established with a similar experimental design on a low to medium soil test K site (86 ± 9 mg K kg^{-1}). 'Asgrow 3701' soybean was no-till planted on May, 2003 in 38 cm rows at 444,600 seeds ha^{-1}. Individual plots were 3 by 12 m. The study was arranged as a randomized complete block design with four replications. Foliar K fertilizer sources included 3-18-18, potassium phosphate, (NA-CHURS/ALPINE); 0-0-30, potassium carbonate, (NA-CHURS/ALPINE); 0-0-25-17, potassium thiosulfate (KTS), (Tessenderlo Kerley); 5-0-20-13, Trisert K+, (Tessenderlo Kerley); 0-0-50, potassium sulfate; 0-0-62, potassium chloride (Kalium); 14-0-44, potassium nitrate, (SQM North America); and 21-0-0-23, diammonium sulfate (DAS) on plots maintained weed-free or sprayed as a mixture with a glyphosate at 0.84 kg ae ha^{-1} (Roundup WeatherMAX® at 1.6 L ha^{-1}) on common lambsquarters, common ragweed, and common waterhemp in June, 2003. Some treatments (3-18-18 and KTS) formed precipitates with Roundup WeatherMAX. The precipitate was removed and the treatment was applied to the plot. The foliar K application rate was maximized based on the physical limitations of the K source; therefore, K application rates varied from 2 to 51 kg K ha^{-1}.

Spray mixture pH was recorded prior to the "weed and feed" application. All treatments were applied with a CO_2 propelled hand sprayer traveling 4.7 km h^{-1} and delivering 140 L ha^{-1} at 117 kPa with 8002 FF nozzles. At the time of application, the air temperature was 30.5 °C with 59% relative humidity. Soybean was 15 to 20 cm tall at the V4 to V5 stage of development: common ragweed was 10 to 20 cm tall with 8 to 14 leaves; common waterhemp was 5 to 30 cm with 4 to 14 leaves; and common lambsquarters was 10 to 15 cm tall with 12 to 18 leaves. Changes in soil test K in the plow layer due to treatment application was determined by sampling at the beginning and end of the growing season. Foliar salt injury was rated 3, 7, and 21 days after application on a scale of 0 (no effect) to 100 (complete crop or weed death). Weed control for individual weed species was recorded 14, 28, and 56 days after treatment. A biomass harvest of soybean and weeds was collected 28 days after application to determine total weed control. Soybean leaf samples were harvested near initial bloom. Grain was harvested and moisture adjusted to 13%.

2004 to 2005 Glyphosate-Foliar K Rate Field Experiments

Field trials were established in 2004 at the University of Missouri Greenley Center in Northeast Missouri and at the University of Missouri Delta Center in Southeast Missouri. Roundup-Ready® soybeans were no-till planted at 444,600 seeds ha^{-1} in 38 cm rows. The study was arranged as a randomized complete block design with four replications. Treatments consisted of four rates (0, 2, 9, and 18 kg K ha^{-1}) of foliar K fertilizer sources (potassium chloride, potassium thiosulfate, 3-18-18 containing potassium phosphate, Trisert K+) and diammonium sulfate (2.9 kg ha^{-1}) either sprayed separately on plots maintained weed-free or sprayed as a mixture with a glyphosate-based herbicide (i.e. Roundup Original® plus nonionic surfactant) on plots with weeds. The spray mixture pH was determined prior to the "weed and feed" application. All treatments were applied at a standard postemergence timing for weed control at a 140 L ha^{-1} carrier volume.

Changes in soil test K in the plow layer due to treatment application were determined. Foliar salt injury was rated 3, 7, 14, 21, and 28 days after application. Weed control for individual weed species was recorded 14, 28, and 56 days after application. A biomass harvest of weeds 28 days after treatment was utilized to evaluate weed control. Leaf samples taken at initial bloom were used to determine crop K status in treated and non-treated plants. Soybeans will be harvested and data analyzed to determine the influence of foliar K fertilizer source on crop response, weed control, and grain yield.

Results and Discussion

2001 to 2002 Initial Field Experiment

Salt injury is common with foliar fertilizer applications; however, no foliar crop injury was observed 3 or 7 days after the V4, R1 to R2, and R3 to R4 application timings of K_2SO_4 or the foliar control, $MgSO_4$, during 2001 and 2002 (data not presented). None of the treatments caused leaf injury despite being applied during the middle of the day under high temperature conditions. A possible reason for the lack of leaf injury was the high carrier volume used (561 L ha^{-1}) because of the relative insolubility of K_2SO_4. Carrier volumes used to apply glyphosate are normally at or below 140 L ha^{-1}.

Grain yields were generally higher in 2001 (Fig. 1A) compared to those observed in 2002 (Fig. 1B), probably due to a better distribution of rainfall in 2001. Soybean grain yields in both 2001 and 2002 were also significantly higher with preplant K compared to foliar-applied treatments. Foliar-applied K at 18 or 36 kg K ha^{-1} increased average grain yield 422 to 648 kg ha^{-1} across all foliar application dates when compared to the untreated or sulfur control in 2001 (Fig. 1A). However, soybean yields were more responsive to foliar K applications from 9 to 36 kg K ha^{-1} under relatively drier conditions in 2002, increasing average grain yields across application timings from 563 to 720 kg ha^{-1} when compared to the untreated or sulfur control (Fig. 1B). Soybean grain yield was maximized (an increase of 727 kg ha^{-1} compared to the control) at a foliar rate of 36 kg K ha^{-1} applied at the R1-R2 stages of development in 2001 when drought stressed conditions were minimal. In contrast, the maximum grain yield increase observed in 2002 was 834 kg ha^{-1} at the V4 application timing. A foliar K application may be more effective when applied from the V4 to the R1-R2 stages of development to obtain optimal yields in years with good rainfall distribution; however, substantial yield increases were observed at low rates when conditions were less optimum. Differences in soybean response to foliar K may be affected by climate since lower soil water content may reduce K uptake through the roots and thereby increase the relative crop response to foliar applications.

The cost-effectiveness of treatments evaluated in this study was ranked preplant K at 280 kg ha^{-1} = preplant K at 140 kg ha^{-1} > preplant K at 560 kg ha^{-1} = foliar K applied at the V4 and R1-R2 at 36 kg ha^{-1} followed by additional foliar treatments and the untreated control. All treatments except the V4 at 9 kg ha^{-1} and R3-R4 timing at 9, 18, and 36 kg ha^{-1} application timings increased gross margins when compared to the untreated control.

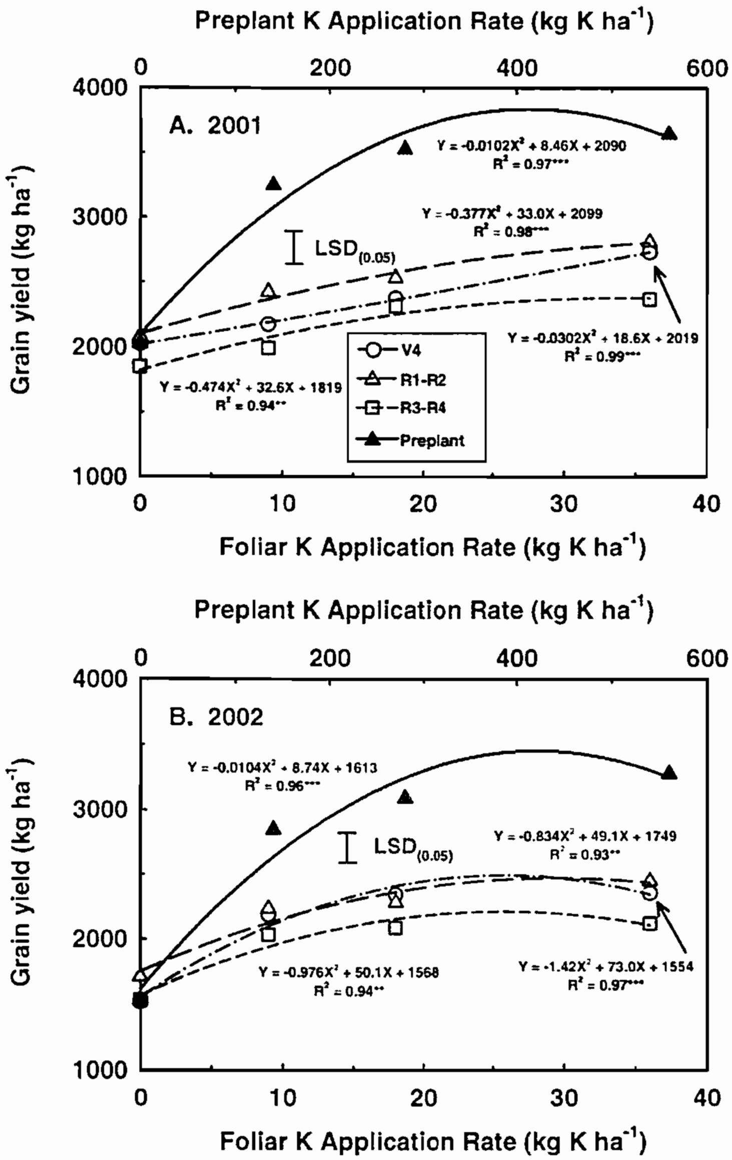

Fig 1 A and B. Soybean grain response to preplant and foliar K fertilization at different soybean growth stages in A) 2001 and B) 2002.

Several tentative conclusions were reached from this preliminary research at a low to medium soil test K site with a claypan soil. First, foliar K applications in soybean may be a possible management tool to mitigate reduced yields caused by K deficiency. However, optimal soybean grain yields and gross margins were obtained with preplant K fertilizer application timings and foliar treatments did not substitute for a preplant K application for optimal soybean production in this research. Foliar K may be a supplemental nutrient management practice when conditions reduce plant K uptake from soil. Second, carrier volumes required for foliar application of K_2SO_4 at rates that were shown to be effective in this research are generally impractical for most farm operations and additional research was needed to evaluate crop response from more soluble K fertilizer sources which would have relatively lower salt indexes and possible compatibility with glyphosate.

2003 to 2004 Glyphosate-Foliar K Field Experiments

Compatibility tests of tank mixing K fertilizer sources with glyphosate were conducted with the highest rate of foliar fertilizer that could be mixed with glyphosate; therefore, not all K sources were mixed at uniform K rates. A slight precipitate was formed when 3-18-18 was tank mixed with Roundup WeatherMAX while KTS formed a viscous solid with Roundup WeatherMAX that was removed prior to the tank mixture application. A poor spray pattern was observed when 0-0-30 was applied with Roundup WeatherMAX and the spray boom height was adjusted to compensate.

Visual injury was primarily necrosis of leaves exposed to foliar application. For the high soil test K site located at the Greenley Center, all treatments except 0-0-30 had less than 10% soybean injury 3 and 7 days after treatment (DAT) with almost complete recovery by 21 DAT (Table 1). Tank mixtures of 3-18-18 and 5-0-20-30 at rates of 11, 21 and 33 kg K ha^{-1} with glyphosate injured soybean more than the foliar fertilizer applied alone 3 DAT. This injury was still evident up to 21 DAT for some treatments and plant height late in the season was shorter than the untreated control (data not shown). The adjuvants present in Roundup WeatherMAX probably increased uptake of the foliar K fertilizers causing increased injury of the fertilizer treatment.

The weed-free soybean grain yield was 2959 kg ha^{-1} in 2003 (Table 1). In the absence of Roundup WeatherMAX, 0-0-30 increased soybean grain yield 336 kg ha^{-1} when compared to the weed-free control at the high soil test K site located at the Greenley Center. At the low to medium soil K test site, foliar-applied 0-0-62 significantly increased soybean grain yield by 134 kg ha^{-1} when compared to the weed-free control (data not shown).

The first year results of these field trials indicate the potential viability of mixing K sources with glyphosate. but also highlight the importance of evaluating both crop K response and weed control to insure grower acceptance of the practice. Potential concerns will be the initial foliar injury observed after spraying some of the foliar K sources and solubility limitations of certain K sources, such as potassium nitrate and potassium sulfate, which would reduce flexibility in increasing foliar K application rates. In addition, soybean yield response to foliar K varied among the K sources and was much lower at both the high and low to medium soil test K field sites compared to the initial field site tested in 2001 and 2002. Our current research is comparing K sources for foliar fertilization at uniform K application rates with and without mixing with glyphosate at several field sites in the state of Missouri.

Summary

Despite the relatively inconsistent soybean K response to foliar K fertilization documented by extensive research, a growing opportunity may exist to provide growers a cost-effective method to apply foliar K to respond to changing environmental and management conditions within a growing season that may reduce soil K availability. Our research indicates that soybeans may respond to foliar K fertilization, especially in low to medium soil test K sites in claypan soils and under relatively drier conditions. However, this method of fertilization will not substitute for a long-term K fertilization program that builds and maintains soil text K at optimum levels. Our ongoing research has been examining mixing foliar K sources with glyphosate since combining foliar fertilization with post-emergence weed control may make foliar fertilization more cost-effective. Among the factors we are considering are the effects of the rate, solubility and salt index of different K sources, K source compatibility with glyphosate, foliar injury after spraying, possible reductions in weed control, and changes in crop yields. Among the challenges facing adoption of this method is improving our understanding of the soil and environmental characteristics that promote soybean crop response to foliar K fertilization and developing methods to assist growers to make rapid assessments during the growing season to decide if and when foliar K fertilization would be cost-effective and beneficial.

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Table 1. Soybean injury and grain yields with K sources in the presence and absence of glyphosate (formulated as Roundup WeatherMAX) in 2003 at a high soil test K site 3, 7, and 21 days after treatment (DAT).

		Injury 3 DAT Roundup		Injury 7 DAT Roundup		Injury 21 DAT Roundup		Grain yield Roundup	
K source[a]	Rate	-[b]	+	-	+	-	+	-	+
	kg K ha^{-1}	%						kg ha^{-1}	
Untreated		0	0[c]	0	0	0	0	1412	2892
Weed-free		0	0	0	0	0	0	2959	3026
3-18-18	30	5	11	2	10	0	7	3026	3026
0-0-30	51	23	19	15	14	5	13	3295	2556
0-0-25-17	43	7	7	4	4	1	3	3094	2219
5-0-20-13	33	9	15	7	11	0	10	3161	2690
5-0-20-13	21	4	12	3	8	0	8	3161	2892
5-0-20-13	11	2	6	1	2	1	3	3094	3094
0-0-50	2	0	1	0	1	0	1	2959	2892
0-0-62	18	3	4	2	2	1	2	3094	3094
14-0-44	2	0	0	0	0	0	0	3026	3026
DAS	0	0	0	0	0	0	0	3026	3161
LSD ($p \leq 0.05$)		3		2		3		336	

[a]K sources: 3-18-18, potassium phosphate, NA-CHURS/ALPINE; 0-0-30, potassium carbonate (Double-OK) NA-CHURS/ALPINE; 0-0-25-17, potassium thiosulfate (KTS) Tessenderlo Kerley; 5-0-20-13, Trisert K+, Tessenderlo Kerley; 0-0-50, potassium sulfate; 0-0-62, potassium chloride (Kalium); 14-0-44, potassium nitrate (SQM North America); and DAS, diammonium sulfate.
[b]All treatments except the untreated control were maintained weed-free with glyphosate (formulated as Roundup UltraMAX).
[c]No additive was included.

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