Soybean Response to Potassium Chloride and Strobilurin Fungicides

K.A. Nelson[1], P.P. Motavalli[2], W. Stevens[3], D. Dunn[3], and C. Meinhardt[1]

[1]Div. of Plant Sciences, Greenley Research Center, University of Missouri, Novelty, MO 63460, [2]Dept. of Soil, Environmental and Atmospheric Sciences, University of Missouri, Columbia, MO 65211, [3]Div. of Plant Sciences, [3]Delta Research Center, University of Missouri, Portageville, MO 63873

MIZZOU.

MIZZOU.

Abstract

Potassium chloride (KCl) preplant- or foliar-applied with fungicides to soybean [*Glycine max* (L.) Merr.] may allow farmers to increase yields when soil potassium (K) availability is reduced and/or when Septoria brown spot (SBS) (*Septoria glycines*), frogeye leaf spot (FLS) (*Cercospora sojina*), or sudden death syndrome (SDS) (*Fusarium solani* (Mart.) Sacc. f. sp. *glycines*) are present. Interactions between fertilizer and fungicide management programs have not been examined in the central United States. Our objective was to evaluate the effect of preplant- and foliar-applied KCl alone or combined with pyraclostrobin, azoxystrobin, or azoxystrobin plus lambda-cyhalothrin on soybean response and severity of SBS, FLS, and SDS. Experiments were conducted in northeastern (Novelty) and southeastern (Qulin) Missouri in 2006 and 2007 on soils with low to medium K. Leaf K concentrations increased 1.4 to 6.1 g kg^{-1} following preplant KCl compared to non-treated or foliar KCl. Leaf Cl concentrations increased significantly with preplant KCl at Qulin and foliar KCl at R4 at Qulin and Novelty. At Novelty, preplant KCl reduced the severity of SBS and FLS up to 6%, and increased yield 340 kg ha^{-1}, while foliar KCl increased yield 110 kg ha^{-1}. An R4 application of strobilurin fungicides increased yields 230 to 360 kg ha^{-1} at Novelty. At Qulin, soybean yield increased 390 kg ha^{-1} with preplant KCl, while there were variable effects of fungicides on the severity of SBS, FLS, or SDS, and no yield increase due to fungicides or foliar KCl. Foliar applications of KCl were no substitute for preplant KCl.

Introduction

Foliar pathogens decrease the area of photosynthetic tissue, which reduces the transfer of assimilates to grain production by diverting assimilates to fungal growth, defense systems, and increased respiration. Researchers have established a link between plant nutrition and the severity of disease, including disease-suppressing effects of Ca, K, Cl, Mn, B, and P (Rupe et al., 2000; Fixen et al., 2004). Optimal soybean grain yields have been obtained with preplant K fertilizer applications; however, foliar K applications may also be used as a management tool to mitigate K deficiency during the growing season and minimize yield loss (Nelson et al., 2005). Preventative fungicides, such as strobilurins, have sometimes increased yields in small grains (Grossmann et al., 1999) and soybean (Dorrance et al., 2010) in the absence of disease due to a physiological effect of the fungicides on plants (Köehle et al., 2002). Although the appropriate timing of fungicide applications may not always coincide with the timing of herbicide applications, a combination of a fungicide with a fertilizer may provide greater fertilizer application flexibility to address not only the crop nutritional needs, but also to manage potentially yield-limiting foliar diseases such as Septoria brown spot and frogeye leaf spot. Using KCl either as a pre-plant or foliar application combined with a fungicide may synergistically reduce the severity of diseases and increase yield. The possible benefits of a foliar application of KCl include reduced application costs, improved disease suppression and nutrient response of the crop, and increased application flexibility in response to environmental conditions during the growing season. We hypothesized that soybean may benefit more from foliar fungicide applications when the plants grow in soils low in K, where they could be more susceptible to some foliar diseases.

Objective

Determine soybean yield response, severity of foliar diseases, and plant tissue concentrations of K and Cl in plots treated with preplant, soil-applied KCl and a foliar application of KCl alone or in combination with foliar strobilurin fungicide applications at two stages of development.

Table 1. The effects of KCl treatments on foliar K and Cl concentration 10 d after the R4 growth stage of soybean plants at Novelty (2006 and 2007) and Qulin (2006). Tissue K concentration was averaged over three fungicide treatments, two foliar application timings (V4 and R4 growth stages), and both years for the Novelty site, while tissue Cl concentration was averaged over all three fungicide treatments.

	Novelty			Qulin		
	Tissue	Tissue Cl		Tissue	Tissue Cl	
KCl treatment†	K	V4‡	R4	K	V4	R4
	------------------- g kg^{-1} -------------------					
None	15.5	2.65	2.79	17.3	12.5	12.2
Preplant KCl	21.6	2.57	2.41	19.3	14.4	14.4
Foliar KCl	15.7	2.84	5.34	17.9	12.8	15.9
LSD ($P \le 0.05$)	1.1	--- 0.69 ---		1.1	----- 1.1 -----	

†Abbreviations: KCl, muriate of potash.
‡Fehr and Caviness (1971).

Table 2. Effect of foliar fungicide and insecticide treatments and application timing on the severity of Septoria brown spot and frogeye leaf spot, tissue K concentration, and soybean grain components at Novelty, Missouri. All data were combined the over two years of this study (2006 and 2007) except for tissue K concentration.

Soybean growth stage and	Tissue K		Septoria	Frogeye	Grain		
fungicide treatment	2006	2007	brown spot†	leaf spot†	Oil	Protein	Yield
	-- g kg^{-1} --		---------------- % ----------------		-- g kg^{-1} --		kg ha^{-1}
V4							
None	20.0	16.3	4	6	194	350	3,870
Azoxystrobin at 0.11 kg ha^{-1} a.i.	20.5	14.9	4	6	194	350	4,000
Azoxystrobin at 0.11 kg ha^{-1} a.i. + lambda-cyhalothrin at 0.02 kg ha^{-1} a.i.	20.2	14.5	4	5	192	353	3,880
Pyraclostrobin at 0.11 kg ha^{-1} a.i.	18.1	17.5	4	6	193	351	3,900
R4							
None	20.0	15.9	4	6	193	351	3,870
Azoxystrobin at 0.11 kg ha^{-1} a.i.	17.3	17.4	3	4	193	350	4,100
Azoxystrobin at 0.11 kg ha^{-1} a.i. + lambda-cyhalothrin at 0.02 kg ha^{-1} a.i.	19.0	14.7	3	4	195	347	4,230
Pyraclostrobin at 0.11 kg ha^{-1} a.i.	19.4	16.0	3	4	194	349	4,180
‡LSD ($P \le 0.05$)	--- 2.5 ---		1	1	1	3	130

†Septoria brown spot (*Septoria glycines*) and frogeye leaf spot (*Cercospora sojina*) were assessed at early R6 (Fehr and Caviness, 1971).

Materials and Methods

- **Field research was conducted near Novelty and Qulin, MO as a three-factor factorial (3 KCl fertilizer treatments x 4 fungicide treatments x 2 application timings) in a randomized complete block design with four replications.**
- **Treatments of KCl included a non-treated control, recommended pre-plant K application broadcast as KCl based on soil test recommendations (420 kg ha^{-1} K in 2006 and 470 kg ha^{-1} K in 2007 at Novelty, and 190 kg ha^{-1} K in 2006 and 200 kg ha^{-1} K in 2007 at Qulin), or a foliar application of spray grade KCl (PCS, Potash Corp. of Saskatchewan, Northbrook, IL) at 18 kg ha^{-1} K. These K treatments were in a factorial arrangement with a no-fungicide control treatment, pyraclostrobin foliar application at 0.11 kg ha^{-1} a.i. plus 0.25% (vol./vol.) non-ionic surfactant (NIS), azoxystrobin foliar application at 0.11 kg a.i. ha^{-1}, or azoxystrobin at 0.11 kg ha^{-1} a.i. plus lambda-cyhalothrin at 0.02 kg ha^{-1} a.i. as a foliar application at the V4 or R4 growth stages.**
- **Foliar injury in each plot was rated.**
- **20 leaves were collected approximately 10 d after the R4 stage from each plot at Novelty in 2006 and 2007, and from Qulin in 2006. Nitrogen, K, P (Mills and Jones, 1996), and Cl (Brown and Jackson, 1955) concentrations were determined (Mills and Jones, 1996).**
- **The severity of diseased plants in each plot was assessed based on a percentage of the canopy (0 to 100%) with symptoms of Septoria brown spot, frogeye leaf spot, sudden death syndrome (SDS) (Howard et al., 1999), and soybean rust at the beginning of the R6 stage (Fehr and Caviness, 1971). These trials were set up primarily to assess the potential impact of these treatments on soybean rust, but none developed at either location. Soybean aphids were present at Novelty in 2007 and were counted weekly on 10 arbitrarily selected plants plot^{-1} (Ragsdale et al., 2007) to evaluate any potential interaction between preplant and foliar KCl applications with or without lambda-cyhalothrin.**
- **A small-plot combine was used to harvest and weigh the center four rows of each plot at Novelty and the center two rows of each plot at Qulin. Seed moisture was determined at harvest and adjusted to 130 g kg^{-1} prior to data analyses. Grain samples were collected from each plot at Novelty in 2006 and 2007, and analyzed for protein and oil concentration with near-infrared spectroscopy (Foss Infratec 1241 Grain Analyzer, Eden Prairie, MN).**
- **Data were subjected to ANOVA and means separated using Fisher's Protected LSD at *P* $\le$ 0.05. Data were combined over years within the Novelty and Qulin sites, and pooled main effects are presented if there were no significant interactions.**

Table 3. The effects of KCl treatments on severity of Septoria brown spot and frogeye leaf spot, and grain composition at Novelty, Missouri. Data were combined over fungicide treatments, application timings, and two years (2006 and 2007).

	Septoria	Frogeye	Grain		
KCl treatment†	brown spot‡	leaf spot‡	Oil	Protein	Moisture
	-------- % --------		-------- g kg^{-1} ------		
None	5	8	192	354	112
Preplant KCl	2	2	197	342	111
Foliar KCl	5	6	192	354	108
LSD ($P \le 0.05$)	1	1	1	2	3

†Abbreviations: KCl, muriate of potash.
‡Septoria brown spot (*Septoria glycines*) and frogeye leaf spot (*Cercospora sojina*) were assessed at early R6 (Fehr and Caviness, 1971).

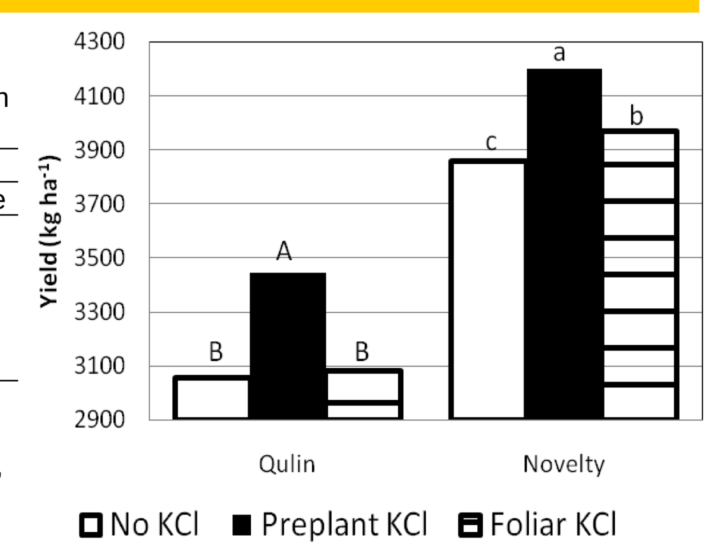

Figure 1. Soybean grain yield response to no KCl, preplant application of KCl at 190 to 200 kg ha^{-1} K, and foliar application of KCl at 18 kg ha^{-1} K at Qulin and Novelty, Missouri. Data were combined over fungicide treatments, foliar application timings, and two years (2006 and 2007). Letters that are different indicate a significant difference between treatments for each site ($P \le 0.05$).

References

1. Brown, J.A., and R.K. Jackson. 1955. A note on the potentiometric determination of chloride. Am. Soc. Hoc. Proc. 65:187.
2. Dorrance, A.E., C. Cruz, D. Mills, R. Bender, M. Koenig, G. LaBarge, R. Leeds, D. Mangione, G. McCluer, S. Ruhl, H. Siegrist, A. Sundermeier, D. Sonnenberg, J. Yost, H. Watters, G. Wilson, and R.B. Hammond. 2010. Effect of foliar fungicide and insecticide applications on soybeans in Ohio. Online. Plant Health Progress doi:10.1094/PHP-2010-0122-01-RS.
3. Fehr, W.R., and C.E. Caviness. 1971. Stages of soybean development. Crop Sci. 11:929-930.
4. Fixen, P.E., C.S. Snyder, H.F. Reetz, Jr., T. Yamada, and T. S. Murrell. 2004. Nutrient management of soybeans with the potential for Asian rust infection. Potash & Phosphate Institute, Norcross, GA.
5. Grossmann, K., J. Kwaltowski, and G. Caspar. 1999. Regulation of phytohormone levels, leaf senescence, and transpiration by the strobilurin kresoxim-methyl in wheat (*Triticum aestivum*). J. Plant Physiol. 154:805.
6. Howard, D.D., A.Y. Chambers, and M.A. Newman. 1999. Reducing sudden death syndrome in soybean by amending the soil with chloride. Communic. Soil Sci. Plant Anal. 30:545-555.
7. Köehle, H., K. Grossmann, T. Jabs, M. Gerhard, W. Kaiser, J. Glaab, U. Conrath, K. Seehaus, and S. Herms. 2002. Physiological effects of the strobilurin fungicide F 500 on plants. pp. 61-74. *In* Modern Fungicides and Antifungal Compounds III. (Dehne, H.W., U. Gisi, K.H. Kuck, P.E. Russell, and H. Lyr, eds.). Bonn: Mann GmbH & Co. KG.
8. Mills, H., and J. Jones. 1996. Plant Analysis Handbook II. MicroMacro Publ., Athens, GA.
9. Nelson, K.A., P.P. Motavalli, and M. Nathan. 2005. Response of no-till soybean [*Glycine max* (L.) Merr.] to timing of preplant and foliar potassium applications in a claypan soil. Agron. J. 97:832-838.
10. Ragsdale, D.W., B.P. McCornack, R.C. Venette, B.D. Potter, I.V. Macrae, E.W. Hodgson, M.E. O'Neal, K.D. Johnson, R.J. O'Neil, C.D. Difonzo, T.E. Hunt, P.A. Glogoza, and E.M. Cullen. 2007. Economic threshold for soybean aphid (Hemiptera: Aphididae). J. Econ. Entomol. 100:1258-1267.
11. Rupe, J.C., J.D. Widick, W.E. Sabbe, R.T. Robbins, and C.B. Becton. 2000. Effect of chloride and soybean cultivar on yield and the development of sudden death syndrome, soybean cyst nematode, and southern blight. Plant Dis. 84:669-674.
12. Yin, X. and T.J. Vyn. 2004. Critical leaf potassium concentrations for yield and seed quality of conservation-till soybean. Soil Sci. Soc. Am. J. 68:1626-1634.

Table 4. Effect of KCl treatments, fungicide treatments, and foliar fungicide application timing on severity of Septoria brown spot, frogeye leaf spot, and sudden death syndrome (SDS) of soybean at Qulin, Missouri. Data were combined over two years (2006 and 2007).

	Septoria brown spot†		Frogeye leaf spot†		SDS†	
KCl and fungicide treatments	V4	R4	V4	R4	V4	R4
	---------------------- % ----------------------					
No KCl						
No fungicide	7	3	4	2	2	5
Azoxystrobin at 0.11 kg ha^{-1}	0	6	3	1	8	3
Azoxystrobin at 0.11 kg ha^{-1} + lambda-cyhalothrin at 0.02 kg ha^{-1}	6	4	0	2	3	3
Pyraclostrobin at 0.11 kg ha^{-1}	4	4	3	3	3	4
Preplant KCl						
No fungicide	5	5	1	2	2	4
Azoxystrobin at 0.11 kg ha^{-1}	6	5	2	5	5	3
Azoxystrobin at 0.11 kg ha^{-1} + lambda-cyhalothrin at 0.02 kg ha^{-1}	5	6	0	1	1	2
Pyraclostrobin at 0.11 kg ha^{-1}	3	5	0	2	3	1
Foliar KCl						
No fungicide	8	8	2	3	5	1
Azoxystrobin at 0.11 kg ha^{-1}	6	10	1	3	6	1
Azoxystrobin at 0.11 kg ha^{-1} + lambda-cyhalothrin at 0.02 kg ha^{-1}	4	9	0	1	4	1
Pyraclostrobin at 0.11 kg ha^{-1}	2	8	4	0	3	1
‡LSD ($P \le 0.05$)	------- 4 -------		----- 2 -----		---- 6 ----	

†Septoria brown spot (*Septoria glycines*), frogeye leaf spot (*Cercospora sojina*), and SDS (*Fusarium solani* (Mart.) Sacc. f. sp. *glycines*) were assessed at early R6 (Fehr and Caviness, 1971).

Results and Discussion

Injury

- **Preplant-applied KCl as well as foliar applied azoxystrobin, azoxystrobin plus lambda-cyhalothrin, and pyraclostrobin alone at the V4 or R4 application timings did not injure soybean (data not presented), but injury increased when KCl was tank-mixed with azoxystrobin, azoxystrobin plus lambda-cyhalothrin, or pyraclostrobin plus NIS.**

Leaf Tissue Analyses

- **There was no effect of fungicide application timing, fungicide treatment, or KCl on leaf P concentration (data not presented). At the Novelty site, azoxystrobin and pyraclostrobin had no significant effect on leaf N concentration compared to the non-treated check plots (data not presented).**
- **Preplant KCl application increased K in leaf tissue 2 g kg^{-1} at Qulin and 6.1 g kg^{-1} at Novelty compared to the control plots (Table 1). Fungicide application timing had an inconsistent effect on leaf K concentration at Novelty (Table 2).**
- **Leaf Cl concentration was three to five times greater at Qulin in 2006 than at Novelty in both years (Table 1). This may be due to the higher soil Cl level at Qulin than at Novelty (data not presented) or because the cultivar planted at Qulin was a Cl includer (Rupe et al., 2000). Elevated soil Cl levels at the Qulin site may have resulted from flood-irrigated rice grown in rotation with soybean. At Qulin, preplant KCl increased Cl concentration in the leaves of soybean compared to the non-treated control plots, but this treatment had no effect on leaf Cl concentration at Novelty. At Qulin and Novelty, foliar-applied KCl at the R4 stage increased leaf Cl concentrations by 2.55 to 3.74 g kg^{-1} compared to the non-treated control plots. The R4 foliar application also increased leaf Cl concentration 1.50 to 2.93 g kg^{-1} compared to the preplant KCl application at Novelty and Qulin.**

Severity of Disease

- **Soybean rust was detected at physiological maturity (R7) in northeast and southeast Missouri in 2007, but none was found in plots at either Novelty or Qulin.**
- **The severity ratings of Septoria brown spot, frogeye leaf spot, and SDS were all <10% at both locations (Tables 4, 6, and 7). Plots treated with azoxystrobin, azoxystrobin plus lambda-cyhalothrin, or pyraclostrobin at the R4 stage reduced the severity of Septoria brown spot and frogeye leaf spot compared to the non-treated plots and compared to all plots treated at the V4 growth stage (Table 2). At early R6, there was less defoliation in the bottom part of the plant due to Septoria brown spot in the KCl treated plots compared to the non-treated controls (visual observation). At Novelty, a preplant KCl application reduced the severity of Septoria brown spot by 3% and frogeye leaf spot by 6% compared to plots with no KCl, but a foliar application of KCl only reduced the severity of frogeye leaf spot 2% and had no effect on Septoria brown spot (Table 3).**
- **There was a significant interaction between KCl treatments, fungicide treatments, and foliar fungicide application timing on the severity of diseases at Qulin (Table 4). In general, preplant applied KCl did not significantly reduce the severity of Septoria brown spot, frogeye leaf spot, or SDS compared to the control plots with no KCl at Qulin. This may be due to the elevated soil Cl levels at Qulin compared to the Novelty site. Rupe et al. (2000) reported that disease and Cl toxicity responses were cultivar-dependent.**

Grain Quality and Yield

- **At Novelty, grain oil increased 5 g kg^{-1} and protein decreased 12 g kg^{-1} in plots with preplant KCl application compared to the non-treated plots or plots with a foliar KCl application (Table 3). However, grain moisture at harvest was 3 to 4 g kg^{-1} lower in plots with foliar-applied KCl than plots with preplant KCl or no KCl. Leaf K concentrations at Novelty were 8.4 g kg^{-1} lower in plots with foliar KCl treatments (Table 1) than the critical leaf K concentration (24.1 g kg^{-1}) for optimum grain oil concentration reported by Yin and Vyn (2004). Fungicide treatments did not affect soybean grain moisture significantly at harvest (data not presented); however, an early (V4) application of azoxystrobin plus lambda-cyhalothrin reduced grain oil concentration 2 g kg^{-1}, while a late application (R4) increased oil concentration 2 g kg^{-1} (Table 2).**
- **Grain yields at Novelty and Qulin increased 230 and 390 kg ha^{-1}, respectively, in plots with a preplant KCl application compared to the non-treated plots or plots with foliar-applied KCl (Figure 1). While there was no significant effect of fungicide treatments or foliar fungicide application timing on soybean grain yield at Qulin (data not presented) nor fungicides applied at the V4 stage at Novelty (Table 2), fungicide treatments applied at the R4 stage of development increased yields 230 to 360 kg ha^{-1} at Novelty (Table 2).**

Conclusions

- **A preplant KCl application significantly reduced the severity of Septoria brown spot and frogeye leaf spot in soybean at Novelty, and increased grain yield by 340 kg ha^{-1} compared to plots with no KCl.**
- **Foliar-applied KCl increased grain yield 110 kg ha^{-1} at Novelty, and when KCl was foliar-applied at R4, while leaf Cl concentrations increased significantly at both the Qulin and Novelty sites in Missouri.**
- **At Novelty, strobilurin fungicides at R4 increased grain yields 230 to 360 kg ha^{-1}.**
- **At Qulin, soybean grain yield increased up to 390 kg ha^{-1} with a preplant KCl compared to plots with no KCl.**
- **Strobilurin fungicide treatments showed variable effects on the severity of the three diseases observed in this study, and there was no significant yield response to foliar fungicides or foliar KCl applications at the Qulin site.**
- **Yield results indicated that foliar applications of KCl were not equivalent to soil-applied KCl in the conditions of the trials evaluated in this research.**