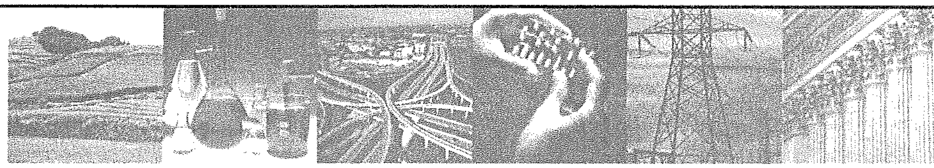
DEKKER REPRINT PROGRAM



MARCEL DEKKER, INC.
270 MADISON AVE, NEW YORK, NY 10016
www.dekker.com

JOURNAL OF PLANT NUTRITION
Vol. 26, No. 12, pp. 2365–2374, 2003

Interaction of a Foliar Application of Iron HEDTA and Three Postemergence Broadleaf Herbicides with Soybeans Stressed from Chlorosis

D. W. Franzen,* J. H. O'Barr, and R. K. Zollinger

North Dakota State University, Fargo, North Dakota, USA

ABSTRACT

Soybeans stressed from chlorosis are often treated with postemergence herbicides to coincide with susceptibility of control of weed seedlings. Three postemergence herbicides, acifluorfen, imazamox, and lactofen were applied to chlorosis stressed soybeans with and without iron HEDTA. At one location, iron amendment resulted in lower yields with acifluorfen and lactofen. Yields were higher with iron amendment in the imazamox treatment, but lower crop injury and poorer weed control was also observed, suggesting that iron amendment antagonized imazamox. Iron amendment did not reduce visual symptoms of chlorosis, herbicide injury, nor did it result in yield increase at any location.

*Correspondence: D. W. Franzen, North Dakota State University, Box 5758, Fargo, ND 58105, USA; E-mail: dfranzen@ndsuext.nodak.edu.

DOI: 10.1081/PLN-120025465
0190-4167 (Print); 1532-4087 (Online)
www.dekker.com

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Application of iron HEDTA with these herbicides would not be recommended for chlorosis relief.

Key Words: Soybean; Iron chlorosis; Herbicides; Weed control; Foliar fertilizer.

INTRODUCTION

Iron chlorosis is common in many areas where soybeans are grown in the north-central United States. It is even more common and severe in the calcareous soils of the Red River Valley of eastern North Dakota and northwestern Minnesota. As a result of increased soybean production and number of hectares planted in the region, an increase in iron chlorosis incidence has been observed.

Chlorosis is related to soil properties such as pH, temperature, $CaCO_3$ content, water content, and the concentration of HCO_3^- in the soil solution.[1,2] These soil factors reduce the ability of soybeans to extract iron from the soil, causing stunted and chlorotic soybean plants. Iron-deficiency chlorosis may be so severe that necrosis and death of the leaf or entire plant may occur. Cool, wet or poorly drained soils intensify chlorosis in calcareous regions where iron deficiencies are common.[3] Soybeans are particularly inefficient in assimilating iron compared to other field crops. Growers who have successfully grown small grains and other crops for decades are often surprised when soybeans turn yellow on these same fields.

Soil pH in the Red River Valley typically ranges between pH 7.5 and 8.5. High soil pH, calcium carbonates, organic matter, and soluble salts[4] in combination with high moisture contribute to chlorosis.[1,5–7] Soil bicarbonate (HCO_3^-) may be the most important factor for chlorosis of in calcareous soils.[8] Bicarbonate can interfere with iron uptake even in soils where adequate amounts of iron are present.[9]

Remedies for overcoming iron chlorosis include foliar application of Fe fertilizers and chelates, iron fertilizer seed coatings, or soil-applied iron treatments.[2] Soybeans generally "green up" for a short time after iron application. It is still unclear if foliar iron treatments significantly increase soybean yield. Current research suggests that cultural practices such as higher seeding rates may decrease chlorosis incidence.[2] Considerable variability between soybean varieties and the degree of chlorosis has been observed.[10] Some varieties are more efficient at obtaining iron from soils than others.[11] Cultivar selection remains the most practical control measure for iron-deficiency chlorosis of soybean.[2] However, foliar application of iron fertilizers is still used to try to combat the problem.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Postemergence herbicides are used by nearly all soybean growers in North Dakota[12] and are an important component of an integrated weed control strategy. Following herbicide label directions and using proper application techniques may cause crop burning, stunting, and chlorosis.[13] Though postemergence herbicides are effective at controlling weeds,[14] crop injury and reduced yield has been observed.

A study was conducted in 2000 to determine if an iron amendment applied at the time of herbicide application would reduce herbicide phytotoxicity on soybean stressed by iron deficiency.

Soybean can be stressed by iron deficiency and soluble salts but may also be stressed from postemergence herbicides. Common foliar effects of postemergence herbicides may include stunting, chlorosis (not associated with a deficiency of iron), bronzing, and crinkling or burning of the leaves. Postemergence broadleaf herbicides have been used extensively for successful weed management as part of an integrated weed control strategy. Although soybean may express symptoms from herbicide activity, soybean growth and yield usually are unaffected if all other stresses are minimized.[15] Early crop injury was observed when bentazon and acifluorfen were applied,[14] however, soybeans recovered by 21 days after application without any significant effect on yield.

Many herbicide labels advise users of temporary injury and under normal conditions yields will not be affected. Current research suggests that under certain stress, some loss is possible. The affects of labeled rates of 12 common postemergence herbicides applied to soybean were measured.[16] The herbicide treatments averaged an 11% yield loss in 1993, a 1% loss in 1994, and a 4% loss in 1995 compared to the untreated check. The researchers concluded that postemergence herbicides resulted in only a slight soybean yield loss compared to a hand weeded check. It was noted that environmental conditions after herbicide application could influence soybean recovery.

Since there is evidence of soybean yield loss under normal growing conditions, research is needed to see how herbicide application under iron chlorosis stress affects yield loss. It is hypothesized that when these two stresses are combined, severe visible injury may result as well as a significant yield loss. It is also hypothesized that each herbicide will affect the yield differently. Currently, there is no research published regarding herbicide treatment and differences in soybean yield when soybeans are stressed from iron-deficiency chlorosis.

Soybean uses various ways to rid toxic herbicides from its system. Plants rapidly metabolize, conjugate, or detoxify herbicides to prevent phytotoxicity. Herbicide degradation in stressed soybean is reduced, resulting in increased injury and yield loss not observed under stress free conditions.

A previous experiment showed that some herbicides significantly decreased soybean yield more than others when applied to soybean stressed from chlorosis.[17] Acifluorfen, lactofen, and imazamox exhibited the greatest crop injury and

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

yield loss in 1998 and 1999 in this study. The objective of this experiment was to determine the interaction of these three postemergence soybean herbicides, amended with an iron fertilizer, and soybeans stressed from chlorosis.

MATERIALS AND METHODS

In 2000, 3 sites were established with two locations in North Dakota, Colfax and Arthur; and one location in Minnesota, Rothsay (Table 1).

Young soybean plants do not exhibit chlorosis until the first trifoliate leaves have emerged, so the exact locations were determined when soybean was in the 1 to 2 trifoliate stage. Locations were selected with uniform chlorosis in order to reduce variability of chlorosis.

Plots were 3 m wide by 6 m long with a 1.5-m border strip between blocks and a 1.5-m border around the entire experiment. The buffer strips were used as a precaution to minimize cooperator herbicide from drifting into the treatment areas. Soil samples were taken from all plots prior to herbicide treatments and consisted of four to five random cores (2.5 cm diameter) taken from the 0–15 cm depth with a hand probe and placed in polyethylene bags.[18] Soil samples were air dried, crushed (<2 mm) and mixed prior to analysis. Soil pH and soluble salts (electrical conductivity, EC) were measured in 1 : 1 soil : water.[19] Calcium carbonate equivalent (CCE) was determined by adding 2N hydrochloric acid (HCl) and measuring pressure given off from the reaction.[20]

Following herbicide applications (Table 2), each plot was evaluated visibly at 14 and 28 days after herbicide application. All evaluations were performed without knowledge of the treatments that were being rated. Herbicide injury with respect to percent stunting, burning, and yellow (chlorosis) was recorded to measure short-term herbicide effects. The scale for stunting was on a percentage basis (0–100%) with 0% stunt = no difference in height from untreated check, 25% = three-fourths the height of the untreated check, 50% stunt = half of the height of the untreated check, etc.

Table 1. Locations, varieties, planting dates, and treatment dates for field experiments.

Location	Variety	Planting date	Treatment date
Walcott, ND	Pioneer RR[a] 91B72	May 19	June 27
Arthur, ND	Pioneer 90B43	May 16	June 28
Rothsay, MN	Pioneer RR 90B70	May 3	June 27

[a]Roundup ready (glyphosate tolerant).

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Table 2. Spray date, time, temperature, humidity, wind speed and direction, percent clouds, and percent initial soybean chlorosis by location.

	Site		
	Walcott	Arthur	Rothsay
Date	Jun-27	Jun-28	Jun-27
Time	10–11 AM	10–12 AM	11–1 PM
Temperature (°C)			
Air	18.9	20	21.1
Soil	21.7	17.8	27.8
Humidity (%)	60	53	74
Wind (km/hr)	0–8 SW	8–12 N	8–14 S
Clouds	0	10	30
Chlorosis	15	18	25

Stunt ratings were measured at ±1% intervals. The scale used for burning was 0% = no burn or necrosis on any leaves, 25% = one quarter of all leaf surfaces with burn or necrosis, 50% = half of all leaf surfaces exhibiting burn or necrosis, 100% = dead plant.

Burn ratings were evaluated from 0 to 100% with intervals of ±1%. The scale used to measure chlorosis was 0% = no chlorosis, 20% = slight general chlorosis of the upper leaves, 40% = moderate interveinal chlorosis of upper leaves, 60% = chlorosis of the entire plant with necrosis and stunting observed, 80% = severe chlorosis, stunting, and necrosis with dead growing point, and 100% = entire plant dead.

Chlorosis ratings were measured from 0 to 100% at ±1% intervals. Evaluating soybean response to herbicide treatments was often difficult because stunting and chlorosis from iron deficiency had to be differentiated from that caused by herbicide application.

Any weeds not controlled from herbicide applications were removed by hand. At maturity, each plot was harvested individually with a plot combine.

The experimental design at each location used a randomized complete block in a split plot arrangement with four replicates. Main plots were herbicide treatment and split plots were herbicide plus iron treatment. Chelated iron (HEDTA 4.5% Fe) [Iron *N*-hydroxyehtylethylenediaminetriacetate] was applied at a rate of 2.3 L/ha giving a total of 0.126 kg/ha Fe. Iron was added to the herbicide treatments and applied at the same time and with the same equipment as outlined in the general procedure (Table 3).

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Table 3. Treatment number, herbicide treatments, Fe HEDTA added or not, and herbicide rates for the chlorosis and herbicide interaction experiment with iron amendment.

Herbicide treatments + adjuvants[a]	Fe HEDTA 4.5%	Herbicide rate (g/ha)
Acifluorfen + NIS[b]	No	420
Acifluorfen + NIS	Yes	420
Lactofen + PO[c]	No	175
Lactofen + PO	Yes	175
Imazamox + PO + UAN[d]	No	35
Imazamox + PO + UAN	Yes	35

[a]Adjuvant selection and rates from label directions.
[b]Nonionic surfactant.
[c]Petroleum oil concentrate.
[d]Urea ammonium nitrate.

RESULTS AND DISCUSSION

Walcott, ND

The soils at Walcott are silty clay loams, with EC ranging from 0.28 to 0.45 mmohs/cm (mean of 0.33 mmohs/cm) and CCEs from 1.8 to 4.4% (mean of 4.0%). The plots were located approximately 5 km north of Colfax, ND.

Significant differences were observed between herbicide treatments and herbicide treatments with iron added (Table 4). Soybeans applied with iron combined with acifluorfen and lactofen had significantly lower yields compared to herbicide applied alone. The iron plus imazamox treatment increased

Table 4. Yield response to herbicide treatments with and without iron amendments, Walcott.

Treatment	With iron yield (kg/ha)	Treatment	Without iron yield (kg/ha)
Acifluorfen + Fe	2,449	Acifluorfen	2720
Imazamox + Fe	2,569	Imazamox	2360
Lactofen + Fe	1,814	Lactofen	2145
LSD (0.05)		161[a]	

[a]LSD compares herbicide vs. herbicide + Fe for subplot comparisons only.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

yield compared to imazamox alone. A reduction in weed control and crop injury was observed suggesting the addition of iron to imazamox may cause some antagonism. Iron added to acifluorfen and lactofen did not appear to minimize the phytotoxic effects of the herbicides.

There were no significant differences in yield between acifluorfen and imazamox treatments. Lactofen however was significantly lower than the other two herbicides (Table 5). Lactofen also showed higher levels of stunting and burning compared to acifluorfen and imazamox. Imazamox treatments were significantly more stunted than acifluorfen.

Arthur, ND, 2000

The Arthur site is characterized by Arveson sandy loam soils, with ECs ranging from 0.16 to 0.22 mmohs/cm (mean 0.20 mmhos/cm) and CCEs ranging from 2.1 to 4.6% (mean 4.1%). This site is located about 5 km west of Arthur, ND.

Significant differences were not observed with respect to soybean foliar injury, herbicide, iron amendment, and yield (Table 6).

Rothsay, MN, 2000

This experiment was located about 16 km east of Kent, MN. The plots at this location can be characterized by Arveson sandy loam soils tending to be

Table 5. Treatment, injury, and yield at Walcott.

	Treatment			
	Acifluorfen	Imazamox	Lactofen	LSD (0.05)
	Percent of injury			
July 12, 2000				
Stunt	12	21	21	8
Yellow	13	18	20	NS
Burn	9	23	24	12
July 26, 2000				
Stunt	3	6	7	NS
Yellow	1	2	0	NS
Burn	4	7	12	7
Yield (kg/ha)	2,585	2,465	1,980	173

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

Table 6. Treatment, injury, and yield at Arthur, ND, 2000 location for the iron chlorosis and herbicide interaction experiment with iron amendment.

	Treatment			
	Acifluorfen	Imazamox	Lactofen	LSD (0.05)
		Percent of injury		
July 12, 2000				
Stunt	8	10	13	NS
Yellow	7	3	4	NS
Burn	9	7	10	NS
July 26, 2000				
Stunt	6	4	11	NS
Yellow	2	0	2	NS
Burn	0	0	0	NS
Yield (kg/ha)	2,546	2,445	2,418	NS

slightly saline with ECs ranging from 0.34 to 1.32 mmohs/cm (mean of 0.65 mmohs) and CCEs from 1.9% to 5.7% (mean 4.7%).

Significant differences in foliar injury were not observed at the 14 or 28 DAT ratings (Table 7). There were no significant differences with the addition of iron to herbicides. However, the acifluorfen treatment was significantly higher in yield than lactofen (Table 7).

Table 7. Treatment, injury, and yield at Rothsay.

	Treatment			
	Acifluorfen	Imazamox	Lactofen	LSD (0.05)
		Percent of injury		
July 12, 2000				
Stunt	6	9	11	NS
Yellow	6	7	7	NS
Burn	11	7	10	NS
July 26, 2000				
Stunt	0	9	6	NS
Yellow	2	3	0	NS
Burn	3	0	2	NS
Yield (kg/ha)	1,912	1,730	1,517	NS

SUMMARY

Addition of an iron amendment showed significant differences at one of three locations. At Walcott, where significant differences were observed, in plots where iron combined with acifluorfen and lactofen were applied, yield was significantly reduced compared to herbicide treatments alone. The iron plus imazamox treatment increased yield compared to imazamox alone. A reduction in weed control and crop injury was observed, suggesting the addition of iron to imazamox may cause some antagonism. Iron added to acifluorfen and lactofen reduced yield and did not minimize the phytotoxic effects of the herbicides.

Iron added at the time of herbicide application would not be recommended. It was not successful at minimizing phytotoxic effects and in some cases made them worse. Also, it can antagonize imazamox, which results in decreased weed control and increased weed competition.

ACKNOWLEDGMENTS

The authors gratefully thank the North Dakota Soybean Council for their financial support of this project.

REFERENCES

1. Inskeep, W.P.; Bloom, P.R. Effects of soil moisture on soil pCO_2, soil solution bicarbonate, and iron chlorosis in soybeans. Soil Sci. Soc. Am. J. **1986**, *50*, 946–952.
2. Goos, R.J.; Johnson, B.E. A comparison of three methods for reducing iron-deficiency chlorosis in soybean. Agron. J. **2000**, *92*, 1135–1139.
3. Moraghan, J.T.; Mascagni, H.J., Jr. Environmental and soil factors affecting micronutrient deficiencies and toxicities. In *Micronutrients in Agriculture*, 2nd Ed.; SSSA Book Series No. 4; Soil Science Society of America: Madison, WI, 1991; 371–425.
4. Dahiya, S.S.; Singh, M. Effect of salinity, alkalinity and iron sources on availability of iron. Plant Soil **1979**, *51*, 13–18.
5. Inskeep, W.P.; Bloom, P.R. Soil chemical factors associated with soybean chlorosis in calciaquolls of western Minnesota. Agron. J. **1987**, *79*, 779–786.
6. Franzen, D.W.; Richardson, J.L. Soil factors affecting iron chlorosis of soybeans in the red river valley of North Dakota and Minnesota. J. Plant Nutr. **2000**, *23*, 67–78.7.

7. Springer, G.; Wienhold, B.J.; Richardson, J.L.; Disrud, L.A. Salinity and sodicity induced changes in dispersable clay and saturated hydraulic conductivity in sulfatic soils. Commun. Soil Sci. Plant Anal. **1999**, *30*, 2211–2220.
8. Inskeep, W.P.; Bloom, P.R. A comparative study of soil solution chemistry associated with chlorotic and nonchlorotic soybeans in western Minnesota. J. Plant Nutr. **1984**, *7*, 513–531.
9. Chaney, R.L.; Hamze, M.H.; Bell, P.F. Screening chickpea for iron chlorosis resistance using bicarbonate in nutrient solution to simulate calcareous soils. J. Plant Nutr. **1992**, *15*, 2045–2062.
10. Byron, D.F.; Lambert, J.W. Screening soybeans for iron efficiency in the growth chamber. Crop Sci. **1983**, *23*, 885–888.
11. Trimble, M.W.; Fehr, W.R. Mixtures of soybean cultivars to minimize yield loss caused by iron deficiency chlorosis. Crop Sci. **1983**, *23*, 691–694.
12. Zollinger, R.K.; Dexter, A.G.; Fitterer, S.A.; Dahl, G.K.; McMullen, M.P.; Walhaus, G.E.; Glogoza, P.; Ignaszewski, K. *Pesticide Use and Pest Management Practices for Major Crops in North Dakota, 1996*; Ext. Rep. 43; North Dakota State University in cooperation with North Dakota Agricultural Statistics Service: Fargo, ND, 1998.
13. Wichert, R.A.; Talbert, R.E. Soybean (*Glycine max*) response to lactofen. Weed Sci. **1993**, *41*, 23–27.
14. Kapusta, G.; Jackson, L.A.; Mason, D.S. Yield response of weed-free soybeans (*Glycine max*) to injury from postemergence broadleaf herbicides. Weed Sci. **1986**, *34*, 304–307.
15. Browde, J.A.; Pedigo, L.P.; Owen, M.D.K.; Tylka, G.L.; Levene, B.C. Growth of soybean stressed by nematodes, herbicides, and simulated insect defoliation. Agron. J. **1994**, *86*, 968–974.
16. Harvey, R.G.; Ateh, C. *Postemergence Soybean Herbicide Injury: A Hidden Yield Robber*?; Agron. Res. Rep.; University of Wisconsin: Madison, WI, 1996.
17. O'Barr, J.H. *Soybean Post Herbicides and Iron Chlorosis*; North Dakota State University: Fargo, ND, 2002; Ph.D. Thesis.
18. Franzen, D.W.; Cihacek, L.J. *Soil Sampling as a Basis for Fertilizer Application*; Circ. SF-990; North Dakota State University Extension Service: Fargo, ND, 1998.
19. Watson, M.E.; Brown, J.R. *Recommended Chemical Soil Test Procedures for the North Central Region*; Missouri Agricultural Experiment Station SB1001: Columbia, MO, 1998; North Cent. Reg. Res. Publ. No. 221 (revised).
20. Nelson, R.E. Carbonate and gypsum. In *Methods of Soil Analysis, Part 2*, 2nd Ed.; Page, A.L., Ed.; ASA: Madison, WI, 1982; 181–196.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016