

Row-applied Iron Chelate for Correcting Iron Deficiency Chlorosis in Dry Bean

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ABSTRACT

Iron-deficiency chlorosis (IDC) reduces the yield of dry edible bean (*Phaseolus vulgaris* L.) grown on high-pH calcareous soils. The objective of this research was to compare the effectiveness of row-applied SoyGreen Fe ethylene diamine-*N,N'*-bis (2-hydroxyphenylacetic acid (FeEDDHA)) on reducing IDC and increasing dry bean yield planted in 56-cm rows. Two commonly grown varieties of Great Northern and Pinto dry bean were grown in a randomized complete block design during 4 yr with four levels of FeEDDHA (0–2.24 kg ha⁻¹). Visual chlorosis ratings showed significant differences in 3 of 4 yr and higher FeEDDHA rates improved chlorosis scores. Yields were increased in 2011 and 2014 but not on the low IDC severity site in 2012 (2013 plots were lost to hail). Relative yields for 2011 and 2014 versus the chlorosis score showed significant increasing yield as chlorosis severity decreased. The relative yield response to FeEDDHA averaged across different varieties and market classes was about 10% and yield was maximized near 1.8 kg ha⁻¹ FeEDDHA. For the Fe-responsive years, the check yield was 3096 kg ha⁻¹ of Great Northern beans and 3125 kg ha⁻¹ for Pinto beans, which translates to an additional 310 kg ha⁻¹ of beans. With current and historic bean prices, the yield increase adds over \$200 ha⁻¹ at a cost of near \$40 ha⁻¹, more than paying for the fertilizer cost.

Core Ideas

- Row-applied Fe chelate at 1.8 kg⁻¹ for dry edible bean increased yields on chlorosis-prone soils.
- Visual chlorosis ratings near flowering were well correlated with final yield.
- Yield responses of 10% above the check were economical at current and historic dry bean prices.
- Chlorosis severity mapping of fields would improve application to the areas most likely to respond to Fe ethylene diamine-*N,N'*-bis (2-hydroxyphenylacetic acid application).

DRY EDIBLE bean is susceptible to IDC when grown on high-pH calcareous soils in the United States (Brown, 1961; Clark, 1982). Early pioneering research showed that soil application of Fe chelates could correct IDC (Heck and Bailey, 1950; Holmes and Brown, 1955; Wallace et al., 1953), but farmer adoption was limited because of the high cost of chelated Fe. Early attempts to identify tolerant dry bean varieties by field screening produced highly variable results (Zaiter et al., 1987) but there was an indication that two gene pairs controlled the Fe deficiency trait (Coyne et al., 1982). The major dry bean breeding and seed production regions in the High Plains of the United States are on high pH soils (Kelly and Cichy, 2013); therefore, some natural selection for IDC tolerance is already present in many varieties and market classes. Iron chlorosis severity is a complex problem related to soil properties including pH, temperature, water content, CaCO₃ content, and soil solution HCO₃ (Inskeep and Bloom, 1986; Moraghan and Mascagni, 1991). Recently developed genetic laboratory techniques can provide more consistent IDC screening results but there has not been an industry-wide adoption of the technology (Ellsworth et al., 1997).

There has been considerable research on soybean [*Glycine max* (L.) Merr.] IDC spanning many years (Goos and Johnson, 2000; Hansen et al., 2006; Penas et al., 1990; Kaiser et al., 2014; Karkosh et al., 1988). Responses to foliar solutions of FeSO₄ to dry bean has shown variable results, from increased yields (Zaiter et al., 1992) to limited effects (Hansen et al., 2006). Foliar application has not been adopted as a common practice by producers, as usually more than one spray is required for IDC correction. Iron is not mobile in the plant, particularly when sprayed onto leaves (Fernández and Ebert, 2005). Unless plants are treated early, foliar treatment may be late enough that IDC will have limited the yield potential (Gamble et al., 2014). Applying Fe at planting may provide early and season-long Fe availability. There is limited research on dry bean with soil-applied Fe products (Zaiter et al., 1986). Nebraskan research on corn (*Zea mays* L.) with seed-placed FeSO₄ significantly increased yields, whereas foliar sprays produced little response (Hergert et al., 1996). The use of Fe ethylene diamine-*N,N'*-bis (2-hydroxyphenylacetic acid) (FeEDDHA) increased yields but the response was greatest for varieties that showed some tolerance to IDC.

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Abbreviations: FeEDDHA, Fe ethylene diamine-*N,N'*-bis (2-hydroxyphenylacetic acid; IDC, Fe-deficiency chlorosis).

Table 1. Site characteristics for the four locations for the top 20 cm.

Measurement	Units	2011	2012	2013	2014
pH	—	8.30	8.38	8.35	8.06
EC†	dS m ⁻¹	0.38	0.30	0.37	0.31
OM	g kg ⁻¹	14.5	14.6	14.0	19.8
Lime‡	—	High	Low	High	High
NO ₃ -N	mg kg ⁻¹	7.71	8.72	6.85	10.1
Olsen P	mg kg ⁻¹	16.5	8.2	10.1	20.8
SO ₄ -S	mg kg ⁻¹	12.1	13.4	11.7	9.34
DTPA-Fe†	mg kg ⁻¹	3.70	3.28	3.32	4.61
DTPA-Zn	mg kg ⁻¹	0.59	1.78	0.85	1.25
DTPA-Mn	mg kg ⁻¹	3.20	3.91	3.15	4.88
DTPA-Cu	mg kg ⁻¹	0.46	0.52	0.49	0.37

† EC, electrical conductivity; DTPA, diethylene triamine penta-acetic acid.

‡ Lime was determined via 3N HCl by a simple fizz test (Richards, 1954).

Interest in the use of FeEDDHA increased once scientists realized that the form of the chelate could affect the response (Lucena, 2003) and product cost decreased. The production of *ortho-ortho* forms of FeEDDHA after 2004 versus earlier versions that contained different percentages of *ortho*- and *para*-EDDHA spurred interest in additional research into IDC for a number of crops. This study was designed to determine whether the addition of banded *ortho-ortho* FeEDDHA in solution would provide significant yield improvement for dry bean grown on high-pH calcareous soils in the inter-mountain West.

MATERIALS AND METHODS

This experiment was conducted during the growing seasons of 2011 through 2014 at the Panhandle Research and Extension Center near Scottsbluff, NE, on fields that had a history of IDC. The soil at all four sites was a Tripp very fine sandy loam (coarse-silty, mixed, superactive, mesic Aridic Haplustolls). Sites in 2011, 2012, and 2013 were on the Scottsbluff Center and were furrow-irrigated. In 2014, the study was on the Mitchell station 6 km north of Scottsbluff and was under sprinkler irrigation. The slope ranged from 0.5 to 3%, depending on the field's location. The experimental sites were soil sampled in early spring to determine site characteristics. Ten soil cores from the 0- to 20-cm depth were composited from each replication of the experiment each year and air-dried following University of Nebraska guidelines (Ferguson et al., 2007).

Soil samples were sent to Ward Laboratories (Ward Laboratories Inc., <https://www.wardlab.com/>, accessed 21 Sept. 2018) and analyzed for standard soil test parameters including pH, salinity, organic matter, Olsen P, nitrate N, and diethylene triamine penta-acetic acid-extractable Zn, Mn, Cu and Fe (Table 1). Analytical methods used were: organic matter (Nelson and Sommers, 1996), nitrate N (Mulvaney, 1996), water pH (Thomas, 1996), salinity (Richards, 1954), Olsen P (Olsen et al., 1954), sulfate-S (Johnson, 1987), and diethylene triamine penta-acetic acid-extractable Zn, Fe, Mn, and Cu (Lindsay and Norvell, 1978).

The crop rotation of the fields used was corn–sugar beet (*Beta vulgaris* L.)–corn–dry bean. Four different bean varieties were used: ‘Marquis’ and ‘Orion’ (Great Northern market class) and ‘Poncho’ and ‘Montrose’ (Pinto market class). These varieties represented about 70% of the Pinto and Great Northern acreage in western Nebraska at the time of the experiment. Planting dates ranged from 5 to 8 June each year (Table 2). Each variety

Table 2. Dry bean planting and harvest dates.

	Years			
	2011	2012	2013	2014
Planting	8 June	5 June	5 Jun	5 June
Harvest	22 Sept.	24 Sept	–†	22 Sept.

† Lost to hail

was planted in a solid block to facilitate easier planting and harvesting. Individual plots were 3.4 m wide (six rows) by 7.6 m long. Row width was 56 cm. A John Deere 71 plate planter (John Deere, Moline, IL) was equipped with a small electric fertilizer pump to row-apply a water solution of *ortho-ortho* FeEDDHA [SoyGreen (West Central Distribution LLC, Willmar, MN) at 6% Fe] at a fixed liquid rate of 56 L ha⁻¹, although the FeEDDHA rates varied. The fertilizer tube placed the Fe solution in the seed furrow. Because of the low salt level of the chelated treatment, there was no concern about seed injury. Treatments were replicated five times in a randomized complete block design. The FeEDDHA treatments were 0, 0.56, 1.12, and 2.24 kg ha⁻¹. The seeding rate was 198,000 seeds ha⁻¹. Plant population was counted near mid-July each year.

Visual chlorosis ratings were taken in mid-July, usually between vining and early flowering. The chlorosis scoring scale was patterned after one developed for soybean (Penas et al., 1990); however, the scale used was slightly modified. In soybean, severe chlorosis (a score of 6) often leads to necrosis and plant death. Iron-deficiency chlorosis in dry bean in the intermountain region of Colorado, Nebraska, Idaho, and Wyoming may be severe but rarely causes plant death. Our chlorosis scoring was based on a visual rating from 1 to 5 (Fig. 1A–E.) Scores were: 1: normal, no chlorosis; 2: near normal, light green, no chlorotic leaves; 3: mild to moderate chlorosis, interveinal yellowing on upper trifoliates; 4: very chlorotic with pronounced interveinal yellowing; and 5: severe chlorosis with upper leaves markedly yellow and lower leaves very chlorotic. Plots were rated by two people at both ends of each plot without knowledge of the treatment, with the values then averaged. Plots were scored in 2011, 2013, and 2014. There was not sufficient chlorosis to warrant scoring in 2012 and the 2013 experiment was lost to hail near harvest.

For harvest, dry bean plots were undercut, lifted, and windrowed in mid-September each year, with harvest in late September. The middle two rows of the plot were harvested with a small plot combine (Classic Model, Wintersteiger Inc., Ankeney, IA). Seed yield and chlorosis scores were analyzed with the SAS software program PROC GLM (SAS Institute, 2014). Treatment × year interaction was calculated for chlorosis scores and seed yield. Additional nonorthogonal analysis (single-degree of freedom tests) were also calculated for yield comparisons of the 0 kg ha⁻¹ rate of SoyGreen versus the means of the 1.12 and 2.24 kg ha⁻¹ rates for chlorosis score and seed yield (SAS Institute, 2014).

Results and Discussion

The soils at the experimental sites were calcareous and alkaline (Table 1). They showed low salinity and organic matter but sufficient P, S, and micronutrients for dry bean production (Hergert and Schild, 2013). Soil moisture conditions at planting and early spring weather varied each year. The final plant stand in 2011 was at the recommended levels for most varieties



Figure 1A to 1E. Rating scale used for scoring chlorosis severity. (A) Score 1: normal, no chlorosis; (B) = score 2: near normal, light green, no chlorotic leaves; (C) score 3: mild to moderate chlorosis, interveinal yellowing on upper trifoliates; (D) score 4: very chlorotic with pronounced interveinal yellowing; (E) score 5: severe chlorosis with upper leaves markedly yellow and lower leaves very chlorotic.

(>100,000 plants) except for Poncho because of early hail and soil crusting (Pearson et al., 2015). Chlorosis developed after the first trifoliolate stage. The spring of 2012 was warm and dry and the site selected has previously shown only moderate chlorosis. The 2012 experimental location (Table 1) had high pH and was

calcareous and the soil diethylene triamine penta-acetic acid-Fe value was low (Hergert and Schild, 2013). Iron-deficiency chlorosis did not develop and plots were not scored for chlorosis. In 2013, the growing season weather was more typical of the region with soil moisture near field capacity at planting. There

Table 3. Effect of row-applied SoyGreen Fe ethylene diamine-*N*, *N'*-bis (2-hydroxyphenylacetic acid) on visual chlorosis rating for 2011, 2013 and 2014.

	Marquis			Orion			Montrose			Poncho			
	2011	2013	2014	2011	2013	2014	2011	2013	2014	2011	2013	2014	
SoyGreen kg ha ⁻¹							Chlorosis rating						
0	1.58a†	2.62a	3.44a	2.58a	2.72a	3.30a	2.83a	2.87a	3.00a	2.61a	2.90a	3.24a	
0.56	1.43b	1.92b	2.51b	2.03b	2.15b	2.54b	1.80b	2.12b	2.42b	1.80b	1.96b	2.42b	
1.12	1.34c	1.68c	2.02c	1.83c	1.90c	2.02c	1.42c	1.56c	1.50c	1.44c	1.58c	1.60c	
2.24	1.33c	1.57d	1.73d	1.60d	1.76d	1.83d	1.33c	1.32d	1.41c	1.29d	1.48d	1.42d	
Fe effect‡													
Pr > F	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
CV	6.1%	3.4%	3.8%	3.1%	2.1%	4.8%	5.3%	5.8%	5.1%	3.9%	1.7%	2.9%	

† Values followed by the same letter are not significantly different at the $P < 0.05$ level based on the LSD.

‡ Single degree of freedom test comparing the check versus the average of the 1.12 and 2.24 kg Fe rates.

Table 4. Effect of row-applied SoyGreen Fe ethylene diamine-*N*, *N'*-bis (2-hydroxyphenylacetic acid) on Great Northern dry bean seed yield for 2011 through 2014.

	Marquis			Orion		
	2011	2012	2014	2011	2012	2014
SoyGreen kg ha ⁻¹	kg ha ⁻¹					
0	3173a†	2746a	3007b	3556b	3013a	2648a
0.56	3318a	2752a	3159ab	3619b	3010a	2932a
1.12	3179a	2734a	3144b	3822a	3022a	2890a
2.24	3194a	2845a	3323a	3816a	2966a	2905a
Fe effect						
Pr>F	0.51	0.81	0.08	0.09	0.99	0.18
CV	5.9%	7.3%	5.4%	6.6%	13.3%	7.6%
Single df test‡ CK vs. 1.12 & 2.24 kg						
Pr > F	NS§	NS	0.01	0.02	NS	0.01

† Values followed by the same letter are not significantly different at the $P < 0.10$ level based on the LSD.

‡ Single degree of freedom test comparing the check versus the average of the 1.12 and 2.24 kg Fe rates.

§ NS, nonsignificant.

was gradual warming through June with near normal rainfall (NOAA, 2015). Final plant populations were around 135,000 plants ha⁻¹. The IDC was more apparent on the two Great Northern varieties in late June and early July and there was less IDC on the Pinto bean cultivars. There were visual IDC symptom differences between Fe treatments, which were similar to those observed in 2011. Immediately before undercutting, a September hail storm resulted in loss of over 50% of the beans. Heavy rains delayed cutting and caused further pod shelling and the plots were abandoned. Spring 2014 was wetter and cooler than the 30-yr average (NOAA, 2015). Significant IDC developed in late June. Final plant populations were around 135,000 plants ha⁻¹. There were significantly different visual Fe treatment differences in early July, which was conducive to potential Fe response (Table 3).

There was a significant ($p = 0.01$) Fe treatment $\times$ year interaction for all four market classes, so the data are presented separately. Chlorosis scores for 2011, 2013, and 2014 showed significant effects for the different varieties and market classes for the different Fe treatments (Table 3). The range of scores indicated that there were some differences between market classes but because varieties were not randomized, a market class comparison could not be determined. The chlorosis scores of the zero-Fe treatment for a given variety across years, however, showed that severity by year was 2014 > 2013 > 2011. For a specific variety across all 3 yr, the average of the 1.12 and 2.24 kg ha⁻¹ rates of SoyGreen versus the check significantly improved chlorosis score at the 0.01 level of probability (Table 3). This was

similar to other studies with soybean (Goos and Johnson, 2000; Karkosh et al., 1988) which showed good early season greening. Color improvements may or may not always predict yield increases, however.

Seed yield for Great Northern bean for the 3 yr harvested (Table 4) showed no effect in 2012, but there were responses to Fe in 2011 and 2014. The Fe treatment $\times$ year analysis for the two responsive years for the four market classes showed no significant differences. The single-degree of freedom analysis for the check versus the average of the higher two SoyGreen rates showed an increase in Marquis yield ($p = 0.01$) in 2014, whereas Orion showed a significant increase in 2011 ($p = 0.02$) and 2014 ($p = 0.01$). The Pinto seed yields for the 3 yr harvested (Table 5) again showed no effect in 2012, but statistically significant yield increases caused by Fe treatments were recorded in 2011 ($p = 0.01$) and 2014 ($p = 0.01$).

A relative yield for each variety was calculated from the highest yield in a given year for that variety as the divisor, plotted versus the chlorosis score (Fig. 2.) The relationship showed a significant decreasing yield ($R^2 = 0.55$) as chlorosis severity increased. The relative yields were then averaged across the different varieties and market classes in 2011 and 2014 and plotted versus SoyGreen rate (Fig. 3). Varietal response varied somewhat between years but the average provides some insight into the overall response to SoyGreen. The check yield (no FeEDDHA) averaged 90%, which is 10% lower than the 100% maximum yield. For the Fe-responsive years, the check yield was 3096 kg ha⁻¹ for Great Northern beans and 3125 kg ha⁻¹ for Pinto

Table 5. Effect of row-applied SoyGreen Fe ethylene diamine-*N*, *N'*-bis (2-hydroxyphenylacetic acid) on Pinto dry bean seed yield for 2011 through 2014.

	Montrose			Poncho		
	2011	2012	2014	2011	2012	2014
SoyGreen kg ha ⁻¹	kg ha ⁻¹					
0	3119b†	3573a	2906b	3240b	3646a	3233c
0.56	3144b	3519a	2969b	3543a	3529a	3371b
1.12	3338a	3311b	3329a	3804a	3809a	3620a
2.24	3250ab	3595a	3452a	3740a	3577a	3468b
Fe effect						
Pr > F	0.08	0.08	0.04	0.04	0.61	0.01
CV	4.7%	4.9%	9.9%	9.1%	9.6%	3.9%
Single df test‡ CK v. 1.12 & 2.24 kg						
Pr > F	0.03	NS§	0.01	0.01	NS	0.01

† Values followed by the same letter are not significantly different at the $P < 0.10$ level based on the LSD.

‡ Single degree of freedom test comparing the check versus the average of the 1.12 and 2.24 kg Fe rates.

§ NS, nonsignificant.

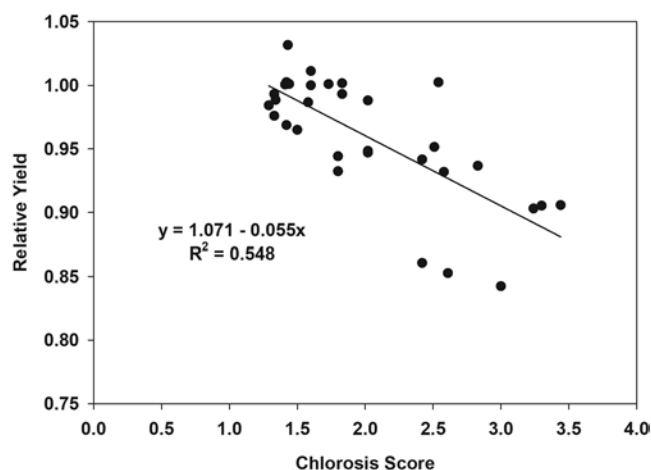


Fig. 2. Regression of relative dry bean yield versus chlorosis score for the four varieties used during 2011 and 2014.

beans. Yield increases of 10% would translate to an additional 310 kg ha⁻¹ of beans. The average of the maximum SoyGreen rate required to produce that yield from the regression response functions was near 1.8 kg ha⁻¹ which, at current costs for SoyGreen, is \$37 ha⁻¹ (S. Roehl, West Central, personal communication, 2018). Dry bean prices in Nebraska have ranged from \$465 to \$965 Mg⁻¹, with a 10-yr average of \$683 Mg⁻¹ (USDA NASS, 2018). At current retail prices, 1.8 kg ha⁻¹ of SoyGreen would cost about \$40 to \$43 ha⁻¹. On average, the additional 310 kg of dry bean would provide a gross return of \$212 ha⁻¹, more than paying for the fertilizer cost.

CONCLUSIONS

Over 4 yr, IDC severity in dry bean varied from none to severe. There was good response to SoyGreen in 2011 and 2014, with visual response in 2013 suggesting a good seed yield response, but plots were lost to hail. In the hot, dry year of 2012 on a less chlorotic site, there was little if any IDC shown. The SoyGreen rate of 1.8 kg ha⁻¹ usually produced a maximum seed yield response of ~310 kg ha⁻¹, which justifies applying the fertilizer. Fertilizing with Fe is not as simple as fertilizing with N or P. In many cases, a whole-field application may not be necessary. Chlorosis severity mapping in more severe IDC years (like 2014) can be used as a base map to drive site-specific application of Fe (Hergert et al., 1996). We did not have active sensor

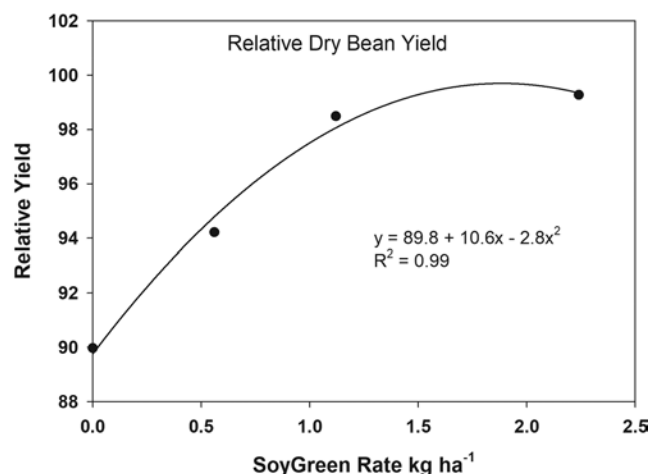


Fig. 3. Regression of relative dry bean yield for the four varieties used in 2011 and 2014 versus SoyGreen rate.

reflectance devices available but they have shown great promise for other crops and nutrients (Bu et al., 2016; Solari et al., 2008; Stone et al., 1996) and should be investigated for future improvements. Our plot areas were selected on the basis of field observations and Google Earth maps, which, if obtained at the right time of year, clearly show IDC areas. This approach should be part of a precision agriculture fertilizer management package for future dry bean production in the High Plains region but it will require promotion and possibly field demonstration, although there has been some producer adoption in the past 2 yr in the Nebraska Panhandle.

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