Effect of Chloride and Soybean Cultivar on Yield and the Development of Sudden Death Syndrome, Soybean Cyst Nematode, and Southern Blight

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ABSTRACT

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Yields of irrigated soybean in Arkansas are threatened by two problems: chloride toxicity and sudden death syndrome (SDS). Soybeans are sensitive to chloride, which accumulates in the upper soil profile when water with high salt content is used for irrigation. Sudden death syndrome is a soilborne disease often associated with well-irrigated fields. Even though these problems both affect irrigated soybeans, there are no reports on the effect of chloride toxicity on SDS. To determine if there is an effect of chloride toxicity on SDS, a test was established at the Cotton Branch Station, Marianna, AR, in 1995 and 1996. Four cultivars were selected that were either susceptible to SDS (S) or resistant to SDS (R) and either translocated chloride to the leaves (includer, I) or confined chloride in the roots (excluder, E). The cultivars were Hartz 6686 (SE), Terra Vig 6653 (SI), Hartz 6200 (RE), and Asgrow 6297 (RI). Soil chloride concentrations were adjusted by the addition of KCl. Before planting, KCl was applied to achieve the recommended concentration of K over the entire field. At V4, chloride treatments were applied by either adding no additional KCl (low Cl) or adding 1,120 kg of KCl per ha (moderate Cl) or 2,240 kg of KCl per ha (high Cl). Soil samples were taken within the center two rows of each plot at planting, flowering (R₂), and harvest and assayed for populations of *Fusarium solani* and *Heterodera glycines*. Soil chloride concentrations were determined at R₂, and leaf chloride levels were determined at R₃. Weekly disease ratings were made on SDS and converted to area under the disease progress curve (AUDPC). Plant lodging and the incidence of southern blight (*Sclerotium rolfsii*) were determined during mid-reproductive growth. Leaf chloride concentrations were influenced by both chloride treatment and cultivar: elevated concentrations occurred with the includer cultivars in the moderate and the high Cl treatments. Soil concentrations of chloride reflected the chloride treatments in 1995, but not 1996. Soil populations of *F. solani* did not respond consistently to either chloride treatment or cultivar; however, *H. glycines* egg densities increased with increased soil chloride treatments in Hartz 6686 (SE) and Terra Vig 6653 (SI) at R₂, but not at harvest. Increased soil chloride treatments increased SDS in both years with Hartz 6686 (SE), but did not affect this disease in the other cultivars. Higher soil chloride treatments decreased yield in all cultivars except Hartz 6200 (RE) in 1996. Although Terra Vig 6653 (SI) did not develop severe levels of SDS foliar symptoms, it did have increased lodging and significant increases in southern blight with moderate and high soil chloride treatments. These results indicate that growers with fields that have both elevated concentrations of soil chloride and SDS should select SDS-resistant excluder cultivars to minimize yield losses due to both problems.

Irrigated soybean production in Arkansas is limited by two important problems: sudden death syndrome (SDS) and chloride toxicity. Sudden death syndrome is caused by the fungus *Fusarium solani* f. sp. *glycines* and is associated with high yield environments (25,26,28). It was first

observed in Arkansas in 1971 and was not found elsewhere until it was reported in Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee in the mid 1980s (27). The disease now occurs in Kansas, Iowa, Ohio, Ontario, Canada, Argentina, and Brazil.

Although caused by a soilborne pathogen, SDS produces distinctive foliar symptoms that usually begin after flowering as interveinal chlorotic spots. These spots may become necrotic or may coalesce into chlorotic and necrotic interveinal streaks while the veins remain green. Severely affected leaves abscise, but the petioles remain attached to the stem. Root systems of heavily diseased plants are reduced in size and have brown discolored vascular tissue while the pith remains white.

Soybean yields can be dramatically reduced in areas with severe SDS (27). These areas often occur in spots within fields where the microclimate is conducive to disease. A number of soil factors have been associated with SDS, especially the soybean cyst nematode (SCN), *Heterodera glycines* (31,33). Most fields with SDS have SCN present, and greenhouse and microplot studies have shown that the presence of the nematode speeds onset and increases severity of SDS (18–20,26). Onset of SDS symptoms is delayed, and severity is reduced in fields planted with cultivars resistant to the SCN race present in the field (29).

Chloride toxicity has been recognized as a problem in soybean fields of the Mississippi River Delta in Arkansas since 1990. This problem is usually due to salt accumulations following repeated applications of well water with elevated salt content to soils with poor internal drainage. Soybean is sensitive to chlorides from salts, which are taken up and either translocated to the foliage (includer cultivars) or stored in the roots (excluder cultivars) (1,2,15). Although chloride can reduce yields in both types of cultivars, yield losses are greater for includer cultivars, where the chloride causes symptoms ranging from faint foliar chlorosis to plant death as leaf and stem chloride concentrations increase (16,23). At intermediate to high chloride concentrations, plant canopies of affected includer cultivars appear scorched.

Elevated concentrations of chloride may affect disease development. Elevated soil chloride concentrations have been reported to suppress *Fusarium* crown and root rot of asparagus caused by *F. oxysporum* f. sp. *asparagi* (10–12), *Rhizoctonia* root and crown rot of table beets caused by *Rhizoctonia solani* (13), *Fusarium* yellows of celery caused by *F. oxysporum* f. sp. *apii* (34), take-all of wheat caused by *Gaeumannomyces graminis* var. *tritici* (5,6,36), stripe rust of wheat caused by *Puccinia striiformis* (32), and stalk rot of corn (38). Elevated concentrations of soil chloride are reported to enhance *Fusarium* crown rot of tomato caused by *F. oxysporum* f. sp. *radicis-lycopersici* (37) and *Phytophthora* rot of soybean caused by *Phytophthora sojae* (3).

Although both SDS and chloride toxicity are associated with irrigated soybean pro-

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duction in Arkansas, information is lacking on their interaction between the two problems and on the effect of chloride on soil populations of *F. solani* and *H. glycines*. The objectives of this research were to determine the effects of cultivar and elevated soil chloride concentrations on yield, development of SDS, and soil populations of *F. solani* and *H. glycines*.

MATERIALS AND METHODS

The test was conducted at a field site with a history of SDS and SCN on the Cotton Branch Station, University of Arkansas, Marianna, in 1995 and 1996. The soil is a Loring silt loam (Fine-silty, mixed Thermic Typic Fragiudalfs). Four cultivars were selected: Hartz 6686, an SDS-susceptible chloride excluder (SE); Terra Vig 6653, an SDS-susceptible chloride includer (SI); Hartz 6200, an SDS-resistant chloride excluder (RE); and Asgrow 6297, an SDS-resistant chloride includer (RI). Susceptibility to SDS was based on results from the 1994 commercial cultivar tests conducted at the Cotton Branch Station (9). Chloride reaction was based on greenhouse evaluations (*unpublished data*).

Soil K concentration for the field was adjusted to optimum concentrations in 1995 with a preplant application of KCl at 112 kg/ha. Soil chloride concentrations were adjusted by soil applications of KCl at the V₄ growth stage (14). The chloride treatments were: no additional KCl (low Cl), 1,120 kg of KCl per ha (moderate Cl), or 2,240 kg of KCl per ha (high Cl). In 1996, preplanting soil K concentrations were found to be at recommended concentrations, so no additional KCl was applied preplant. To ensure elevated concentrations of Cl, the V₄ KCl applications made in 1995 were made in 1996 in the same plots. The experimental design was a split-split plot with year as the main effect, chloride treatment as the split-plot effect, and cultivar as the split-split plot effect. Each plot was four rows wide with 91 cm between rows, 6 m long with a 1.5-m alley between plots. There were five replications.

Soil chloride concentrations were determined on samples taken at R₂ within the row of the two center rows of each plot using a Haake-Buchler Digital Chloridometer (Haake-Buchler Instrument, Inc., Saddlebrook, NJ 07662). A 1-g sample of dry soil was placed into a 250-ml Erlenmeyer flask containing 50 ml of deionized water (22). The mixture was shaken for 20 min and filtered through Whatman no. 1 filter paper. Three milliliters of the filtered solution was placed in a vial to which 1 ml of nitric acid reagent (288 ml of distilled water + 12 ml of nitric acid + 200 ml of glacial acetic acid) and 100 µl of gelatin reagent solution (0.62 g of gelatin reagent, provided by the chloridometer manufacturer, dissolved in 100 ml of boiling distilled water) were added. The vial was then

placed on the chloridometer, and the concentration of Cl ions in the solution was determined by silver nitrate precipitation.

Leaf chloride concentrations were determined on 8 August 1995 and 15 August 1996 (growth stages R₃ and R₄, respectively) by a process similar to the one used for soil chloride determination. Leaf samples consisting of the leaflets of the third leaf from the top of each of five plants within a subplot were collected and dried. Samples were ground to pass through a 40-mesh screen. A 0.1-g leaf sample was placed into a 250-ml Erlenmeyer flask containing 50 ml of distilled water, and leaf chloride concentration was determined in a process identical to that used for soil chloride determination.

Soil populations of *F. solani* and *H. glycines* were determined at planting, at R₂, and at harvest each year. Samples taken from the top 15 cm of soil within the row of the two middle rows of each plot (30) were thoroughly mixed by hand, and approximately 600 cm³ were removed for the nematode assay. To determine the SCN cyst (i.e., females and cysts), egg, and second-stage juvenile (J2) populations, a 100 cm³ aliquot of well-mixed soil from each sample was suspended in water and poured through nested 841-, 250-, and 38-µm-pore sieves. The material caught on the 250-µm-pore sieves (including cysts, egg masses, and debris) was clarified by sucrose (1.25 kg of sucrose per liter of water) centrifugal flotation (17), and the number of cysts (including females) was determined. This cyst-bearing material was crushed in a tissue grinder and poured through nested 149- and 25-µm-pore sieves to remove coarse debris and collect eggs. The eggs were counted. The material caught on the 38-µm-pore sieve in the initial sieving was clarified by sucrose (714 g of sucrose per liter of water) centrifugal flotation, and the SCN J2 and other plant parasitic nematodes present were identified and counted.

Numbers of CFU of *F. solani* in a 2-g subsample of each soil sample were determined on modified Nash and Snyder's medium (21). This medium consisted of 20 g of agar, 15 g of peptone, 1 g of KH₂PO₄, 0.5 g of MgSO₄·H₂O, and 1 liter of deionized water. The medium was autoclaved for 20 min and cooled to 45°C, and then 300 mg of streptomycin, 100 mg of neomycin, 100 mg of chlortetracycline, 50 mg of Rifampicin, and 240 mg of pentachloronitrobenzene were added to the medium, which was then thoroughly mixed and poured into 9-cm-diameter plastic petri dishes. Each soil subsample was placed in 100 ml of deionized water in 250-ml flasks, the flasks were agitated on a wrist-action shaker for 30 min, and 10 ml of the suspension was transferred into another 250-ml flask and thoroughly mixed with 90 ml of deionized water (dilution 1). Fifty milliliters of dilution 1 were mixed with 50

ml of deionized water, then 1-ml portions of each dilution were spread on the surface of modified Nash and Snyder's medium (21) in each of five plates. After incubation for 5 to 7 days, the *F. solani* colonies were enumerated and expressed as CFU per gram of dry soil. Soil moisture was determined gravimetrically by weighing a 2- to 5-g subsample of soil from each sample before and after drying at 105°C for 24 h. Soil moisture was expressed on a wet weight basis. *F. solani* colonies from this field enumerated in this manner have been identified as the SDS pathogen (4).

Disease severity (percent leaf area with symptoms) and incidence (percent plants with disease) of SDS were determined on plants in the two center rows of each plot using the Horsfall-Barratt scale (24). Disease ratings were taken weekly in August and September (eight ratings per year) until the plants reached the R₇ growth stage. Disease was expressed as total leaf area affected, which was determined by multiplying percent incidence by percent severity. These ratings were used to calculate the area under the disease progress curve (AUDPC) (35).

The incidence of southern blight, caused by *Sclerotium rolfii*, and the incidence of lodging of plants in the center two rows of each plot were rated using the Horsfall-Barratt scale. The incidence (percentage) of southern blight was determined on 29 August 1995 (R₅) and 12 September 1996 (R₆). Lodging was determined on 29 September 1995 and 19 September 1996 (growth stage R₆ in both years) and was expressed as percent.

At the end of the season, plot yields were determined by harvesting the center two rows of each plot and expressed as kilograms per hectare with a seed moisture of 13%. Seed weight, expressed as grams per 100 seeds at 0% moisture, was determined by weighing 100 randomly selected seeds from each plot. Protein, oil content, and moisture, expressed as percent dry matter, were recorded from subsamples of each plot using a Tecator InfraTec Model 1225 Whole Grain Analyzer (NIR Systems, Inc., Silver Springs, MO). Seed germination was determined after 7 days in rolled paper towels at 25°C (8).

The data were analyzed using SAS (SAS Institute, Cary, NC) as a split-split plot design with year as the main plot factor, chloride treatment as the split-plot factor, and cultivar as the split-split plot factor. An analysis of variance was conducted on each variable, and the significant interactions were reported. Mean separations were determined by LSD ($P \leq 0.05$) (7).

RESULTS

Chloride treatments, year, and cultivar alone or interactions of these factors significantly affected most of the parameters measured (Tables 1 and 2). Soil chloride concentrations strongly reflected chloride

treatment in 1995 with significant increases in chloride concentrations with each increase in soil chloride (Table 3). Soil chloride levels in 1996 were similar in all treatments. Leaf chloride concentrations increased with increased soil chloride treatments in all cultivars, but the increases were only significant for Asgrow 6297 and Terra Vig 6653, the includer cultivars (Table 4). Within these cultivars, leaf chloride concentrations increased significantly between the low Cl and the moderate Cl treatments, but not between moderate Cl and high Cl in 1995. In 1996, leaf chloride concentrations significantly increased with each increase in soil chloride treatment in these cultivars. Terra Vig 6653 had significantly higher leaf concentrations of chloride than any other cultivar in moderate Cl and high Cl treatments in 1996.

Chloride treatment did not affect soil populations of *H. glycines* eggs at planting, but populations were significantly lower in 1995 than 1996 (111 versus 411 eggs per 100 cm³). At R₂, populations of *H. glycines* eggs were significantly higher in Hartz 6686 in the moderate Cl treatment than in the low Cl treatment, but were not significantly different than the high Cl treatment (Table 5). Populations of *H. glycines* were significantly higher in the high Cl treatment than in the other chloride treatments on Terra Vig 6653. Chloride treatment did not affect populations of *H. glycines* on Asgrow 6297 or Hartz 6200. At harvest, populations of *H. glycines* eggs were not different among treatments or between years, ranging from 319 to 676 eggs per 100 cm³ in 1995 and from 384 to 1,200 eggs per 100 cm³ in 1996.

The effect of chloride treatment on soil populations of *F. solani* was not clear. The significant year by chloride by cultivar interaction (Tables 1 and 2) for planting populations of *F. solani* was due to high soil populations in the Terra Vig 6653/low Cl treatment in 1996 (1,414 CFU/g) and very low densities for Hartz 6200/high Cl treatment in 1996 (207 CFU/g). Excluding those treatments, soil populations ranged from 761 to 1,208 CFU/g in 1995 and 605 to 1,283 CFU/g in 1996. At R₂, there was a significant year by chloride by cultivar interaction in *F. solani* populations, but there were no consistent trends with either cultivar or chloride treatment between years. Soil populations were more variable in 1995 (range 560 to 1,311 CFU/g) than in 1996 (range 1,024 to 1518 CFU/g). Populations of *F. solani* at harvest were significantly higher in 1996 (1,353 CFU/g) than in 1995 (743 CFU/g).

Sudden death syndrome was more severe on Hartz 6686 when chloride was increased, but not in the other cultivars (Table 6). The difference was significant

between moderate Cl and high Cl treatments. The severity of SDS was higher in 1996 than in 1995 on Hartz 6686. Chloride treatment did not significantly affect SDS development in the other cultivars.

Lodging was significantly greater in Terra Vig 6653 than in the other cultivars at each soil chloride treatment in both years (Table 7). Lodging was greater, but not significantly greater, in the moderate and high chloride treatments than in the low chloride treatment. The incidence of southern blight on Terra Vig 6653 was significantly more severe in moderate Cl and high Cl treatments than in low Cl treatment and was greater in that cultivar in 1995 than in 1996. Southern blight of Hartz 6686 also was greater in the moderate Cl treatment than with the low Cl or the high Cl treatments. Terra Vig 6653 had significantly more southern blight than the other cultivars in moderate Cl and high Cl, but not in the low Cl treatment.

Higher soil chloride treatments resulted in reduced yields in most cultivars in both years (Table 8). The largest yield reduc-

Table 3. Effect of soil chloride treatments^a on soil chloride levels (mg Cl/kg) in 1995 and 1996 at the Cotton Branch Station, Marianna, AR

Year	Chloride treatment		
	low Cl	moderate Cl	high Cl
1995	170	378	577
1996	114	121	112
LSD _{same chloride} = 64 ^b			
LSD _{different chloride} = 63			

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b LSD calculated for differences ($P \leq 0.05$) within or across chloride treatments or years.

Table 1. Analysis of variance (P values) of disease, plant, and chemical factors in response to year, chloride treatment, and cultivar

Factor	df	SDS ^a	Chloride			Seed		
			Plant	Soil	Yield	Weight	Protein	Oil
Rep	4	0.0018	0.0535	0.0001	0.0010	0.0001	0.0001	0.0648
Chloride (CL)	2	0.1250	0.0001	0.0001	0.0001	0.0071	0.0006	0.0575
Year (Y)	1	0.0001	0.0188	0.0001	0.0078	0.0001	0.0274	0.0001
Y*CL	2	0.6840	0.0267	0.0001	0.6451	0.1492	0.7005	0.8901
Cultivar (CV)	3	0.0001	0.0001	0.0910	0.0001	0.0001	0.0001	0.0001
CL*CV	6	0.0001	0.0001	0.9775	0.0001	0.0001	0.0049	0.0001
Y*CV	3	0.0001	0.0001	0.4927	0.0002	0.0001	0.0001	0.0001
Y*CL*CV	6	0.3317	0.0001	0.6391	0.0062	0.0001	0.0002	0.0376

^a Sudden death syndrome (SDS) expressed as area under the disease progress curve.

Table 2. Analysis of variance (P values) of soil densities of *Fusarium solani* and *Heterodera glycines* and incidence (%) of southern blight and plant lodging in response to year, chloride treatment, and cultivar

Factor	df	<i>Fusarium solani</i> ^a			<i>Heterodera glycines</i> -egg			Southern blight	Lodging
		Planting	R ₂	Harvest	Planting	R ₂	Harvest		
Rep	4	0.0017	0.0010	0.0001	0.2340	0.2925	0.8726	0.0730	0.2387
Chloride (CL)	2	0.8063	0.1838	0.5767	0.7607	0.1499	0.1497	0.0016	0.9030
Year (Y)	1	0.2711	0.0036	0.0001	0.0001	0.1694	0.0034	0.0326	0.7041
Y*CL	2	0.5488	0.6963	0.0557	0.8032	0.1079	0.1996	0.4386	0.5082
Cultivar (CV)	3	0.0050	0.0160	0.0632	0.1031	0.0001	0.9447	0.0001	0.0001
CL*CV	6	0.0196	0.1401	0.8357	0.6198	0.0114	0.0977	0.0001	0.0424
Y*CV	3	0.0174	0.0001	0.7190	0.2455	0.1856	0.4091	0.0350	0.0146
Y*CL*CV	6	0.0014	0.0095	0.3122	0.2850	0.2944	0.2186	0.1736	0.2222

^a Soil densities of *F. solani* and *H. glycines*-egg determined at planting, R₂, and harvest.

tions between the low Cl and the high Cl treatments occurred in Terra Vig 6653, which lost 808 and 1,159 kg/ha in 1995 and 1996, respectively. Yields of all cultivars were significantly lower in the high Cl treatment than in the low Cl treatment in both years, except for Hartz 6200. Yield differences between low Cl and high Cl treatments for the other cultivars were 350, 485, and 357 kg/ha in 1995 and 586, 721, and 88 kg/ha in 1996 for Hartz 6686, Asgrow 6297, and Hartz 6200, respectively. Seed size was not significantly reduced with high soil chloride applications in 1995, but in 1996, seed size in Terra Vig 6653 and Hartz 6200 was significantly lower in the high Cl treatment than in the low Cl treatment (12.11 versus 9.65 and 13.06 versus 11.68 g per 100 seed, respectively). There were significant differences in seed weight among cultivars: Hartz 6686 (12.60 g per 100 seed), Hartz 6200 (11.19 g per 100 seed), Terra Vig 6653 (10.11 g per 100 seed), and Asgrow 6297 (9.70 g per 100 seed). There were significant differences in germination relating to year, chloride treatment, and cultivar, but these differences were of little agronomic importance, since germination was high in all treatments, ranging from 96.2 to 100%.

Seed protein and oil content were affected by chloride treatment and cultivar. Protein concentrations were significantly lower for the high Cl treatment than for the low Cl treatment for Asgrow 6297, Terra Vig 6653, and Hartz 6200 in 1995 and for all cultivars in 1996 (Table 8). Terra Vig 6653 and Hartz 6200 had higher protein concentrations than Hartz 6686 or Asgrow 6297 in all chloride treatments in 1995, and Hartz 6200 had the highest protein concentrations in 1996. There were significant increases in oil concentration between low Cl and high Cl treatments in Hartz 6686 and Asgrow 6297 in 1995 and Hartz 6200 in 1996. Hartz 6200 had significantly lower oil concentrations than all other cultivars in each chloride treatment in both years (19.16 versus 20.49%, respectively).

DISCUSSION

Elevated concentrations of soil chloride increased SDS severity in the susceptible excluder cultivar Hartz 6686, but not in the other cultivars. This chloride effect on SDS occurred in both years, even though SDS was more than twice as severe in 1996 as it was in 1995. Since chloride excluder cultivars like Hartz 6686 prevent chloride from moving from the root to the foliage (15) and the fungus is confined to the root system (27), the chloride may be affecting the plant's resistance to infection and colonization by *F. solani* f. sp. *glycines*

or may affect toxin production by the fungus. It is important to note that elevated concentrations of soil chloride did not affect SDS development in the SDS-resistant cultivars Hartz 6200 and Asgrow 6297. At least with these cultivars, chloride does not appear to be a factor that could induce a susceptible reaction on cultivars previously considered resistant.

The effect on SDS of the soil chloride treatments appears to be due to the added Cl and not to the added K. In previous studies, soil levels of K were either not related to severity of SDS (31) or were

Table 5. Effect of soybean cultivar and soil chloride treatments^a on R₂ soil populations of *Heterodera glycines* (eggs per 100 cm³)^b averaged over 2 years at the Cotton Branch Station, Marianna, AR

Cultivar	Chloride treatment		
	Low Cl	Moderate Cl	High Cl
Hartz 6686 (SE) ^c	389	701	550
Terra Vig 6653 (SI)	246	355	599
Hartz 6200 (RE)	254	332	222
Asgrow 6297 (RI)	360	346	366
LSD _{same chloride} = 120 ^d			
LSD _{different chloride} = 167			

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b Soil densities of *H. glycines* eggs were determined from soil collected in the top 15 cm of soil within the center two rows of each plot.

^c Cultivars were either susceptible (S) or resistant (R) to sudden death syndrome and either chloride excluders (E) or chloride includers (I).

^d LSD calculated for differences ($P \leq 0.05$) within or across chloride treatments.

Table 6. Effect of cultivar and soil chloride treatments^a averaged over years and the effect of cultivar and year averaged over chloride treatments on the development of sudden death syndrome (AUDPC, %-days) at the Cotton Branch Station, Marianna, AR

Cultivar	Chloride			Year	
	Low Cl	Moderate Cl	High Cl	1995	1996
Hartz 6686 (SE) ^b	306	355	487	195	563
Terra Vig 6653 (SI)	68	10	28	5	67
Hartz 6200 (RE)	1	8	0	5	1
Asgrow 6297 (RI)	0	6	4	3	4
LSD _{same chloride} = 83 ^c				LSD _{same year} = 68	
LSD _{different chloride} = 94				LSD _{different year} = 81	

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b Cultivars were either susceptible (S) or resistant (R) to sudden death syndrome and either chloride excluders (E) or chloride includers (I).

^c LSD calculated for differences ($P \leq 0.05$) within or across chloride treatments or years.

Table 4. Effect of the interaction of year, chloride treatment^a, and cultivar on chloride levels (mg Cl/kg)^b in the plant at the Cotton Branch Station, Marianna, AR

Cultivar	1995			1996		
	Low Cl	Moderate Cl	High Cl	Low Cl	Moderate Cl	High Cl
Hartz 6686 (SE) ^c	1,611	2,012	2,807	1,003	1,311	2,519
Terra Vig 6653 (SI)	2,768	5,823	6,554	3,055	10,431	14,626
Hartz 6200 (RE)	1,582	1,876	3,515	980	1,265	1,630
Asgrow 6297 (RI)	2,034	5,819	6,385	1,595	5,541	8,474
LSD _{same chloride and year} = 1,816 ^d						
LSD _{same chloride different year} = 2,036						
LSD _{different chloride and year} = 2,149						

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b Plant chloride levels determined from the third leaf from the top of five plants per plot on 8 August 1995 and 15 August 1996.

^c Cultivars were either susceptible (S) or resistant (R) to sudden death syndrome and either chloride excluders (E) or chloride includers (I).

^d LSD calculated for differences ($P \leq 0.05$) within chloride treatments, across chloride treatments within a year, or across years.

positively related to severity of SDS only when K was below recommended concentrations (33). Since the soil concentrations of K were at least at recommended levels throughout the field, it is unlikely that K contributed to the increase in SDS severity observed in Hartz 6686.

Another factor that could affect SDS development was the increase in *H. glycines* populations. The increases in SDS that occurred in Hartz 6686 were preceded by increases in *H. glycines* egg populations at R₂. The presence of *H. glycines* has been associated with increases in SDS in both greenhouse and microplot studies, and cultivars susceptible to the nematode often have higher levels of SDS in the field (18–20,26,29,33). Soil populations of the

nematode at R₂ are the results of two to three generations of the nematode since planting. These generations occurred before the onset of foliar symptoms of SDS, which began after R₂. Between R₂ and harvest, another two or three generations of the nematode occur, but reproduction during this period can be greatly reduced on plants with severe SDS (*unpublished data*). When that happens, the relationship of nematode populations at harvest to SDS severity can be very different than at planting or R₂. The same may be true with southern blight. Terra Vig 6653 had increases in *H. glycines* egg densities at R₂ with increased chloride, but not at harvest. Southern blight occurred after R₂ and was more severe with increased soil applications

of chloride. So, as with SDS, plants weakened by southern blight may not be able to support nematode reproduction as well as nondiseased plants, and this may account for the lack of effect of either chloride treatment or cultivar on harvest populations of *H. glycines* eggs. Neither chloride treatment nor increased severities of SDS were related to soil populations of *F. solani*.

Soil chloride concentrations reflected the chloride treatments in 1995, but not in 1996, possibly due to the mobility of the chloride ion in the soil. Chloride moves both horizontally and vertically in the soil profile, making accurate assessments of soil chloride concentrations difficult. However, based on leaf chloride concentrations in the includer cultivars, Asgrow 6297 and Terra Vig 6653, the chloride treatments had the expected effect on plant chloride concentrations. Higher leaf chloride concentrations in 1996 than in 1995 with the includer cultivars may be due to carryover of chloride from the previous year.

Seed yields reflected both SDS severity and chloride treatment. Yield losses of the SDS-susceptible excluder cultivar, Hartz 6686, were similar to those of the SDS-resistant includer cultivar, Asgrow 6297. Since the SDS-resistant excluder cultivar, Hartz 6200, experienced little yield loss with increased chloride, it can be assumed that the yield losses in Hartz 6686 were probably due mainly to the increases in SDS and, to a lesser extent, to the elevated chloride. Seed weights were inconsistently affected by chloride treatment, suggesting that the yield loss was associated more with a reduction in seed number than in seed size. Seed protein concentrations tended to decrease and, to a lesser extent, oil concentrations to increase as soil chloride increased.

The strongest effects of soil chloride concentrations were on the susceptible

Table 7. Effect of soybean cultivar and soil chloride treatments^a averaged over 2 years and the effect of cultivar and year averaged over chloride treatment on lodging and southern blight at the Cotton Branch Station, Marianna, AR

Factor ^b Cultivar	Chloride			Year	
	Low Cl	Moderate Cl	High Cl	1995	1996
Lodging (%)					
Hartz 6686 (SE) ^c	7	10	5	8	7
Terra Vig 6653 (SI)	39	55	50	41	55
Hartz 6200 (RE)	15	13	12	13	14
Asgrow 6297 (RI)	17	3	10	15	5
LSD _{same chloride} = 17 ^d				LSD _{same year} = 14	
LSD _{different chloride} = 18				LSD _{different year} = 15	
Southern blight (%)					
Hartz 6686 (SE)	0.25	6.21	2.69	4.43	1.95
Terra Vig 6653 (SI)	3.01	14.53	10.18	12.12	6.35
Hartz 6200 (RE)	0.04	0.73	0.69	0.76	0.20
Asgrow 6297 (RI)	2.36	3.05	3.06	3.46	2.18
LSD _{same chloride} = 4.60				LSD _{same year} = 3.75	
LSD _{different chloride} = 4.81				LSD _{different year} = 4.46	

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b Lodging and southern blight expressed as percent plants affected on 29 August 1995 and 12 September 1996 for lodging and 29 September 1995 and 19 September 1996 for southern blight.

^c Cultivars were either susceptible (S) or resistant (R) to sudden death syndrome and either chloride excluders (E) or chloride includers (I).

^d LSD calculated for differences ($P \leq 0.05$) within or across chloride treatments or years.

Table 8. Effect of the interaction of year, chloride treatment^a, and cultivar on yield and seed protein content of plants grown at the Cotton Branch Station, Marianna, AR

Factor Cultivar	1995			1996		
	Low Cl	Moderate Cl	High Cl	Low Cl	Moderate Cl	High Cl
Yield (kg/ha)						
Hartz 6686 (SE) ^b	2,503	2,326	2,153	2,699	2,352	2,114
Terra Vig 6653 (SI)	2,481	1,768	1,671	2,181	1,702	1,025
Hartz 6200 (RE)	2,732	2,996	2,372	2,455	2,520	2,366
Asgrow 6297 (RI)	3,170	2,920	2,688	3,125	2,788	2,403
LSD _{same chloride and year} = 319 ^c						
LSD _{same chloride different year} = 401						
LSD _{different chloride and year} = 381						
Protein (%)						
Hartz 6686 (SE)	42.43	41.36	41.70	41.84	41.46	40.94
Terra Vig 6653 (SI)	43.32	42.46	42.26	42.18	41.75	41.38
Hartz 6200 (RE)	42.82	42.52	41.94	43.78	43.20	42.20
Asgrow 6297 (RI)	42.04	41.46	40.56	41.32	40.82	40.52
LSD _{same chloride and year} = 0.49						
LSD _{same chloride different year} = 0.74						
LSD _{different chloride and year} = 0.78						

^a Chloride treatments were established at V4 by either adding no KCl (low Cl), adding 1,120 kg of KCl per ha (moderate Cl), or adding 2,240 kg of KCl per ha (high Cl).

^b Cultivars were either susceptible (S) or resistant (R) to sudden death syndrome and either chloride excluders (E) or chloride includers (I).

^c LSD calculated for differences ($P \leq 0.05$) within chloride treatments, across chloride treatments within a year, or across years.

includer cultivar, Terra Vig 6653. Although little SDS developed in this cultivar in any treatment, Terra Vig 6653 had the greatest reduction in yield with increased leaf chloride concentrations of any of the cultivars. Loss of yield was associated with an increase in lodging and an increase in southern blight. These two effects have not been associated with chloride toxicity in soybean before. Although occurring in the same cultivar, the increase in lodging does not appear to be a result of the increase in southern blight, since lodging was worse in 1996 and southern blight was worse in 1995. Just how much of the yield loss in Terra Vig 6653 can be attributed to lodging and southern blight cannot be calculated, but certainly the combination of these factors and chloride toxicity contributed to the severe reduction in yield. The strong reaction to chloride and the lack of SDS symptoms in Terra Vig 6653 make it difficult to draw any conclusions on the effect of chloride toxicity on the development of SDS in susceptible includer cultivars.

This is the first report on the effect of toxic levels of soil chloride on the development of either SDS or southern blight. These data show that with the SDS-susceptible chloride excluder cultivar, Hartz 6686, damage from SDS can be increased in the presence of toxic concentrations of soil chloride and suggest that these increases in SDS compromised the yield advantage gained by using an excluder cultivar. It is also important to note that chloride toxicity did not affect the SDS reaction of the cultivars resistant to SDS. Since only four cultivars were used in this study, it is not possible to determine how applicable these results are to other cultivars, but these results do suggest that growers with both a chloride toxicity problem and an SDS problem select SDS-resistant excluder cultivars in fields to minimize yield loss from both problems. Finally, the response of southern blight to chloride toxicity indicates that other diseases may be exacerbated when chloride levels are high, and that cultivar resistance or susceptibility to some diseases may only be observed under specific stresses.

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