IRON DEFICIENCY IN SOYBEAN

Introduction

The element iron [Fe] is required to form chlorophyll, the green pigment in plants. When iron uptake from the soil is limiting to plants, plants become iron-deficient. The most common symptom is interveinal chlorosis in newly developed leaves [termed iron deficiency chlorosis or IDC] where the leaf tissue turns yellow while the veins remain green. Iron deficiency can cause moderate to severe yield reductions in soybeans [NCSRP–SRII; Pioneer, 2009]. Iron deficiency/IDC occurs to some extent in soybeans that are grown on the high-pH soils in the Black Belt region of east Mississippi [MSU Info. Sheet 873].

IDC is the most visual and most commonly measured symptom of iron deficiency. IDC severity is most often measured using a visual scale; however, the visual scale is extremely subjective and highly variable among raters. The lack of standard phenotyping for variety IDC symptoms is a challenge for researchers who are conducting investigations to determine physiological differences between iron efficient and inefficient soybean genotypes [*see below for descriptions of these types*]. Recently, image-based IDC rating systems have been developed that use pictures and computer imaging software to extract green, yellow, and brown pixel counts that are related to IDC severity. Also, destructively sampling soybean leaves to determine their relative chlorophyll concentrations is an alternative approach that could be considered to provide an objective measure of IDC symptom severity [Merry et al., Crop Sci. 62:36-52 (2022)].

IDC is not caused by iron deficiency in the soil, but rather by the plant's inability to extract it from the soil. Soybean plants obtain iron from the soil by releasing acids that solubilize the iron in soil to a form that is readily taken up by the roots. In high pH soils with high levels of bicarbonates and soluble salts, this process can be limited by the chemical reactions between these materials and the iron. In other words, iron becomes less soluble at higher soil pH, especially when the soil contains large amounts of calcium carbonate.

Soil pH is not a good indicator of where IDC will occur and does not correlate well with IDC. However, there is a direct correlation between IDC and high concentrations of calcium carbonate and soluble salts in soil. Thus it is important to determine the levels of these materials in soil on sites planned for soybean production [Asgrow, 2013; Pioneer, 2009], and take remedial action if those levels suggest the potential occurrence of IDC.

An excellent source of issues related to and remedies for soybean production on sites that have known IDC-inducing conditions can be viewed on the PMN webcast presented by Dr. Daniel Kaiser.

In the March-April 2012 issue of Crops & Soils Magazine, Mr. John Morgan developed an article from Dr. Kaiser's PMN webcast that includes a pictorial presentation of IDC ratings of soybeans. Dr. Kaiser also discusses in great detail the soil chemistry aspects associated with and that contribute to IDC. From that article, the following points are pertinent.

- The problem exhibited by IDC in soybean is an absence of enough iron to grow a healthy plant.
- IDC is not caused by an iron deficiency in the soil.
- In many cases, digging into the soil will reveal a carbonate layer at a shallow depth in many soils where IDC is observed.
- The crux of the IDC problem is due to an overabundance of bicarbonate in the soil and not a dearth of iron. This can be exacerbated by wet soils with limited air exchange, decaying organic matter that adds to the amount of carbon dioxide in the soil, and high levels of soil nitrate.

Management Strategies

The best strategy for managing IDC is to select a soybean variety with tolerance [Helms et al., Agron. J., Vol. 102, 2010; Asgrow, 2013; NCSRP–SRII]. Ratings for many varieties that are grown in Mississippi can be accessed here. **Ratings of private varieties against IDC made by the originating**

company are likely the best source for selecting varieties with IDC tolerance. However, rating for IDC is not available for all varieties, and the ratings are highly subjective and variable among raters.

The Mississippi IDC ratings data are for varieties that were grown in tests located on known IDC sites in East Miss. in 2014-2024. The ratings indicate that none of the tested varieties are completely tolerant, but several had ratings of 2-3, which indicates moderate tolerance. Varieties with these low ratings were generally the top yielders on these sites, whereas varieties that were rated 5 or higher [moderately susceptible to susceptible] were generally lower yielding. It is recommended that any variety with a rating of 5 or higher should not be planted on sites with a history of IDC symptoms in previous soybean plantings.

Iron chelate fertilizer placed close to the seed at planting [either as a dry formulation or a water solution applied in-furrow] can be effective for getting iron into the plant, but its cost should be considered. Results from research or recommendations for applying iron chelate to the seed are mixed [Liesch et al., Agronomy Journal, Vol. 103, 2011; NCSRP–SRII].

Applying iron as a foliar fertilizer is unpredictable in its effect or will not correct the problem [Liesch et al., Agronomy Journal, Vol. 103, 2011; NCSRP–SRII]. According to results from research conducted by Chatterjee et al. [CFTM, Sep. 2017], foliar applications of iron fertilizer forms and adjuvants might have an effect on regreening of leaves, but soybean seed yield will not be significantly improved. They conclude that **integrating selection of IDC-tolerant soybean varieties** with practices such as planting in soils with low nitrate levels, increasing seeding rates, and using Fe-EDDHA fertilizer with seed at planting is more likely to result in a yield increase from fields with conditions that promote IDC. The use of Fe-EDDHA fertilizer at planting has also resulted in economical yield increases of dry beans that were planted on sites known to promote severe IDC [Hergert et al,, Agron. J., Vol. 111, 2019.]

Wiersma [Crop Science, Vol. 52, 2012] presents evidence that iron-efficient and iron-inefficient soybean varieties have seed iron contents that are distinctly different from each other, and the maximum iron content in seeds of each of the variety classes are seldom exceeded. Thus, soybean plants tend to maintain iron in the seed within genetically controlled limits. Furthermore, he concludes that:

- Seed iron content is useful for identifying soybean genotypes that have resistance to iron deficiency.
- Using iron content of soybean seed is equivalent or superior to using visual chlorosis score as an indicator of resistance to iron deficiency.
- Conventional plant breeding can be used to increase seed iron content in order to improve resistance to iron deficiency.
- Iron content of soybean seed that are to be planted can be used to successfully predict IDC.
- It should be possible to measure iron content in seed from a chlorosis nursery and relate this trait to genotypic resistance to iron deficiency.
- Soybean breeders should explore this methodology to ascertain its usefulness as a selection criterion for developing varieties with resistance to IDC. The use of seed iron content as a proxy for IDC resistance may be of use in breeding programs designed to develop IDC-resistant soybean varieties.

A summary of results from the following two linked studies provide additional insight into mitigation of IDC.

Results from a 2010-2012 study [Agronomy Journal, Vol. 106, 2014] that was conducted in the Blackbelt region of Alabama shed new light on how IDC can be managed in affected fields in the southeastern U.S. The study was conducted on high-pH soils at two sites–one a Sumter soil series with an average pH of 8.2, and the other a Leeper soil series with an average pH of 7.9. Treatments were various iron chelate materials applied either in-furrow at planting, as a foliar spray at the V3 growth stage, or a combination of the two. Major findings are:

- Visual chlorosis scores [VCS–range of 1 = no chlorosis to 10 = necrotic and stunted or dead plants] ranged from 3.8 to 6.6 at the higher pH site, and 2.8 to 4.6 at the lower pH site.

- VCS ratings were not lowered enough by any treatment to reduce chlorosis level to that of a non-chlorotic plant.
- **Fe-EDDHA [6% iron] applied at 4 lb/acre either in-furrow at planting or as a split application between in-furrow and a foliar spray at V3 was effective in improving yield when a variety with moderate sensitivity to IDC was used.** Average yield increase for the best treatment was 3.25 bu/acre above the average 16.7 bu/acre yield for the untreated control.
- Soybean prices used in this study were $11.17, $11.99, and $14.71 per bushel in 2010, 2011, and 2012, respectively. Fe-EDDHA price was $6.82/lb, or $27.28 for the 4 lb/acre rate. Thus, returns were increased by about $9 to $20.50/acre across the 3 years using the 3.25 bu/acre best yield increase measured in this study.
- Using the yield increase of 3.25 bu/acre and the Fe-EDDHA cost of $27.28/acre for the 4 lb/acre rate used in this study, soybean price will have to be above about $8.40/bu for this to be a profitable treatment to alleviate IDC in soybeans.
- The magnitude of the yield effect measured in this study should be determined in a higher yielding environment, where yields were in the 16.5 to 20 bu/acre range. In other words, will the yield effect be greater as yields increase, or will it remain the same regardless of the yield level?
- The findings from this study should be confirmed on several varieties that are known to be IDC-sensitive, and/or that are known to have varying degrees of IDC sensitivity among them. This can be done on a known IDC site with varieties that have a confirmed history of IDC sensitivity.

In the realm of agricultural research, affirmation of prior results and statements is a valuable tool in the quest to provide accurate information about pertinent subjects to producers.

Such is the case with the second article titled "Comparison of Field Management Strategies for Preventing Iron Deficiency Chlorosis in Soybean" and authored by Kaiser, Lamb, Bloom, and Hernandez. The study was conducted from 2010 to 2012 in Minnesota. A summary of their findings and conclusions follow.

- Fe-EDDHA [6% iron] applied in-furrow at 3 lb/acre was effective in improving yield when an IDC-susceptible soybean variety was grown on sites that promoted moderate to severe IDC.
- An IDC-tolerant soybean variety without IDC management produced yields similar to those of the susceptible variety that received the in-furrow Fe treatment when both were grown on sites that promoted IDC.
- Yields of the IDC-sensitive variety that received the Fe treatment were no better than those of the tolerant variety with or without the Fe treatment.
- On sites that promoted severe IDC, yields of both the IDC-susceptible and -tolerant varieties with no IDC management were reduced, but the yield from the susceptible variety was 39% less than that from the tolerant variety.
- At the time of this research, the Fe-EDDHA cost for the rate used was $8/lb or $24/acre. Thus, a yield increase of about 2.5 bu/acre would cover its cost when soybean commodity price is $10/bu.
- Since the susceptible variety with IDC management did not result in greater yield than the tolerant variety when both were grown under moderate to severe IDC conditions, **growing an IDC-tolerant/iron efficient soybean variety is the best management strategy on sites that promote IDC.**
- **These results indicate that in-furrow application of Fe-EDDHA is a relatively cheap solution to mitigate the effects of moderate to severe IDC in susceptible soybean varieties.**

There are two reports that provide impetus for investigating the use of cover crops to aid in IDC mitigation.

The first is Managing Iron Deficiency Chlorosis in Soybean by Kaiser, Lamb, and Bloom, which reports results from studies in Minnesota. Points from that article follow.

- Using a companion crop such as oat that is planted at or before soybean planting can use excess soil nitrate and also dry a wet soil to reduce bicarbonate buildup.
- Oat must be killed at the proper growth height to realize this benefit. This ensures that oat did in fact

reduce the level of soil nitrate.

The second is Growing Productivity with Innovative Research from Pioneer. Data from a one-year study on a high pH site in the Black Belt region of Alabama provided the following results.

- Using a wheat cover crop increased yield of all soybean varieties in the test, but the increase from the IDC-sensitive variety was by far the greatest.
- Yields of all varieties in the test were similar when a cover crop was used.
- The findings suggest that using a wheat cover crop before soybean planting can reduce the severity of IDC on high pH soils. This may be tied to the reduction of soil nitrate as mentioned above.

Assessment of Results

The conclusions that can be inferred from these studies follow.

- **Fe-EDDHA applied in-furrow at planting can improve yield when IDC-sensitive soybean varieties are grown on soils that promote moderate to severe IDC, and this yield increase likely will be profitable**.
- **The best strategy for managing IDC is to select a soybean variety with tolerance.** The problem with this strategy is that there is no information about IDC tolerance in many currently used varieties.
- The use of cover crops to mitigate problems on IDC-inducing soils planted to soybean should be further investigated on those sites.
- Fields that promote IDC in soybeans should be well-drained, and depressional areas in those fields should be remedied by minimum to moderate land-forming.

The effect of IDC and its remedies are not exclusive to soybeans. In a multi-year (2011-2014) study [Hergert et al,, Agronomy Journal, Vol. 111, 2019] that was conducted in Nebraska with dry edible beans [Great Northern and Pinto], the authors report results that are similar to those obtained from using Fe-EDDHA fertilizer in the soybean studies cited above.

The above summaries of cited research reports lead to the conclusion that variety trials in states that have soils that promote IDC in soybeans should have a variety trial on a site with a known history of soybeans exhibiting IDC symptoms. This trial could be a limited version of the larger variety trials that are conducted throughout the state–i.e. a trial on such a site should at least contain the known top yielders among the larger group of variety trial entries to determine their susceptibility or tolerance to IDC.

An experiment of the above type could also incorporate a cover crop variable to determine the repeatability of results from the studies cited above.

A Crop Science journal article titled "Iron deficiency in soybean" by Merry et al. provides a complete summary of the present status of iron nutrient deficiency in soybean. This article is a comprehensive literature review of iron deficiency physiology and soybean's response to iron deficiency stress. Following is a summary of the article's pertinent contents.

- IDC is a common symptom of Fe deficiency in soybean, and is characterized by interveinal chlorosis of the leaves. This is related to reduced chlorophyll in the leaves since iron is necessary for chlorophyll synthesis. Thus, there is a reduction in photochemical efficiency of iron-deficient soybean plants. Also, iron-deficient leaves may be damaged by intense levels of photosynthetically active radiation because of their reduced chlorophyll content.
- For clarity and arguably the most accuracy, soybean genotypes are defined as having high or low resistance to IDC when describing IDC symptomology. This terminology implies that the soybean plant is actively responding to Fe deficiency stress and suggests that the IDC symptom occurs in varying degrees of severity, which is the actual case.
- It is important to note that complete resistance to IDC is not present in soybean genotypes, and that resistance to IDC does not accurately describe genotype differences in Fe physiology.
- Fe efficiency of a soybean genotype implies that 1) it is better able to acquire available Fe from the soil, 2) it is more efficient at converting unavailable

Fe to a form available to soybean, and/or 3) it is efficient at moving Fe throughout the plant. Thus the terms "**efficient**" and "**inefficient**" should be used to refer to soybean genotypes with respect to Fe physiology and not IDC.

- "Iron sufficient" and "iron deficient" should be used when referring to Fe availability in soybean's growing environment. Thus, Fe deficiency is managed through agronomic prevention–e.g. application of iron chelates, reducing excess soil nitrates–as well as using iron-efficient soybean varieties.
- **Numerous sources indicate that variety selection is the best strategy to offset Fe deficiency in the field.**
- Many studies have shown that there are quantitative trait loci [QTL] that confer resistance to IDC. This discovery should assist researchers in combining the knowledge about the physiological mechanisms that govern Fe deficiency responses and the QTL's that confer IDC resistance.
- Even though Fe may be abundant in soil, the form of Fe and soil chemistry–e.g. pH, soil moisture-driven carbonate release, soil nitrates, multiple nutrient-deficiency stresses, soil microbial interactions with soybeans in iron-deficient soils–determine Fe availability for uptake by soybeans.
- Management of Fe deficiency in soybean can involve addition of iron chelates as soil amendments and preventing the carryover of excess soil nitrates to a following soybean crop. **However, as stated previously, the best management strategy is to plant soybean varieties that have been identified as IDC-tolerant.**
- Foliar applications of iron compounds may be effective in alleviating IDC symptoms [e.g. regreening of leaves] in some cases, but have not been effective in alleviating iron-deficiency soybean yield reductions in field environments. This could be the result of soybean nodules still being iron-limited after foliar Fe applications, thus resulting in reduced biological N fixation and subsequent yield reductions.
- Complete resistance to IDC is not likely to be attained. However, since genetic variation in IDC resistance in soybean is present in the soybean germplasm, it should be possible to develop varieties with improved IDC resistance.
- Research has indicated a physiological basis for resistance to IDC. This may enhance the ability to detect gene candidates within the soybean genome that can be investigated to understand Fe efficiency in soybean and the development of IDC-resistant varieties.
- The physiology of Fe deficiency in soybean is tied to the reduction of Fe^{3+} to Fe^{2+} for Fe uptake into the soybean plant.
- Iron reductase enzymes are crucial for the uptake of Fe^{2+} by the soybean plant. Once Fe^{3+} is released from iron oxides or other chemical bonds in the soil, it can be reduced at the soybean root surface by iron reductase and transported into the root.
- Iron-deficiency symptoms in soybean are not usually visible until the V3 growth stage or later. This is a result of sufficient iron being available from the cotyledons to support growth of the emerging soybean plant through this vegetative stage.
- Literature reviewed for this compilation of current Fe deficiency knowledge in soybean showed that there is a correspondence between increased nicotianamine production and increased deposition of iron in soybean seed. Also, all soybean genes that have been directly related to Fe efficiency in soybean had some relationship to both nicotianamine and citrate levels.
- The role of root exudates in soybean's Fe deficiency response, the role of soil microbes in soybean Fe efficiency, and identifying mycorrhizal fungi that can acquire Fe and then transport that iron into soybean plants are areas that might provide fruitful research results into soybean iron efficiency/deficiency.

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