Soybean variety responses to increasing rates of Fe-EDDHA

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Research to reduce or alleviate Fe deficiency in soybeans by applying various seed, soil, or foliar Fe chelates or fertilizers has been conducted for decades. Although the results have been mixed and are seldom directly comparable, positive responses to foliar, seed, and soil treatments have been reported. Other researchers have observed only small, if any, response to similar treatments. Lack of consistent results may be related to inconsistent levels of chlorosis severity, soil, environmental, and genetic differences, and/or the low rates of Fe applied to ensure economic feasibility. Although usually more effective than inorganic forms of Fe, chelated forms such as IDHA-, EDTA-, DTPA-, EDDHA-, and HBED-Fe chelates are expensive. Chelated Fe products usually are applied to high-value crops such as citrus and only recently have soybeans commanded a price that improves economic feasibility.

To determine whether or not applying an Fe chelate will provide a reasonable return on investment, producers should consider: (i) rate of application (lbs acre⁻¹) required to substantially increase yield and at that rate of application, the cost of the Fe product ($ lb⁻¹); (ii) soybean prices needed to realize profits ($ bu⁻¹); (iii) expected increases in yield (bu). Selecting resistant varieties has long been promoted as the best strategy to reduce or alleviate Fe deficiency. However, not all soybean producers have access to high-yielding, Fe deficiency resistant varieties.

High pH, highly calcareous soils, common in western Minnesota, restrict the availability of soil Fe needed for optimum soybean growth and yield. On such soils, the amount of Fe fertilizer applied must surpass a threshold before there is sufficient available Fe in the soil solution to induce a positive growth response. Only a limited number of management tactics designed to improve the availability of Fe have been studied with soybean. These include variety selection, seeding density, seed-applied or in-furrow materials, and foliar treatments.

Several trials involving different years, soybean varieties, and Fe chelate rates are summarized in this report. They should provide examples that growers can use to determine the economic feasibility of applying higher rates of Fe chelates to reduce yield losses to Fe deficiency.

Iron Chelate Rates

Generally, increasing Fe-EDDHA rates will reduce early visual chlorosis ratings (early and/or mid-season) and often will increase grain yield when soybean is grown where Fe deficiency is moderate to severe. Five varieties, one resistant(R: Agassiz), two moderately resistant/moderately susceptible (MR/MS: Glacier, Tracker), and 2 susceptible (S: Solano, Stine 0670) to Fe deficiency and five rates of Fe-EDDHA (0,1,2,3, and 4 lbs acre⁻¹) were grown during 1997, 1998, and 1999 at Crookston, MN. Grain yields with and without Fe-EDDHA, the amount of Fe-EDDHA required to maximize yield, and break-even prices are given in Table 1. Averaged over three years, the amount of Fe-EDDHA required to maximize yield was least with the R variety, whereas the 2 S varieties and the 2 MR/MS varieties required higher rates of Fe-EDDHA to maximize yields (Table 1). When applying the amount of Fe-EDDHA required to maximize yield, the return on investment realized at various soybean prices was substantially higher with S varieties and moderately higher with R varieties compared to MR/MS varieties (Table 2). Rates of return were higher with S varieties primarily because of the large increase in maximum yield when Fe-EDDHA was added and they were higher with resistant varieties because of the lower rate of Fe-EDDHA required to maximize yield.

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**Susceptible Varieties:** \( Y = 33.32 + 9.668X - 1.51X^2; \ r^2 = 0.95 \)

Yield without Fe-EDDHA: 33.32 bu

Maximum grain yield occurs at Fe-EDDHA = 3.2013 lbs and that maximum = 48.79 bu

Increase in yield: 48.79 – 33.32 = 15.47 bu

Therefore, adding 3.2013 lbs Fe-EDDHA at $8.04 lb\(^{-1}\) = $25.74

Increasing grain yield by 15.47 bu at $5.00 bu\(^{-1}\) (this soybean price is used as an example) = $77.35

Return on investment = (77.35 – 25.74) = $51.61 acre\(^{-1}\)

Soybean price required to break even: $1.66 bu\(^{-1}\)

**Mod. Susceptible/Mod. Resistant Varieties:** \( Y = 40.27 + 2.03X - 0.275X^2; \ r^2 = 0.87 \)

Yield without Fe-EDDHA: 40.27 bu

Maximum grain yield occurs at Fe-EDDHA = 3.69 lbs and that maximum = 44.02 bu

Increase in yield: 44.04 – 40.27 = 3.765 bu

Therefore, adding 3.69 lbs Fe-EDDHA at $8.04 lb\(^{-1}\) = $29.67

Increasing grain yield by 3.75 bu at $5.00 bu\(^{-1}\) (this soybean price is used as an example) = $18.75

Return on investment = (18.75 – 29.67) = $ - 10.92 acre\(^{-1}\)

Soybean price required to break even: $7.91 bu\(^{-1}\)
**Resistant Varieties:** \( Y = 40.80 + 5.02X - 0.982X^2; r^2 = 0.94 \)

Yield without Fe-EDDHA: 40.80 bu

Maximum grain yield occurs at Fe-EDDHA = 2.556 lbs and that maximum = 47.22 bu

Increase in yield: 47.22 – 40.80 = 6.42 bu

Therefore, adding 2.556 lbs Fe-EDDHA at $8.04 lb\(^{-1}\) = $20.55

Increasing grain yield by 6.42 bu at $5.00 bu\(^{-1}\) (this soybean price is used as an example) = $32.10

Return on investment = (32.10 – 20.55) = **$ 11.55 acre\(^{-1}\)**

Soybean price required to break even: $3.20 bu\(^{-1}\)

Table 1. Grain yields with and without Fe-EDDHA, amount of Fe-EDDHA required to maximize yield, and the break-even price of soybeans needed to pay for the added Fe-EDDHA estimated from trials done during 1997-1999 involving 5 varieties and 5 rates of Fe-EDDHA.

<table>
<thead>
<tr>
<th>Varietal characterization of resistance to Fe deficiency(^\dagger)</th>
<th>Yield without Fe-EDDHA (bu acre(^{-1}))</th>
<th>Maximum yield with Fe-EDDHA (bu acre(^{-1}))</th>
<th>Fe-EDDHA required to maximize yield (lbs acre(^{-1}))</th>
<th>Soybean break-even price ($ bu(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible</td>
<td>33.3</td>
<td>48.8</td>
<td>3.2</td>
<td>1.66</td>
</tr>
<tr>
<td>Mod. R / Mod. S(^\ddagger)</td>
<td>40.3</td>
<td>44.0</td>
<td>3.7</td>
<td>7.91</td>
</tr>
<tr>
<td>Resistant</td>
<td>40.8</td>
<td>47.2</td>
<td>2.6</td>
<td>3.20</td>
</tr>
</tbody>
</table>

\(^\dagger\) Five varieties were selected for study based on published visual chlorosis scores (VCS) and included 1 resistant, 2 susceptible, and 2 varieties characterized as moderately resistant/moderately susceptible.

\(^\ddagger\) Mod. R is moderately resistant; Mod. S is moderately susceptible.

Table 2. Return on investment ($ acre\(^{-1}\)) at various soybean prices, when applying the amount of Fe-EDDHA needed to maximize yield.

<table>
<thead>
<tr>
<th>Soybean price ($ bu(^{-1}))</th>
<th>$3.00</th>
<th>$5.00</th>
<th>$7.00</th>
<th>$9.00</th>
<th>$11.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varietal characterization of resistance to Fe deficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Susceptible</td>
<td>$20.67</td>
<td>$51.61</td>
<td>$82.55</td>
<td>$113.49</td>
<td>$144.43</td>
</tr>
<tr>
<td>Mod. R/Mod. S</td>
<td>-$18.42</td>
<td>-$10.92</td>
<td>-$3.42</td>
<td>$4.08</td>
<td>$11.58</td>
</tr>
<tr>
<td>Resistant</td>
<td>-$1.29</td>
<td>$11.55</td>
<td>$24.39</td>
<td>$37.23</td>
<td>$50.07</td>
</tr>
</tbody>
</table>
In studies designed to determine if seed Fe concentration was predictive of resistance to Fe deficiency, we established trials involving substantially higher rates of Fe-EDDHA during 2002 and 2003. Although we measured numerous characters, the results given here refer to varietal responses to rates of Fe-EDDHA, similar to that reported for the 1997-1999 trials.

Two resistant (R) and two susceptible (S) varieties were grown at five rates of Fe-EDDHA (0, 2, 4, 6, 8, and 10 lbs) at Crookston, MN in 2002. The high rates of Fe-EDDHA were used to determine whether higher rates promoted increases in harvest seed Fe, or whether seed Fe concentrations were determined primarily by the genetics of the variety. Two resistant (R: MN 0302, Norpro) and two susceptible (S: GCS 3104, WS 2020) varieties and six rates of Fe-EDDHA (0, 2, 4, 6, 8, and 10 lbs) were studied during 2002. Grain yields with and without Fe-EDDHA, the amount of Fe-EDDHA required to maximize yield, and break-even prices are given in Table 3.

The amount of Fe-EDDHA required to maximize yield was considerably higher with the R varieties, whereas the 2 S varieties required lower rates of Fe-EDDHA to maximize yields (Table 3). When applying the amount of Fe-EDDHA required to maximize yield, the return on investment (ROI) realized at various soybean prices was substantially higher with S varieties than with R varieties (Table 4). ROI was higher with S varieties primarily because of the large increase in maximum yield when Fe-EDDHA was added and they were lower with resistant varieties because of the much higher rate of Fe-EDDHA required to maximize yield. Another way of looking at this is that susceptible varieties required nearly 6 lbs ($48.24) Fe-EDDHA to match yields of the resistant varieties without any added Fe-EDDHA. It may be more profitable to plant a resistant variety, if its level of resistance is known to be fairly high and consistent.

\[
\text{Susceptible Varieties: } Y = 38.5 + 4.06X - 0.24X^2; \quad R^2 = 0.98
\]

Yield without SoyGreen: 38.5 bu

Maximum grain yield occurs at Soygreen = 8.4 lbs. and that maximum = 56.07 bu

Increase in yield: 56.07 – 38.50 = 17.57 bu

Therefore, adding 8.4 lbs SoyGreen at $8.04/lb = $67.54

Increasing grain yield by 17.57 bu at $ 5.00/bu =$87.85

ROI: $20.31/acre

Soybean price required to break even: $3.84/bu
**Resistant Varieties:**  \[ Y = 52.2 + 0.63X - 0.023X^2; \]  \[ R^2 = 0.89 \]

Yield without SoyGreen: 52.2 bu

Maximum grain yield occurs at SoyGreen = 13.7 lbs. and that maximum = 56.5 bu

Increase in yield: 56.5 – 52.2 = 4.3 bu

Therefore, adding 13.7 lbs SoyGreen at $8.04/lb = $ 110.15

Increasing grain yield by 4.3 bu at $ 5.00/bu = $21.50

ROI: - $88.65/acre

Soybean price required to break even: $25.61/bu

Table 3. Grain yields with and without Fe-EDDHA, amount of Fe-EDDHA required to maximize yield, and the break-even price of soybeans needed to pay for the added Fe-EDDHA estimated from trials done during 2002 involving 4 varieties and 6 rates of Fe-EDDHA.

<table>
<thead>
<tr>
<th>Varietal characterization of resistance to Fe deficiency†</th>
<th>Yield without Fe-EDDHA (bu acre(^{-1}))</th>
<th>Maximum yield with Fe-EDDHA (bu acre(^{-1}))</th>
<th>Fe-EDDHA required to maximize yield (lbs acre(^{-1}))</th>
<th>Soybean break-even price ($ bu(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible</td>
<td>38.5</td>
<td>56.1</td>
<td>8.4</td>
<td>3.84</td>
</tr>
<tr>
<td>Resistant</td>
<td>52.2</td>
<td>56.5</td>
<td>13.7</td>
<td>25.61</td>
</tr>
</tbody>
</table>

† Five varieties were selected for study based on published visual chlorosis scores (VCS) and included 1 resistant, 2 susceptible, and 2 varieties characterized as moderately resistant/moderately susceptible.

‡ Mod. R is moderately resistant; Mod. S is moderately susceptible.

Table 4. Return on investment ($/acre\(^{-1}\)), at various soybean prices, when applying the amount of Fe-EDDHA needed to maximize yield.

<table>
<thead>
<tr>
<th>Varietal characterization of resistance to Fe deficiency</th>
<th>Soybean price ($/bu(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$3.00</td>
</tr>
<tr>
<td>Susceptible</td>
<td>- $14.83</td>
</tr>
<tr>
<td>- $14.83</td>
<td>$20.31</td>
</tr>
<tr>
<td>- $88.65</td>
<td>$55.45</td>
</tr>
<tr>
<td>- $80.05</td>
<td>- $71.45</td>
</tr>
<tr>
<td>- $97.25</td>
<td>- $62.85</td>
</tr>
</tbody>
</table>

This trial was repeated in 2003 at two locations and included six varieties and six rates of Fe-EDDHA. As with other experiments we have done, the magnitude (especially) and direction of differences between susceptible and resistant varieties varied with the harshness of the environment, i.e., responses were environment specific as well as variety specific. Smaller differences might be expected if the severity of Fe deficiency was either very harsh or very mild.
The linearity of response shown in Fig. 3 indicates that any additional increment (within the range from 0 to 10 lbs chelate acre\(^{-1}\)) of Fe-EDDHA will at least pay for the cost of the chelate once the price of soybeans is equal to the cost of each increment of added Fe. The linearity of response also indicates that even at very high rates of Fe-EDDHA, Fe deficiency still limited plant growth and grain yield.

Where Fe deficiency was moderate (Crookston, 2002 and Fisher, 2003) susceptible varieties exhibited large, linear responses to Fe-EDDHA rate while resistant varieties had linear but smaller responses. The severity of Fe deficiency was especially harsh at Crookston in 2003, where yields of both R and S varieties increased linearly in response to increases in Fe-EDDHA. The responses paralleled each other, but neither appeared to reach a maximum yield even at the highest rate of applied Fe. The ROI of these trials are not provided, but they are similar to earlier examples. Every year and variety can lead to different responses.

![Graphs showing the increase in grain yield in response to increasing rates of Fe-EDDHA for Fe deficiency resistant and susceptible soybean cultivars grown in three environments.](image-url)
As mentioned earlier, it is only recently that soybeans have commanded a price that improves the economic feasibility of applying organic chelates. Although many producers have experienced the costs and returns of applying chelates, hopefully the examples given here of research conducted in our area will provide producers additional information for highly calcareous, high pH soils.

Because roots of plants grown within a row intermingle and synergistically increase soil Fe availability, higher seeding rates also improve resistance to Fe deficiency. Our research during 2000-2001 involving five seeding rates and three varieties indicated that differences between susceptible, moderately susceptible, and resistant varieties were quite similar to varietal differences in response to increasing Fe-EDDHA rates. Varieties susceptible to Fe deficiency increased dramatically in response to increasing plant populations, whereas resistant varieties showed little response. Although we would like to think that our results are exactly what producers will experience, it is important to remember that neither our results nor those of others in our area will apply to all situations. Cheaper chelates are needed.