Micronutrient Soil Fertility

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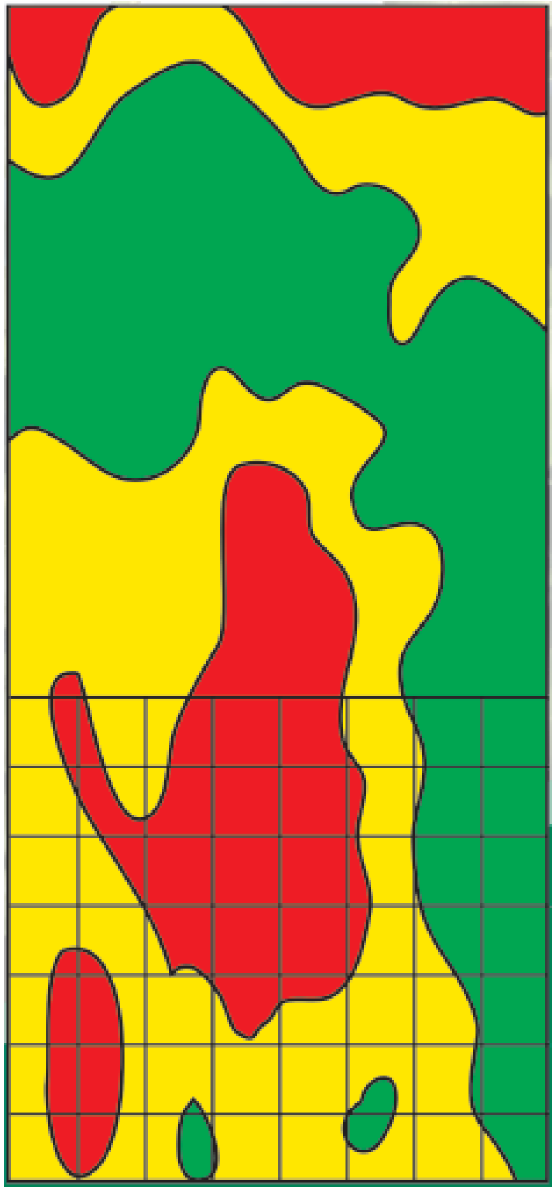

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Essential elements for plant growth and reproduction

- 17 essential elements
- Macronutrients: required in large quantities
  - C, H, O – supplied by water and carbon dioxide
  - N, P, K, S – supplied by soil and fertilizer
  - Ca, Mg – supplied by soil (mostly)
- Micronutrients: required in small quantities
  - B, Cu, Fe, Mn, Zn, Mo, Ni – supplied by soil (mostly)
  - Cl – supplied by soil and fertilizer

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Micronutrient overview

- Micronutrient deficiencies occur around the world
- Micronutrient needs are crop and soil specific
  - Parent materials and what elements are found in soil minerals
  - Soil properties (soil forming factors CLoRPT)
    - Soil pH
    - Soil texture
    - Soil organic matter
  - Cropping history
    - Crop nutrient removal
    - Soil erosion

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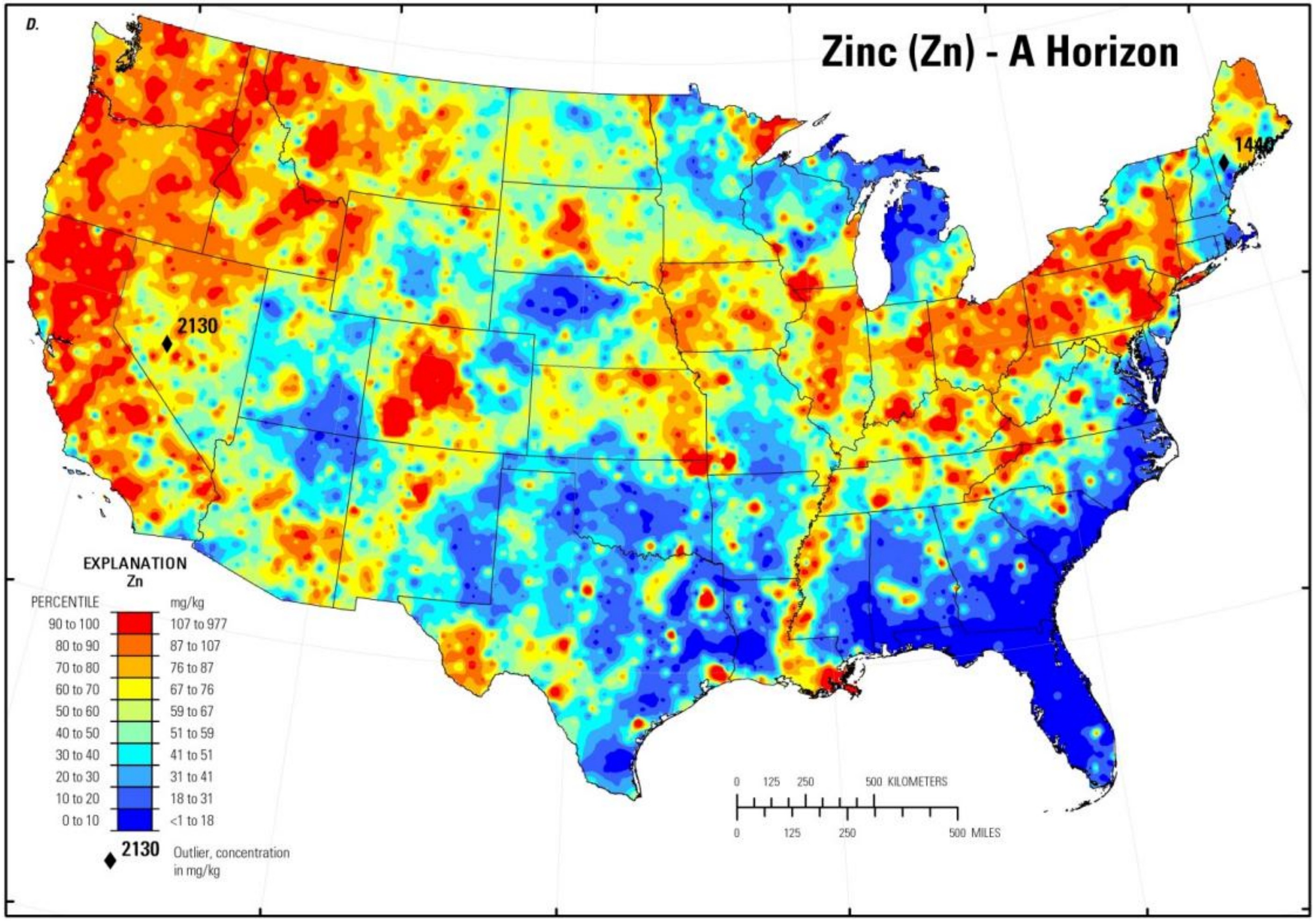
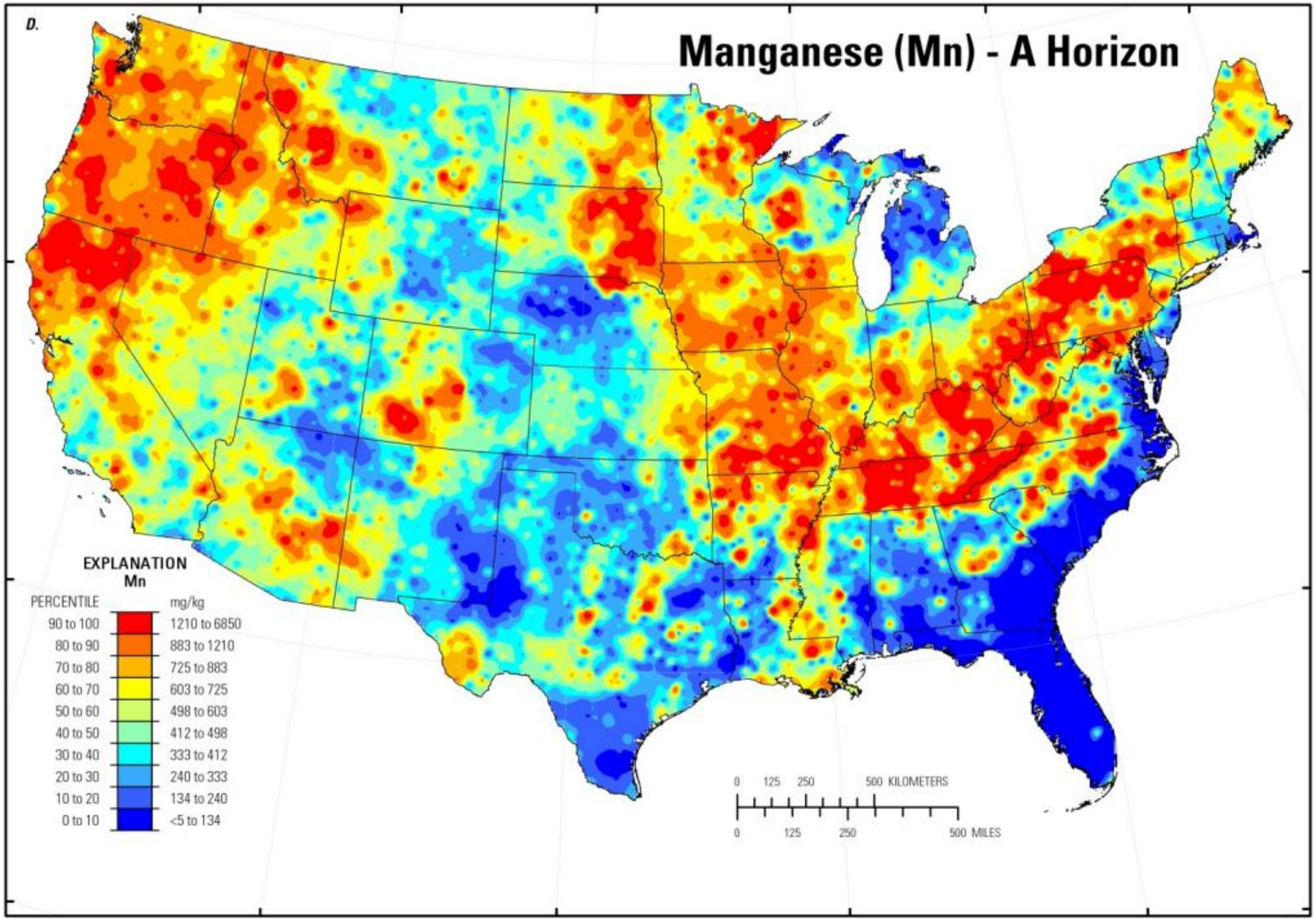
Geology and parent material
TOTAL Zn ppm across USA



Smith, D.B., W.F. Cannon, L.G. Woodruff, F. Solano, and K.J. Ellefson. 2014. Geochemical and mineralogical maps for soils of the conterminous United States. U.S. Geol. Survey Open-File Rep. 2014-1082 https://dx.doi.org/10.3133/ofr20141082 (accessed 8 Dec. 2025)

Geology and parent material TOTAL Mn ppm across USA



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Soil pH and nutrient availability

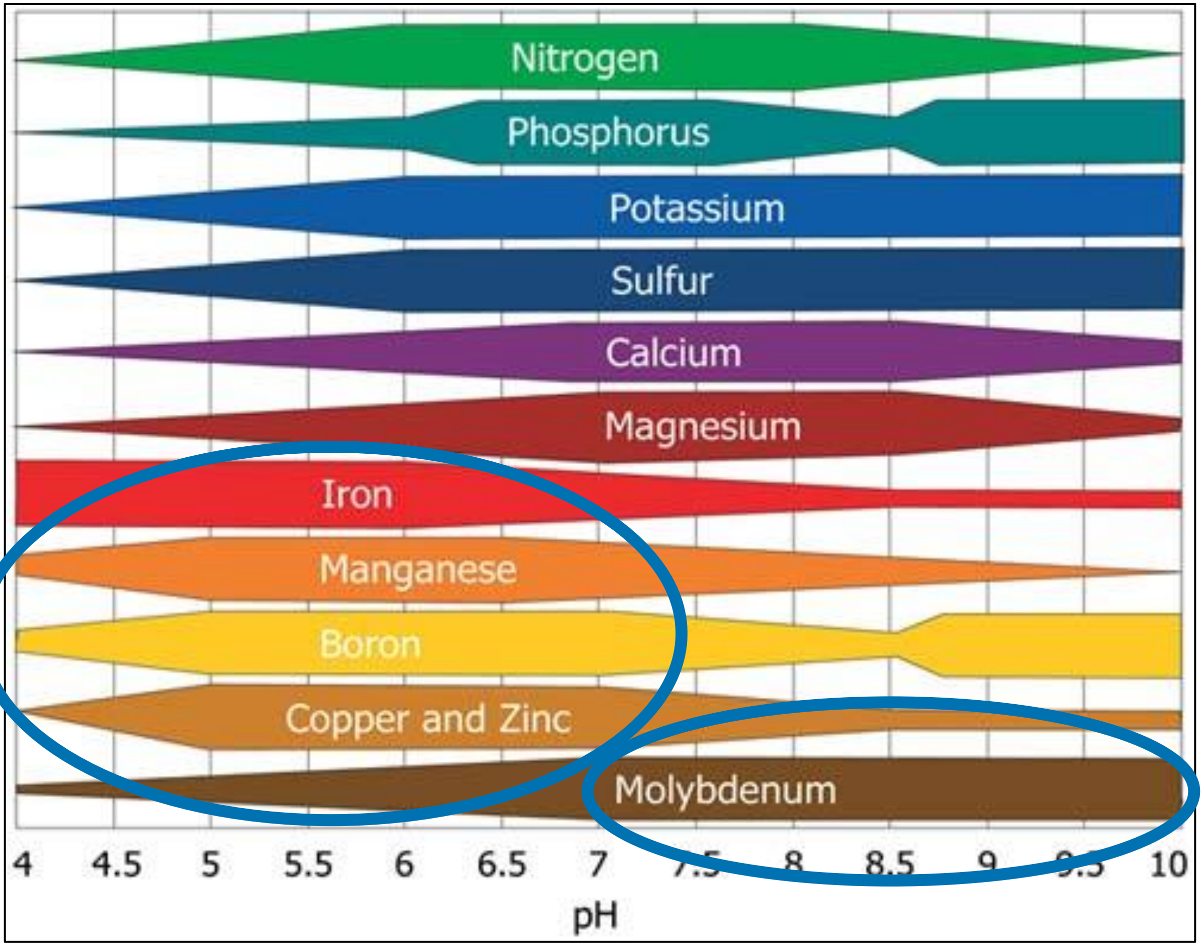

Photo: Gene Hettel/CIMMYT. https://flic.kr/p/8Ke1Jr

Soil organic matter and micronutrient cycling/complexation

- Micronutrient (metals) are "cycled" in soil organic matter, complexed (bound) and released over time
  - Soils with low SOM often have low micronutrient soil test levels (B, Cu)
  - Sandy soils often have low SOM
  - Eroded soils often have low SOM
- Organic soils (>20% SOM, peat/muck) are problematic and too much SOM might cause excessive complexation and less availability (Cu, Mn)

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Topography and erosion influence micronutrient availability

- Loss of soil is a direct loss of micronutrients
- Loss of soil organic matter that cycles micronutrients
- Increase in soil pH (carbonate) that decrease micronutrient availability

Upland

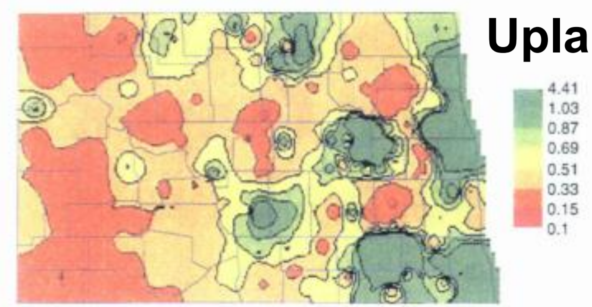

Figure 1. North Dakota copper levels, ppm, non-manured sites, upland positions.

Sloping

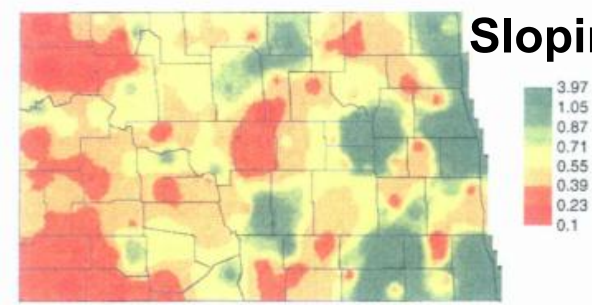

Figure 2. North Dakota copper levels, ppm, non-manured sites, sloping positions.

Depression

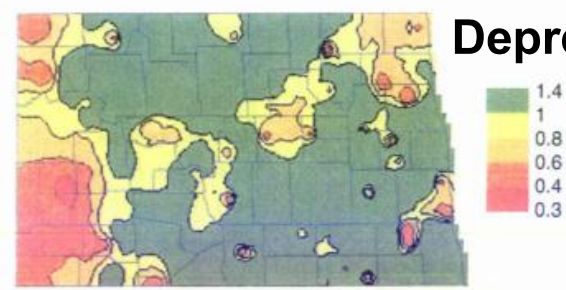

Figure 3. North Dakota copper levels, ppm, non-manured sites, depressional positions.

Soil test Cu (ppm)

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Franzen, D.W. 1999. North Dakota survey of soil copper, pH, zinc, and boron levels. NDSU Ext. Rep. 52. North Dakota State Univ., Fargo, ND.

Losing soil fertility? Stop soil erosion!

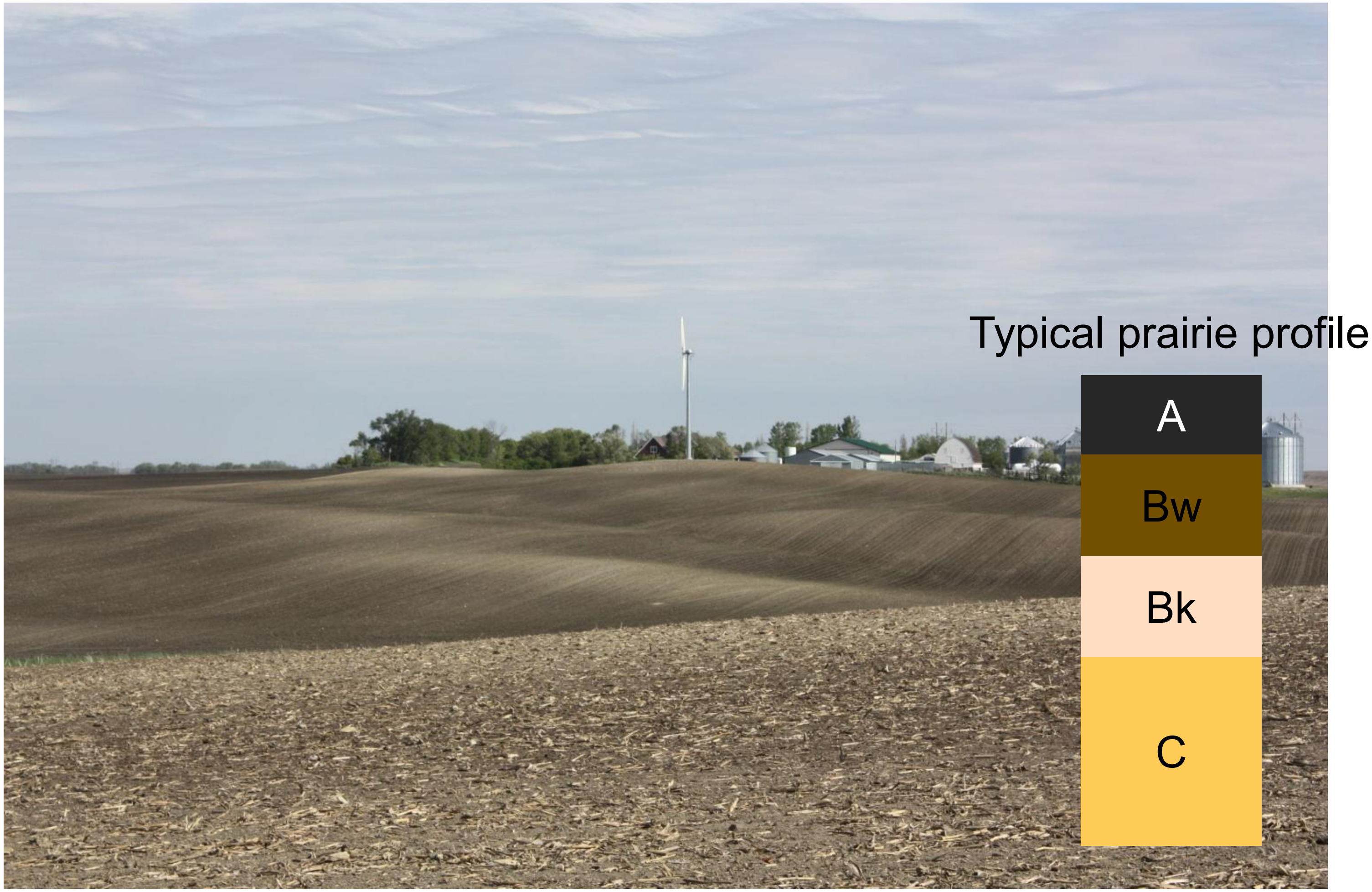

Photo from Bohn, M., D. Hopkins, C. Gasch, D. Steele, and S. Tuscherer. 2018. Predicting soil health and function using remote-sensed evapotranspiration and terrain attributes for a benchmark soil. In: Franzen, D.W., chair, 2018 NDSU Soil and Soil Water Workshop, Fargo, ND. 17 Jan. 2018. North Dakota State Univ., Fargo, ND.

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Micronutrient recommendations

- Some university guidelines may be “older.” Continued research on micronutrients is ongoing at regional scales.
- Soil testing is a good predictor of crop response for some micronutrients (zinc), but may require additional soil and environmental factors for others (boron, iron).
- Plant analysis can help diagnose deficiencies, but should utilize paired good-bad plant samples for confirmation.
- Measured crop yield response is best evaluation tool.

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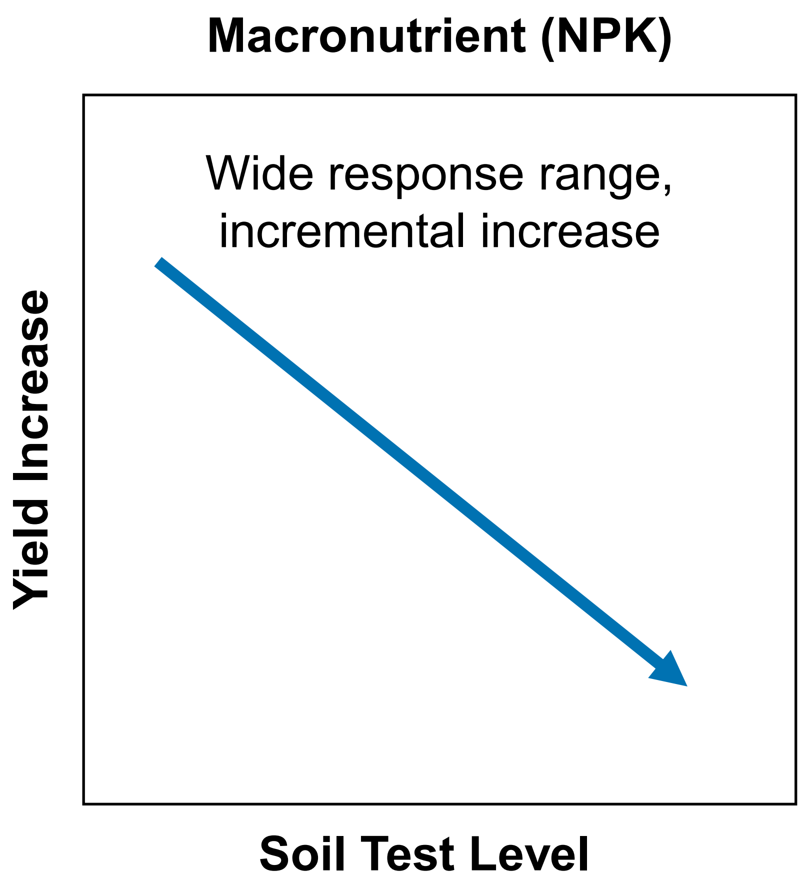
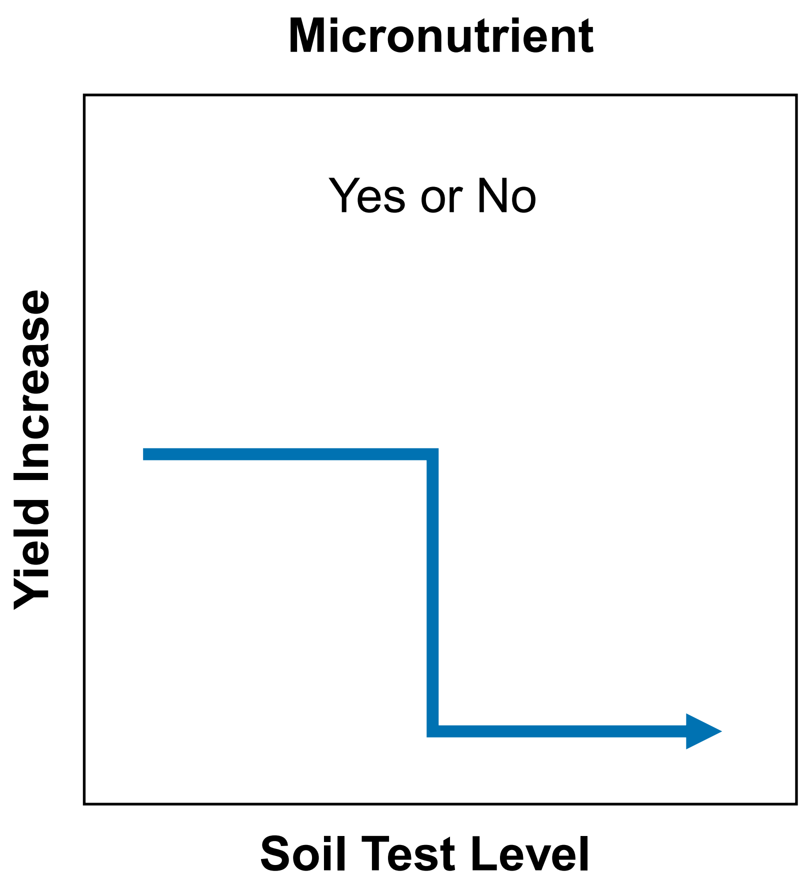
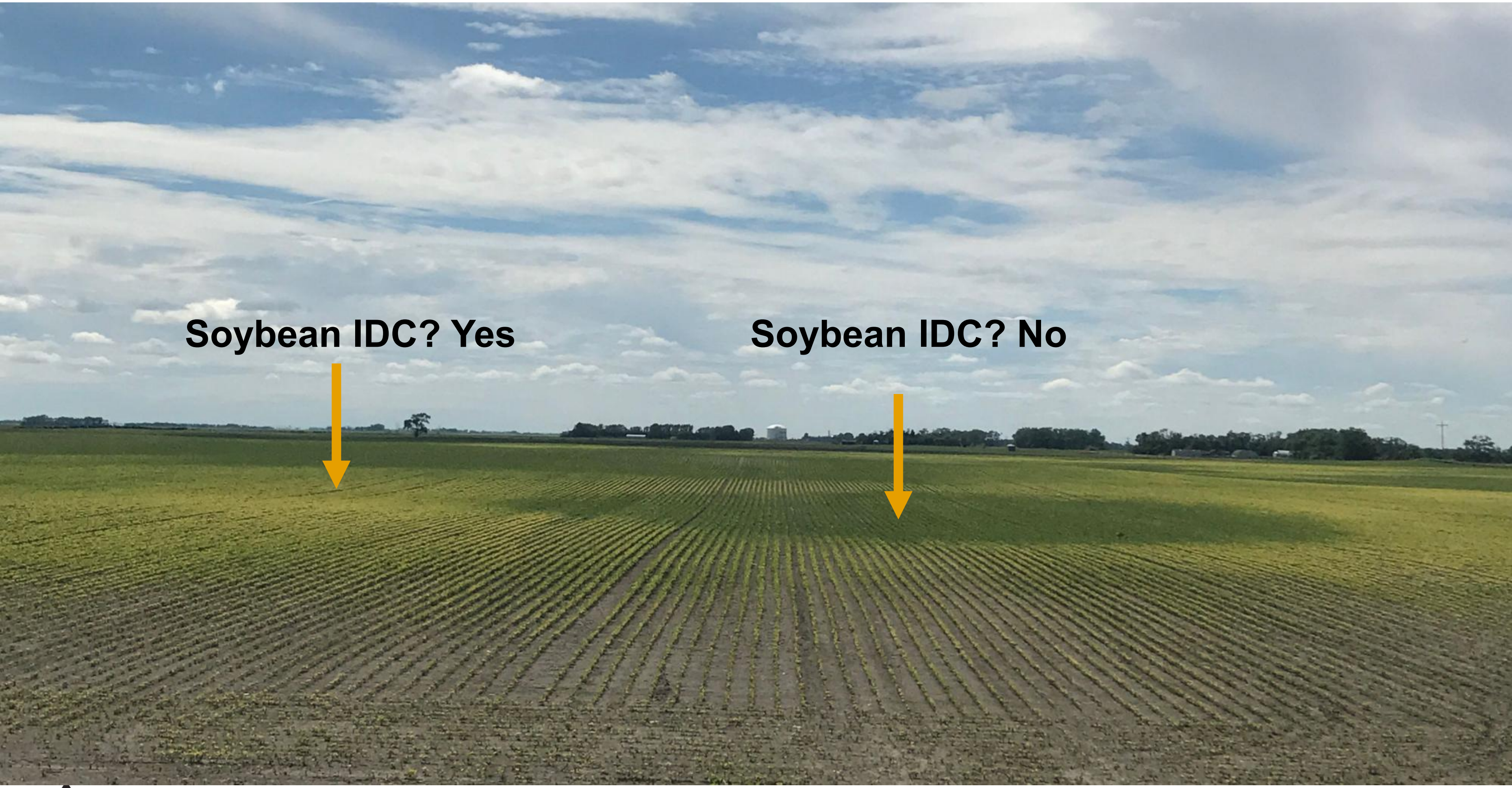
Crop response for macros vs. micros





How stark can those deficiencies be?



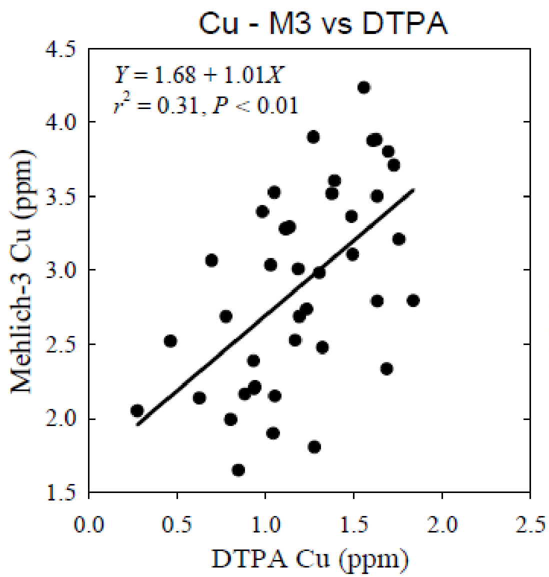
Micronutrients: Boron, Copper, Iron, Manganese, Zinc

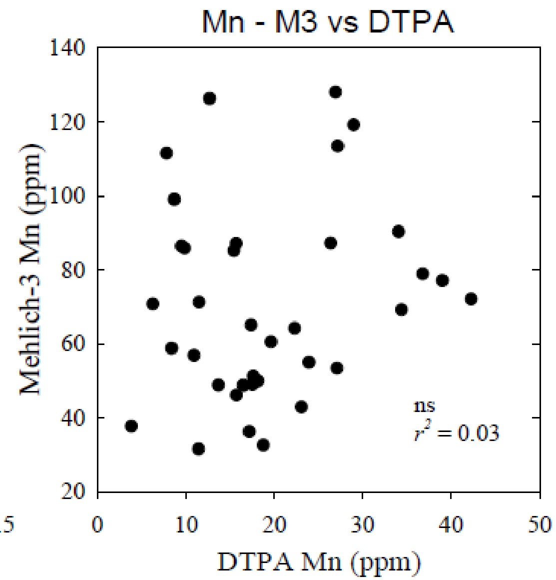
DTPA-sorbitol micronutrient method
Micronutrient crop response is soil- and crop-specific. Use soil test methods with research in our region; some micronutrients may have little research in our region. Use in conjunction with plant analysis to confirm the deficiency.

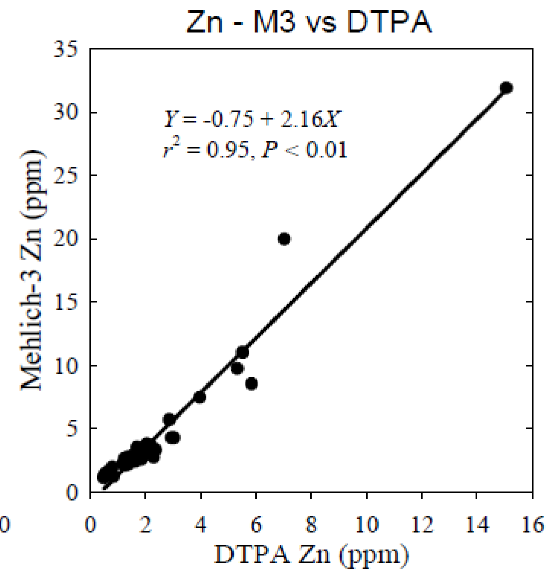
Soil test category	DTPA-sorbitol soil test (ppm)				
	Boron	**Copper**	**Iron**	**Manganese**	**Zinc**
Very Low	<0.40	<0.20	<2.5	<1.0	<0.30
Low	0.41-0.80	0.21-0.40	2.6-5.0	1.1-2.0	0.31-0.60
Medium	0.81-1.20	0.41-0.60	5.1-7.5	2.1-3.0	0.61-1.00
High	1.21-1.60	0.61-0.80	7.6-10.0	3.1-4.0	1.01-2.00
Very High	>1.60	>0.80	>10.0	>4.0	>2.00

Different soil test methods produce different numbers, esp. for micronutrients

All micronutrient research in the North Central Region was done with DTPA method. Mehlich-3 micronutrient soil test data is not correlated in our region.







Mallarino, A.P., J.J. Camberato, D.E. Kaiser, C.A.M. Laboski, D.A. Ruiz-Diaz, and T.J. Vyn. 2015. Micronutrient fertilization for corn and soybean: A research update. Proceedings of the 45th North Central Extension-Industry Soil Fertility Conference. Des Moines, IA. 4-5 Nov. 2015. Intl. Plant Nutr. Inst., Brookings, SD. p. 44-57.

List of most responsive or sensitive crops

Boron	Copper	Iron	Manganese	Zinc
Alfalfa	Barley	Flax	Oat	Corn
Broccoli	Oat	Soybean		Dry Bean
Cauliflower	Wheat		Dry bean?	Flax
Sugar beet	Carrot		Soybean?	Potato
	Onion		Wheat?	
Canola?			Onion?	
Sunflower?				

Not an exhaustive list--focusing on common field and vegetable crops in the North Central region. Consult additional resources on micronutrient deficiencies and crop responses in other fruits, vegetables, and ornamentals.

AGVISE Ag Handbook for micronutrient sensitivities and fertilizer rates

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Agricultural Handbook & Fertilizer Guidelines

2024

Boron Guidelines

Broadcast application only. Do not place boron with seed.

Soil test category	Soil test B	High Sensitivity	Medium Sensitivity	Low Sensitivity
		Alfalfa Broccoli Cauliflower	Birdsfoot trefoil Cabbage Canola Carrot Clover Corn, sweet Potato Sainfoin Sugar beet Strawberry Sunflower Tomato Vegetable garden	Other crops
	ppm, 0-6 inch	lb/acre B		
		broadcast	broadcast	broadcast
Very low	≤ 0.40	3	2	1
Low	0.41 – 0.80	2	1	0
Medium	0.81 – 1.20	1	0	0
High	> 1.20	0	0	0

Chloride Guidelines

A chloride guideline for small grains (barley, oat, rye, triticale, wheat) is generated. A chloride guideline for corn is generated as a trial. If soil chloride (0-24 inch) is less than 40 lb/acre Cl, the chloride guideline will increase the total soil chloride (0-24 inch) plus fertilizer chloride to 40 lb/acre Cl.

Copper Guidelines

Soil test category	Soil test Cu	High Sensitivity		Medium Sensitivity		Low Sensitivity	
		Barley, grain Carrot Onion Vegetable garden Wheat		Alfalfa Barley, hay Birdsfoot trefoil Broccoli Cabbage Canary grass Cauliflower Clover Flax Grass, seed Potato Oat Sainfoin Sorghum Strawberry Sunflower Tomato		Other crops	
	ppm, 0-6 inch	lb/acre Cu					
		broadcast	band	broadcast	band	broadcast	band
Very low	≤ 0.30	5	2	3	1	2	1
Low	0.31 – 0.50	3	1	2	1	0	0
Medium	0.51 – 0.80	2	1	1	0	0	0
High	> 0.80	0	0	0	0	0	0

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AGVISE Ag Handbook available at https://www.agvise.com/resources/guides/

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Guides

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AGVISE Guides

Sampling and General Interpretation

For over 40 years, AGVISE Laboratories has provided our customers with prompt service and valuable agronomic support. To help you reach your full potential in the field, we provide crop fertilizer guidelines for over 70 different crops grown in the upper Midwest and northern Great Plains. The fertilizer guidelines were developed utilizing university and industry research along with the professional experience of AGVISE agronomic staff.

AGVISE Agricultural Handbook and Fertilizer Guidelines

- Soil Sample Preparation Checklist
- Bulk Soil Samples and Pairing Multi-Depth Soil Samples

- Soil Sampling Guide
- Plant Sampling Guide
- Soybean Cyst Nematode (SCN) Sampling Guide

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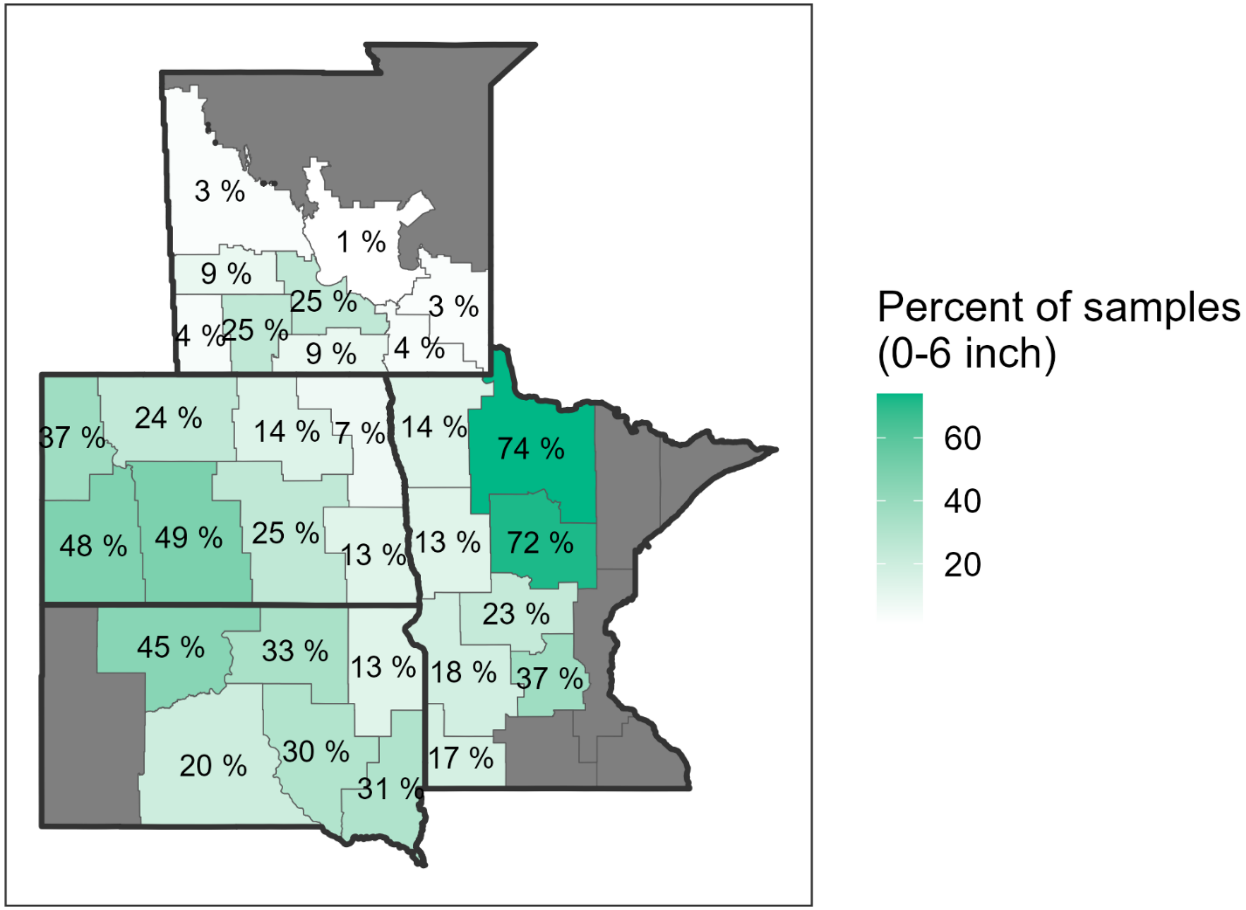
Soil samples with soil test boron below 0.4 ppm in 2025



Data not shown where n< 100
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Boron management

- Sensitive crops: alfalfa, broccoli, cauliflower, sugar beet, canola (?), sunflower (?)
  - Soil test boron less than 0.4 ppm (0-6 inch depth)
  - Depends on soil organic matter and soil texture
  - Often drought-driven deficiency
- Low soil test boron found where:
  - Low soil organic matter, sandy soils
- Boron fertilization
  - Sodium borate (11-20% B), broadcast only, never apply boron with seed
  - Keep rescue foliar rates low (<0.3 lb B/acre), leaf burn possible
  - Boron toxicity: Do not overapply, very effective soil sterilant

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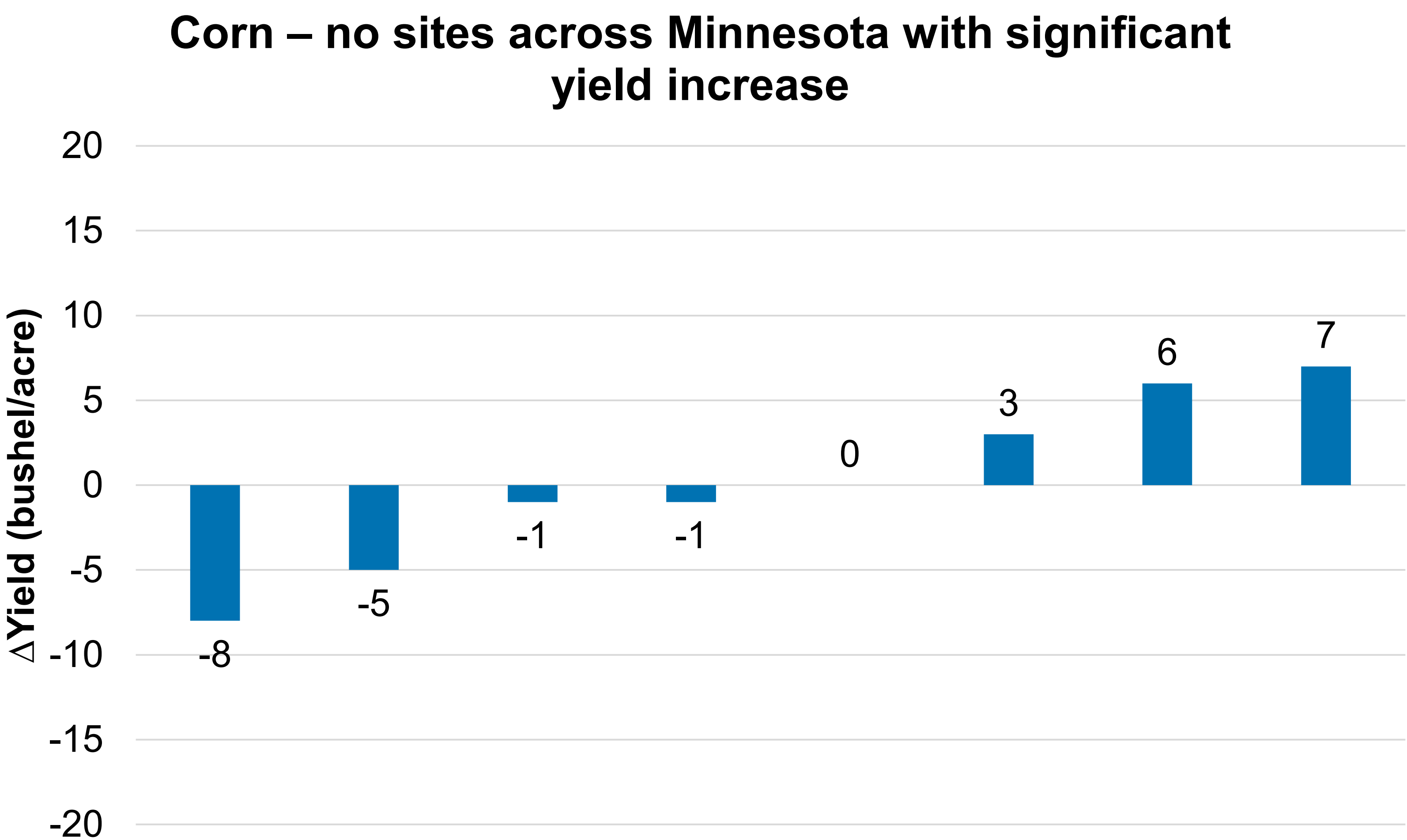
Boron deficiency

Alfalfa
Stunting and chlorosis of upper leaves. Necrosis of growing points.

Sugar beet
Chlorosis and necrosis of new center leaves and growing point. Petioles become fragile and crack.

Kaiser, D.E., C.J. Rosen, and A.K. Sutradhar. 2024. Boron for Minnesota soils. UMN Ext. Circ., Univ. Minnesota, St. Paul, MN. https://extension.umn.edu/micro-and-secondary-macronutrients/boron-minnesota-soils (accessed 8 Dec. 2025)

Crop response to B fertilization Corn (MN) : 2011-2013



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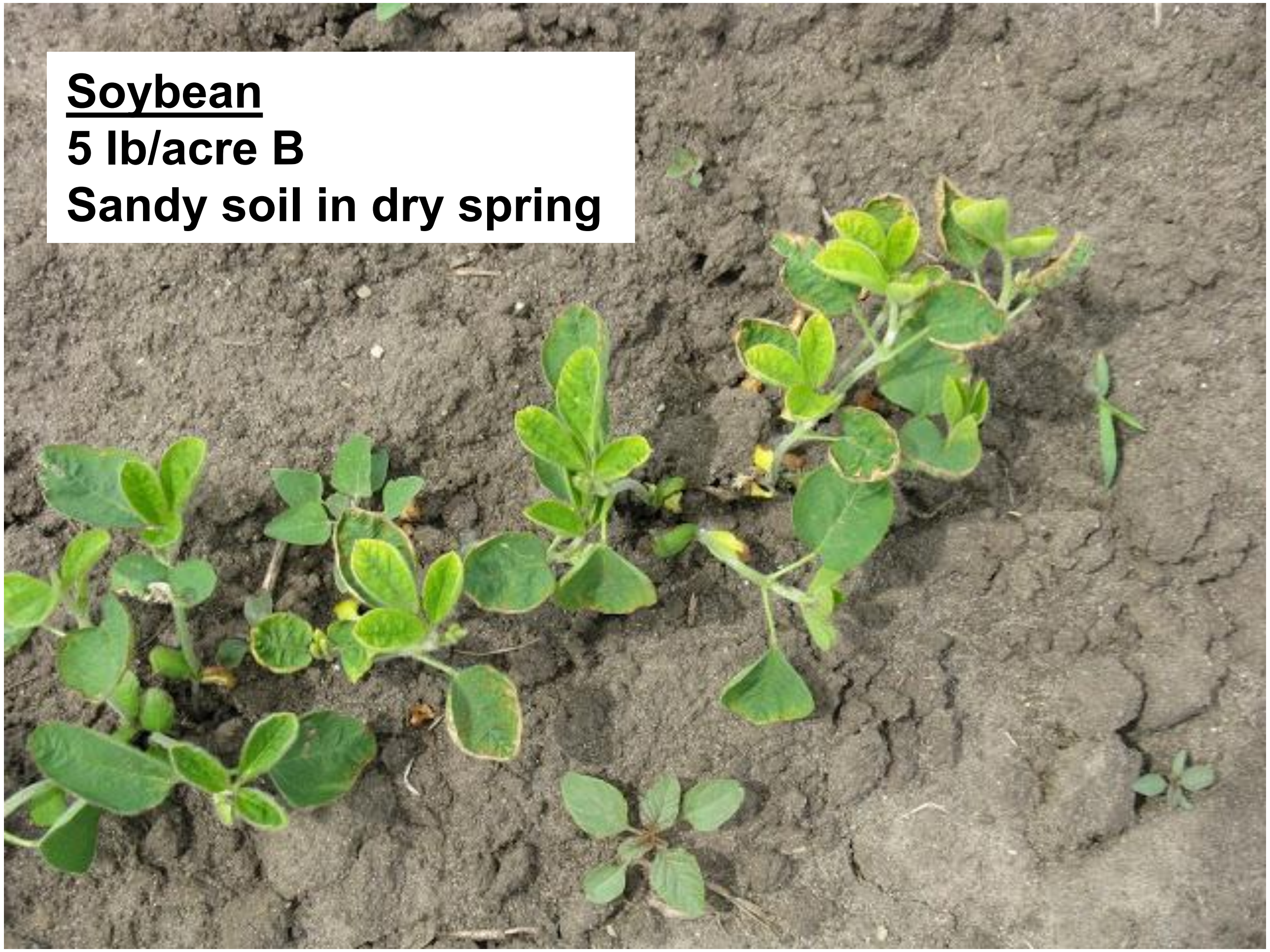
Boron toxicity: Applying too much of a good thing



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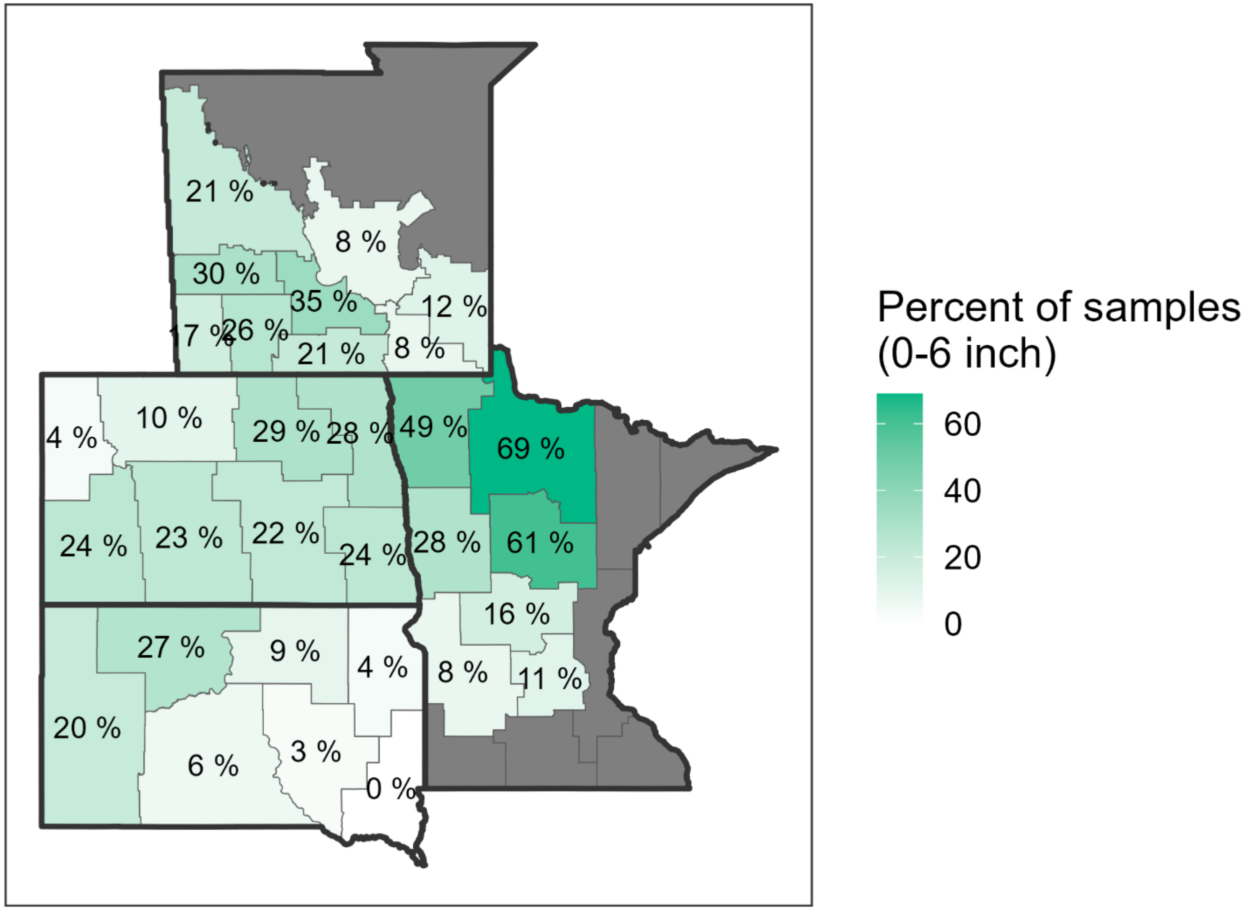
Soil samples with soil test copper below 0.5 ppm in 2025



Data not shown where n< 100
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Copper management

- Sensitive crops: small grains (barley, oat, wheat), carrot, onion
  - Soil test copper less than 0.5 ppm (0-6 inch depth)
  - Disease suppression if deficient (flowering period and potential Fusarium head blight, ergot)
- Low soil test copper found where:
  - High soil pH, low soil organic matter, sandy soils, eroded hilltops
  - High soil organic matter (peat)
- Copper fertilization
  - Copper sulfate (25% Cu), broadcast + incorporate
  - Chelated Cu, seed-placed or foliar

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Copper deficiency

Barley
Pale green coloration to newest leaves. Twisted ‘rattail’ leaves, deformed heads.

Wheat
Pale green coloration to newest leaves. Twisted ‘rattail’ leaves, deformed heads.

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Photographs from Intl. Plant Nutr. Inst.

Manganese management

- Sensitive crops: oat, dry bean (?), soybean (?), wheat (?), onion (?)
  - Soil test manganese less than 1.0 ppm (0-6 inch depth)
  - Depends on soil pH and soil organic matter
  - Crop responses are infrequent and uncommon, local geology important
- Low soil test manganese found where:
  - High soil pH, high soil organic matter (peat), low soil water content
- Manganese fertilization
  - Manganese sulfate (32% Mn), banded or foliar
  - Chelated Mn (EDTA), seed-placed or foliar

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Manganese deficiency

Oat
Gray oval-shaped spots and interveinal streaking, called "gray speck."

Soybean
Interveinal chlorosis in newest leaves, then necrosis. Similar to Fe deficiency.

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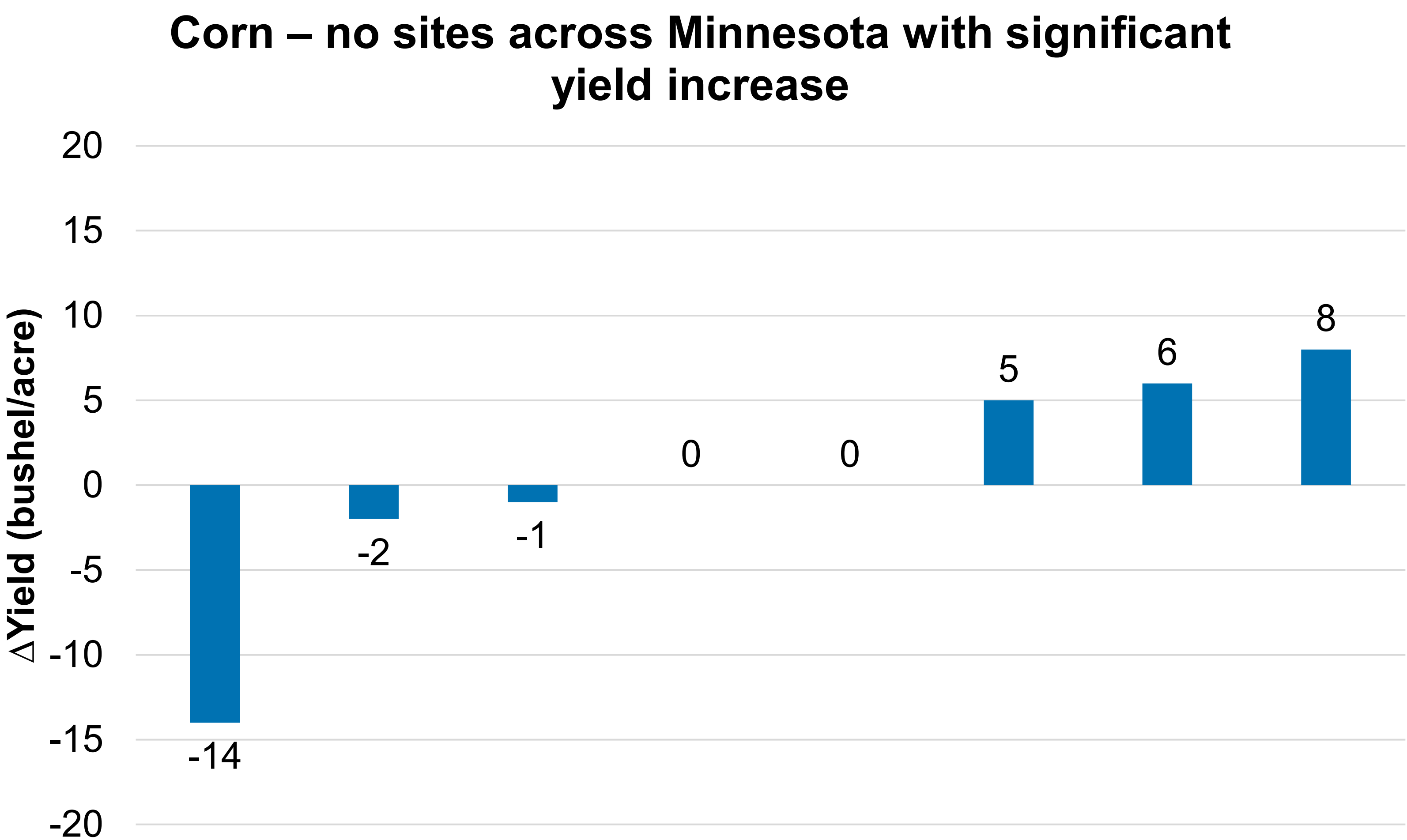
Photographs from https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-oats and Intl. Plant Nutr. Inst.

Crop response to Mn fertilization Corn (MN): 2011-2013



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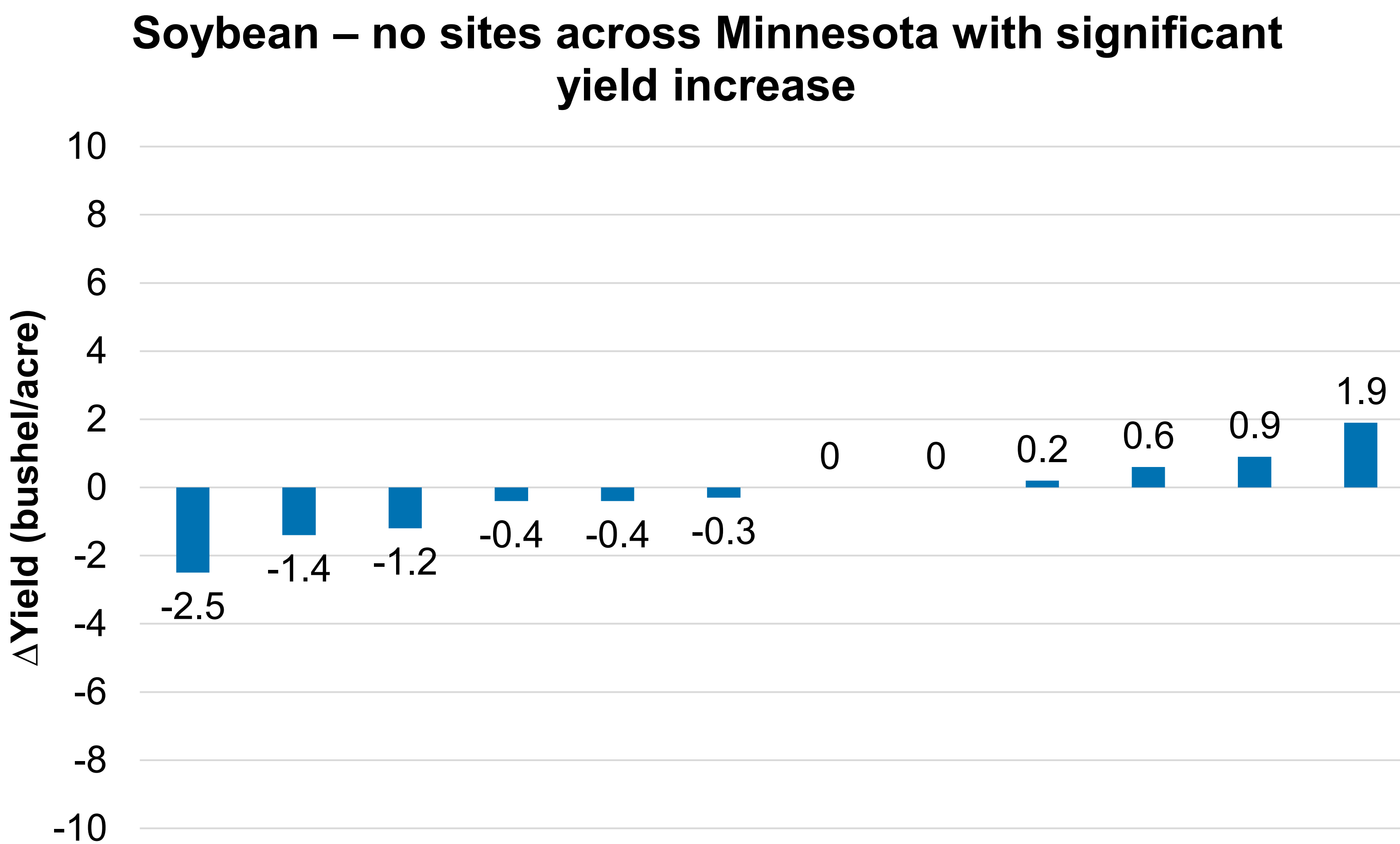
Crop response to Mn fertilization Soybean (MN): 2013-2014



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Manganese toxicity

- Excess Mn^{2+} in soil, problem in acidic soils with pH < 5.5, often during "wet" periods
- Similar to aluminum toxicity in acidic soils
  - Managed with liming and crop choice
- Diagnosed with paired good-bad soil and plant samples

Mn toxicity in canola

Image from https://www.canolacouncil.org/canola-watch/2016/06/23/when-you-see-something-new/ (accessed 5 Jan. 2026)

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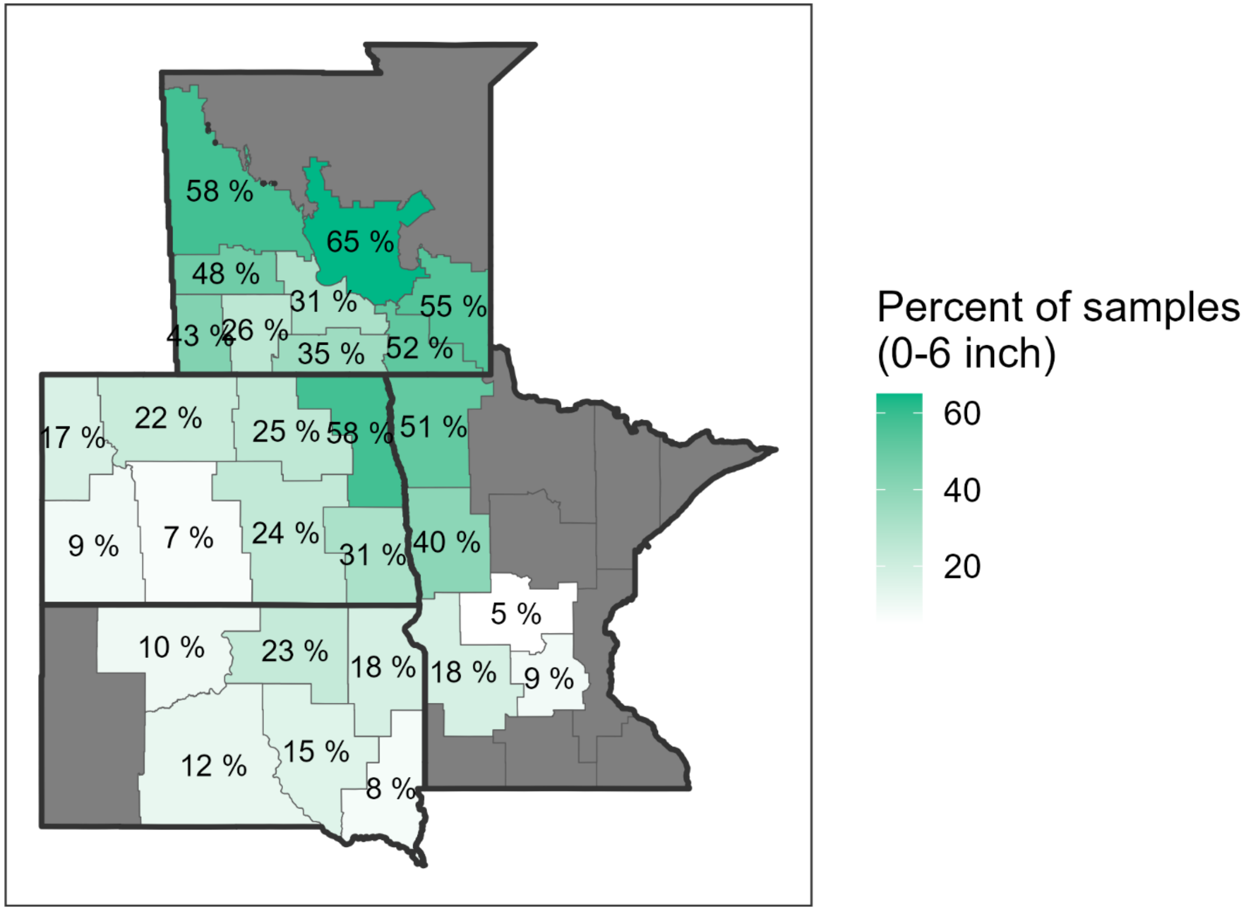
Soil samples with high soybean iron deficiency chlorosis risk in 2025



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Iron management

- Sensitive crops: flax, soybean, dry bean (?), potato (?)
  - Depends on soil pH and carbonate content
  - Worsened by soil salinity and high soil nitrate
- Low iron availability found where:
  - High soil pH, high carbonate
- Iron fertilization
  - Choose resistant varieties
  - Chelated Fe (EDDHA or HBED), seed-placed

AGVISE Soybean IDC Risk Index

	Soybean IDC risk potential		
EC(1:1)	**Calcium carbonate equivalent (CCE)**		
dS/m	**< 2.5 %**	**2.6 – 5.0 %**	**> 5.0 %**
< 0.25	Low	Low	Moderate
0.26 – 0.50	Low	Moderate	High
0.51 – 1.00	Moderate	High	Very high
> 1.00	Very high	Very high	Extreme

Based on observations and soil samples from 103 fields (2001)

Foundational research from Franzen, D.W., and J.L. Richardson. 2000. Soil factors affecting iron chlorosis of soybean in the Red River Valley of North Dakota and Minnesota. J. Plant Nutr. 23(1):67–78.

Manage soybean IDC with soil testing

Identify fields with low IDC risk

- Soil test for carbonate and salinity
- Choose low IDC risk fields

Mitigating moderate to high IDC risk

1. Variety selection
2. Variety selection
3. Variety selection
4. Wider rows (plants closer together reduces IDC)
5. Apply high-quality chelated Fe (EDDHA) with seed
6. Plant companion cereal with soybean (uses excess water and nitrate)

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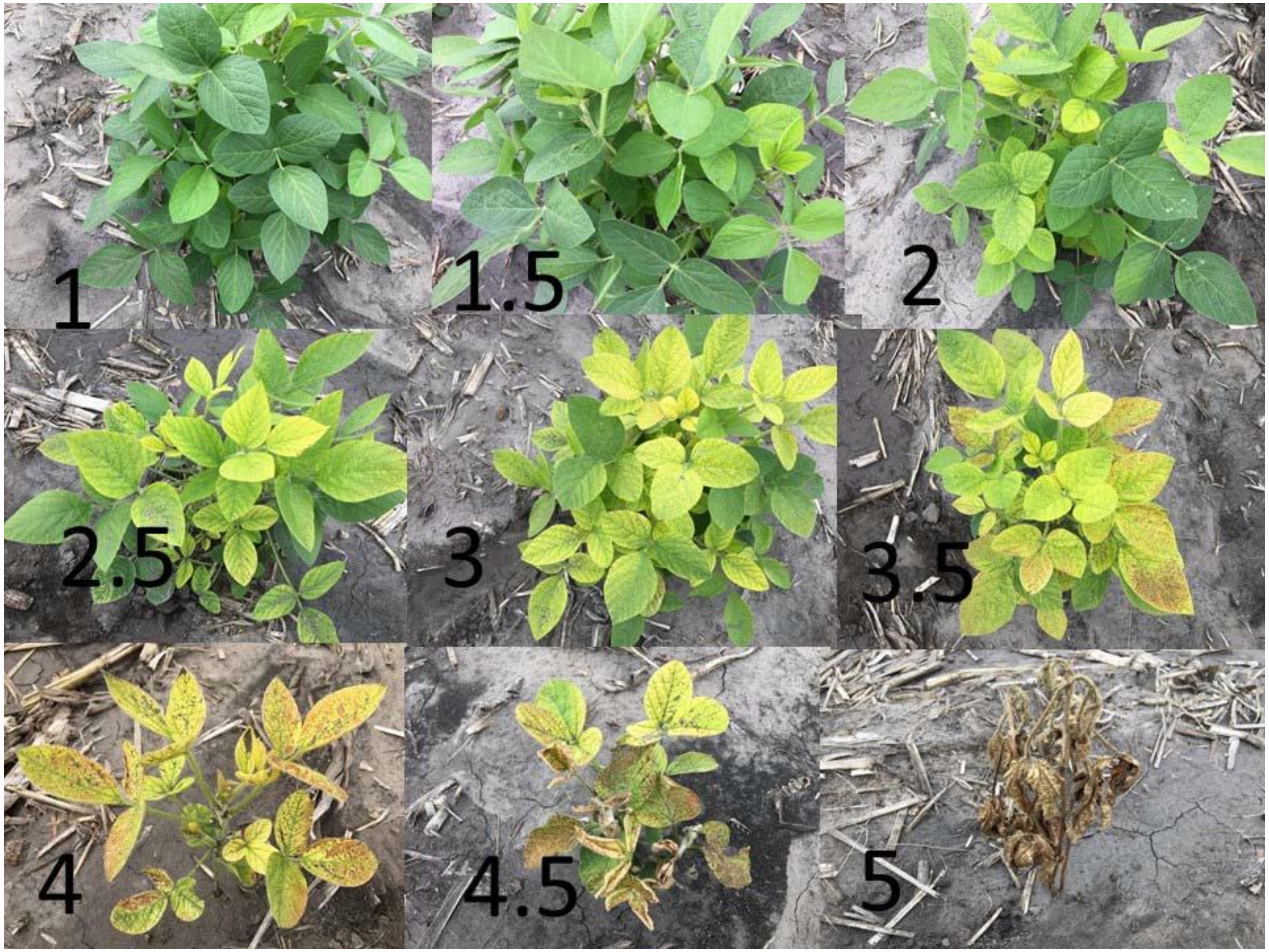
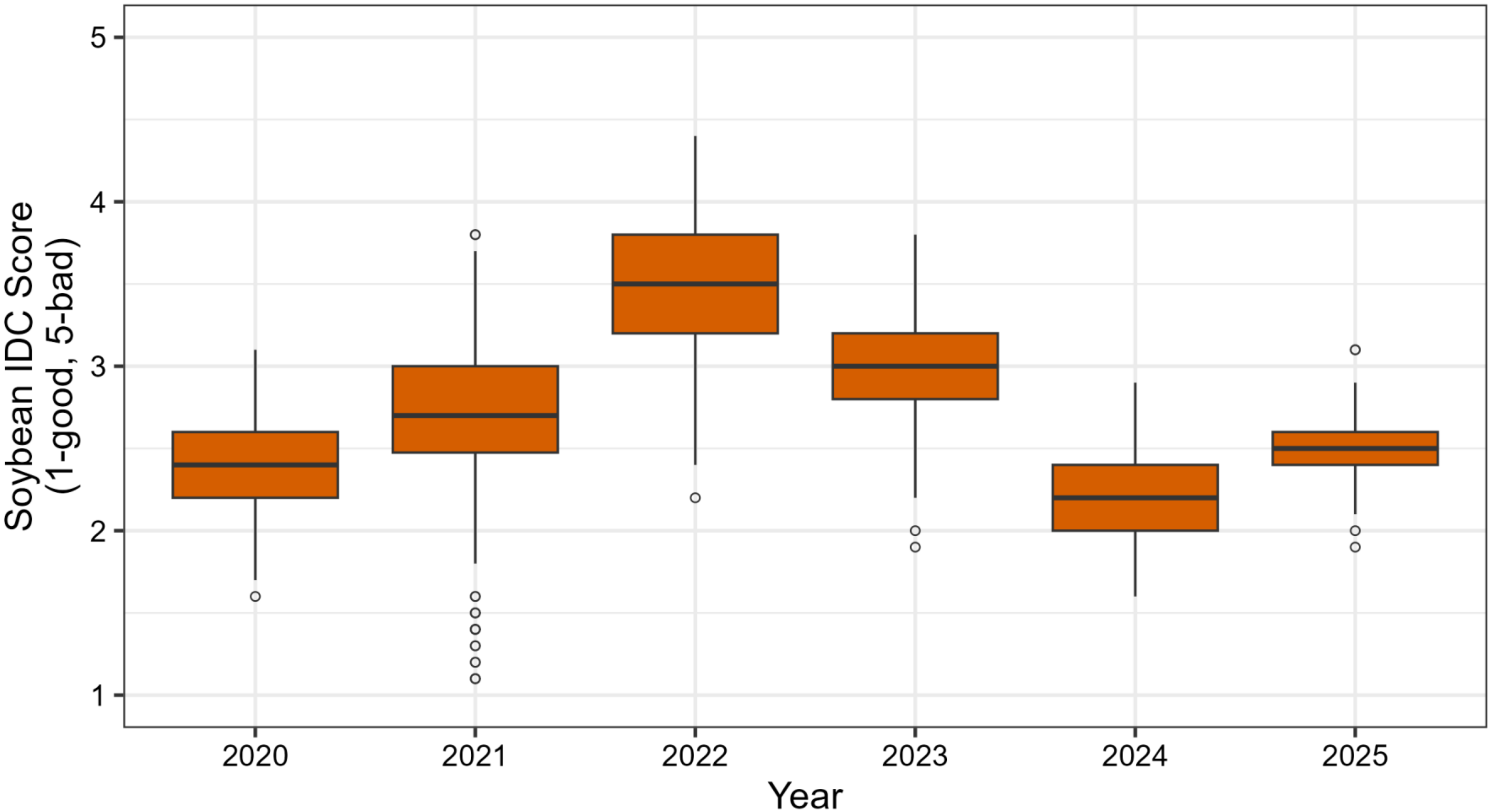
NDSU soybean IDC rating scale for variety selection



NDSU Soybean IDC Trials

Summary of all HT soybean varieties submitted for evaluation



Adapted from NDSU Soybean Variety Trials, 2020-2025.
Includes Enlist, LLGT27, RR, Xtend.

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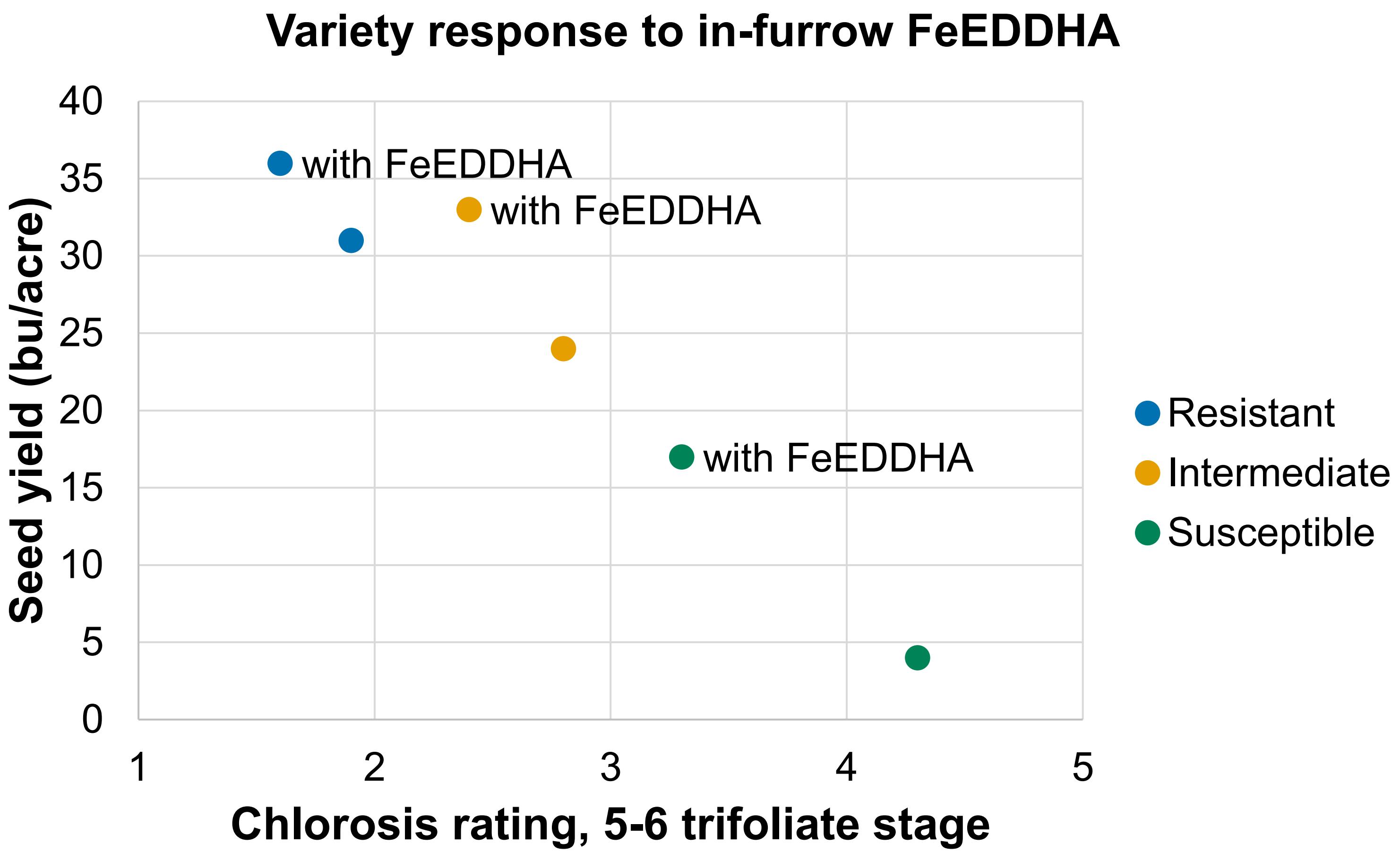
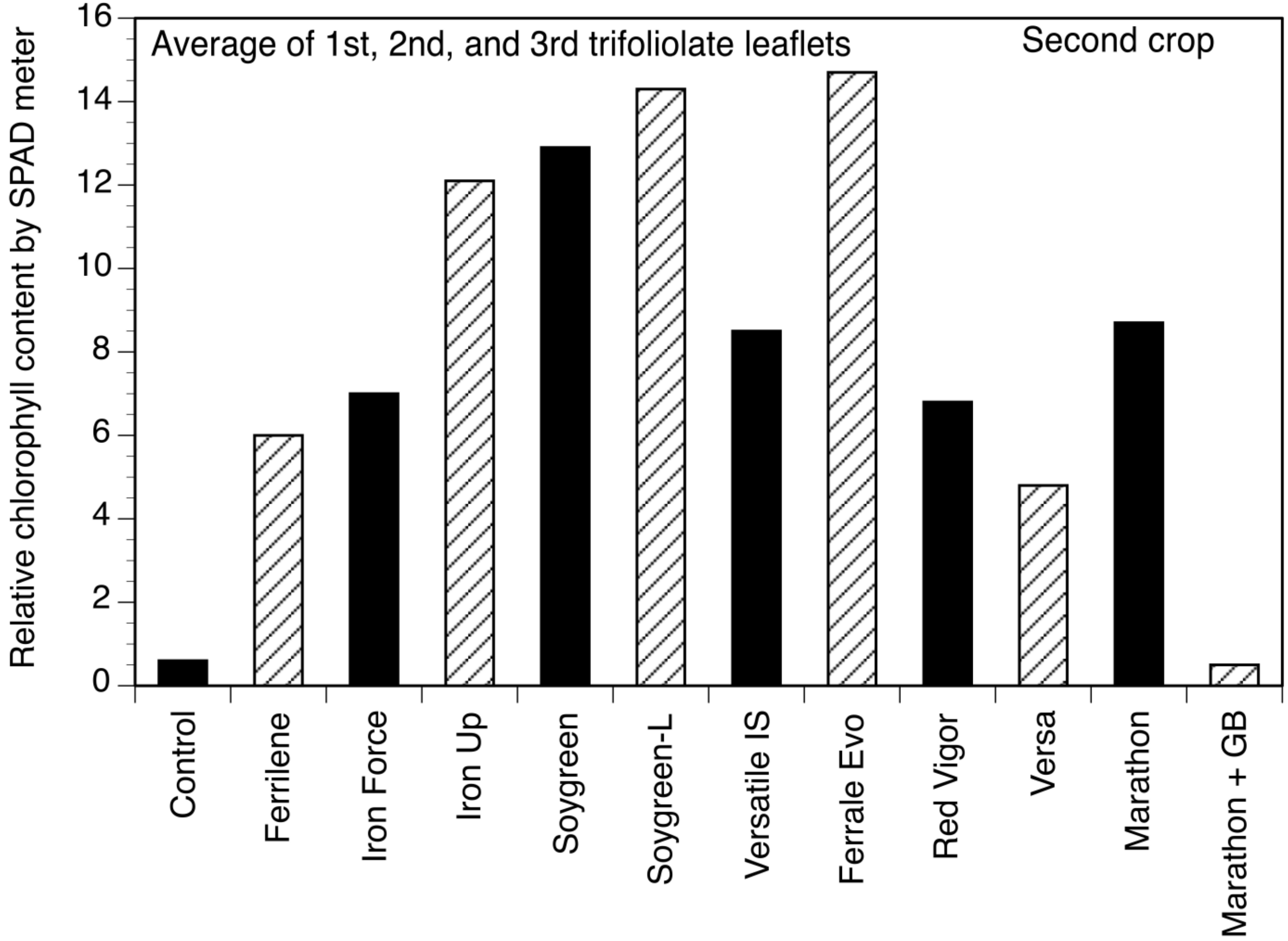
FeEDDHA can help with resistant and susceptible varieties



Goos, R.J. 2018. Iron deficiency chlorosis: Soil and plant answers to a Festering problem. In: Endres, G. and Glogoza, P., chairs, 26th Advanced Crop Advisers Workshop, Fargo, ND. 13-14 Feb. 2018. North Dakota State Univ., Fargo, ND; Univ. Minnesota, St. Paul, MN.
Goos, R.J., and B.E. Johnson. 2000. A comparison of three methods for reducing iron-deficiency chlorosis in soybean. Agron. J. 92(6):1135–1139.

Know your FeEDDHA quality



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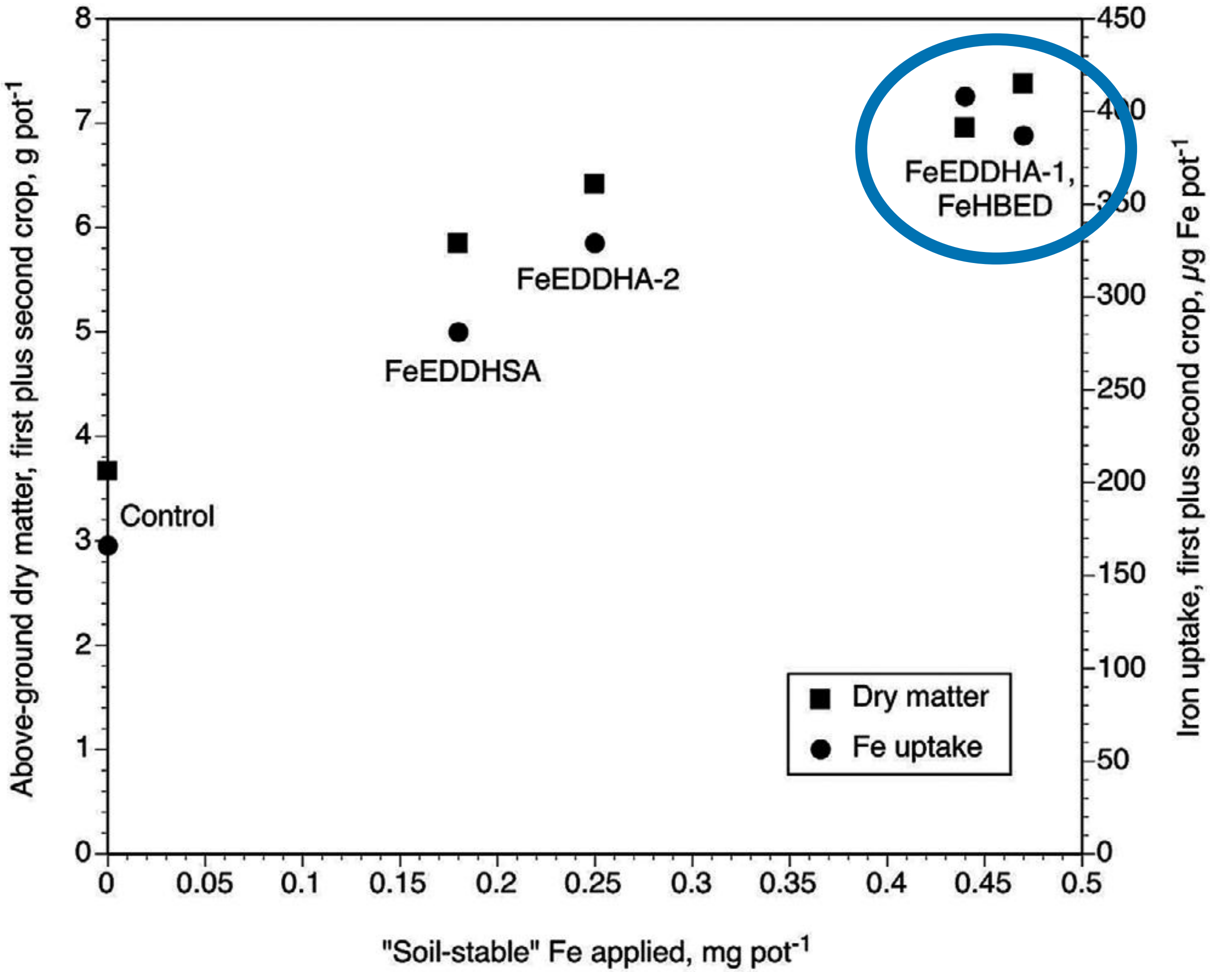
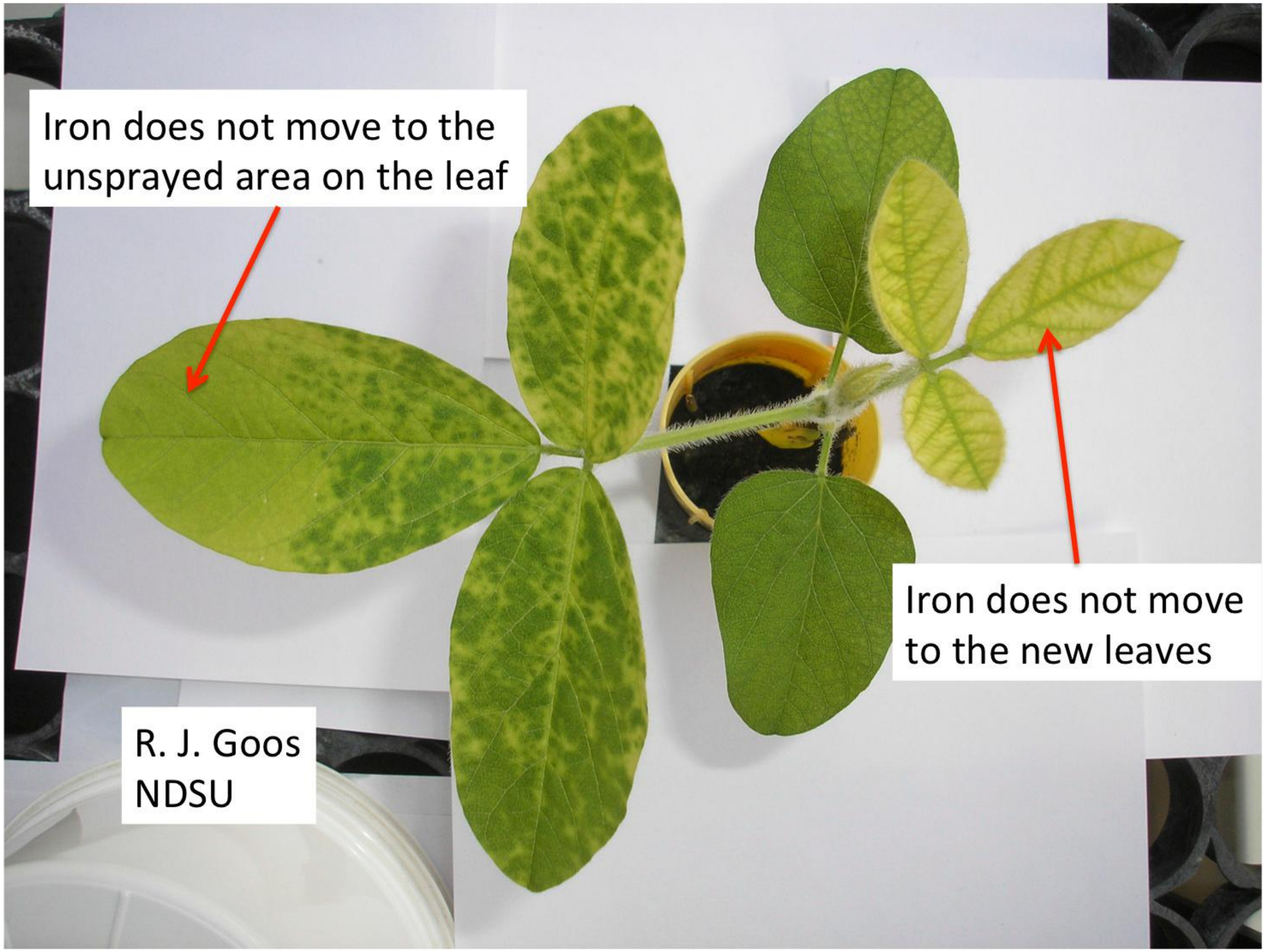
New iron fertilizers?

FeHBED performs the same as a high-quality FeEDDHA



Goos, R.J. 2021. Laboratory and greenhouse evaluation of four iron fertilizer sources. Agric. Environ. Lett. 6(4): e20052.

Foliar Fe not effective for rescue



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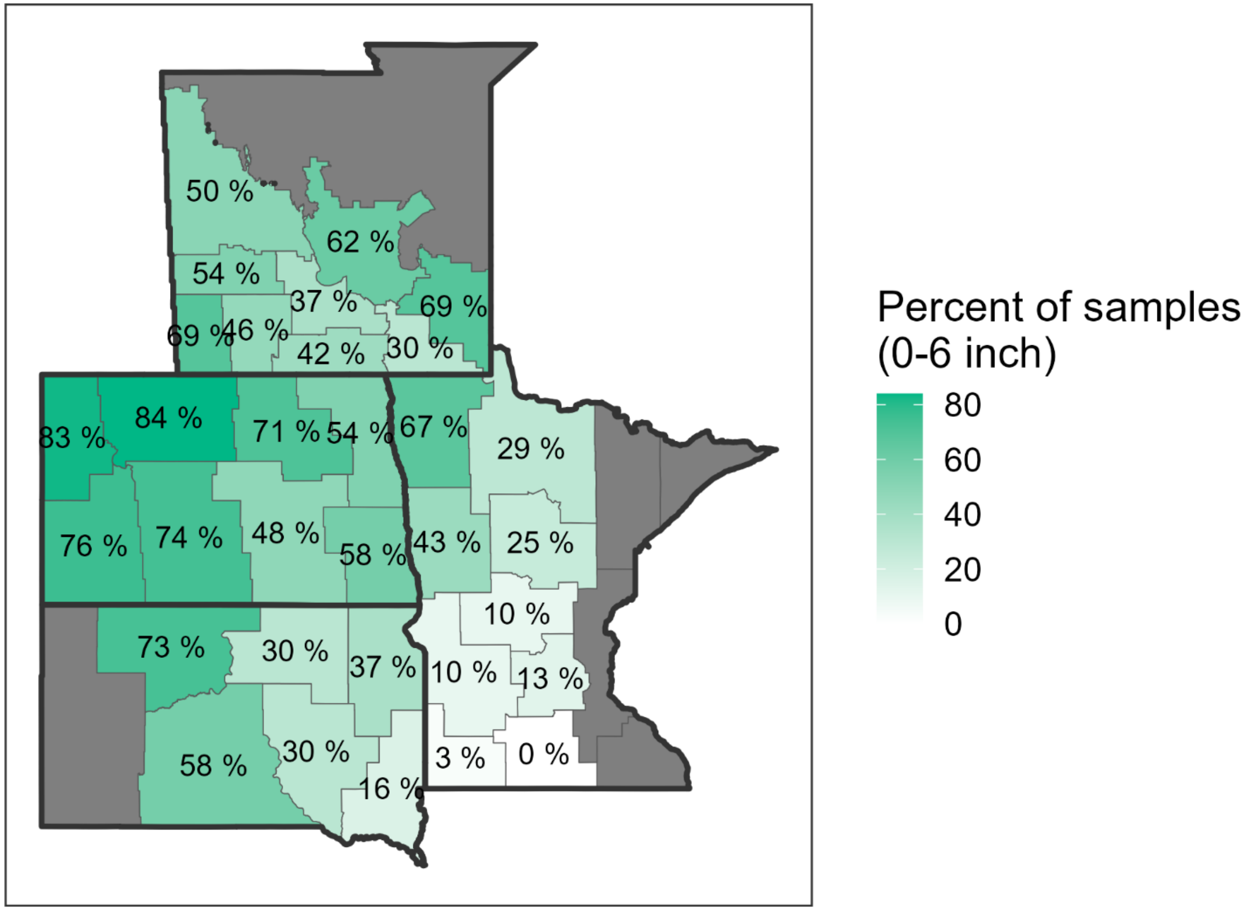
Soil samples with soil test zinc below 1.0 ppm in 2025



Data not shown where n< 100
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Zinc management

- Sensitive crops: corn, dry bean, flax, potato
  - Soil test zinc less than 1.0 ppm (0-6 inch depth)
- Low soil test zinc found where:
  - High soil pH, high carbonate, erosion
  - Lack of Zn fertilizer use history because of infrequent Zn-sensitive crop production

- Zinc fertilization
  - Zinc sulfate (36% Zn), broadcast + incorporate
  - Zinc-containing P fertilizer, broadcast or seed-placed
  - Zinc-ammonia complex, seed-placed
  - Chelated Zn (EDTA), seed-placed
  - Manure sources (diet dependent)

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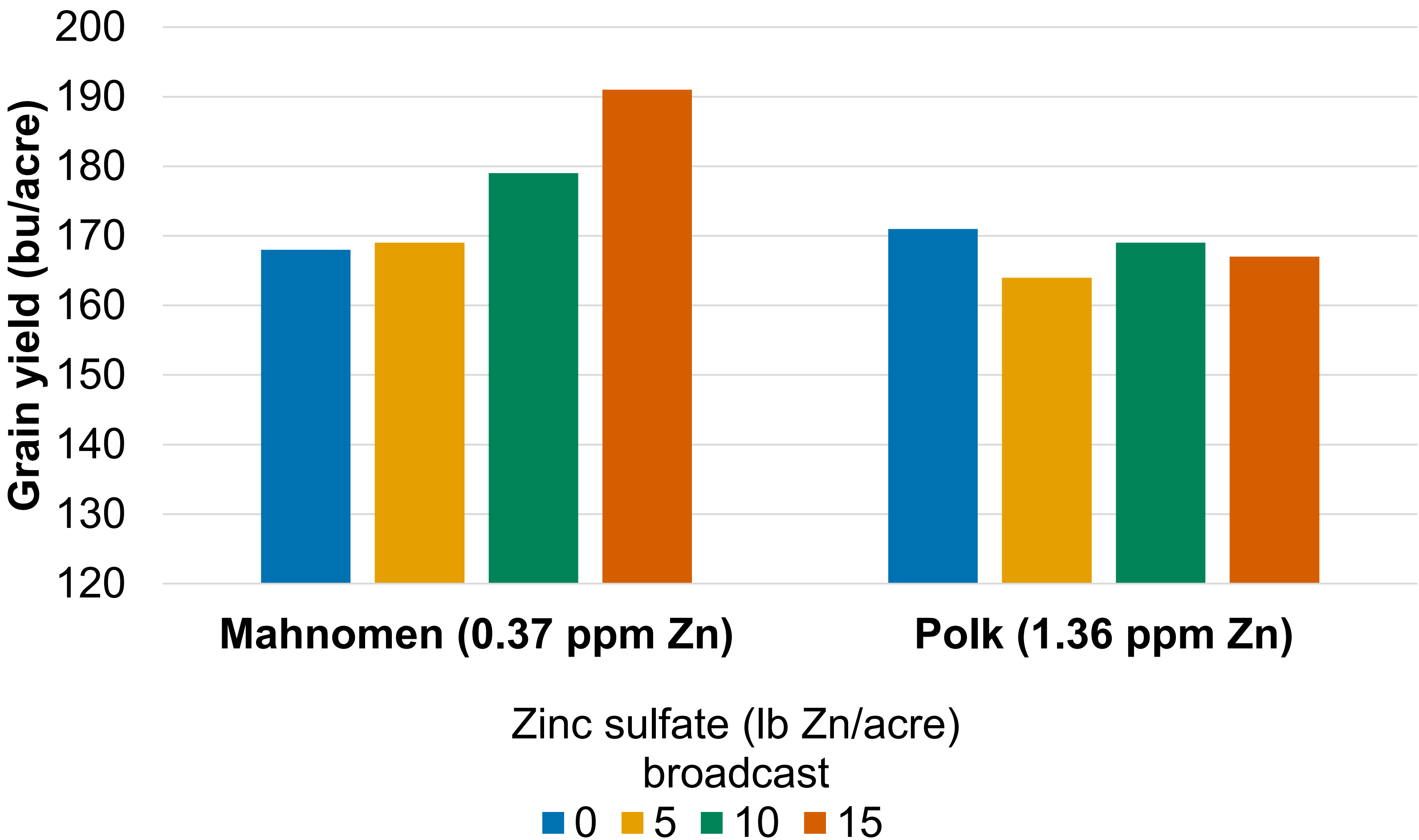
Corn yield response to zinc Minnesota



Sutradhar, A.K., D.E. Kaiser, and C.J. Rosen. 2016. Zinc for crop production. UMN Ext. Circ., Univ. Minnesota, St. Paul, MN. https://extension.umn.edu/micro-and-secondary-macronutrients/zinc-crop-production (accessed 22 Jan. 2021)

Fallow syndrome and zinc

- Concern when following fallow or a non-mycorrhizal crop like canola or sugar beet
- Poor colonization of mycorrhizal fungi to facilitate P and Zn uptake
- Include starter Zn if following with a Zn-sensitive crop

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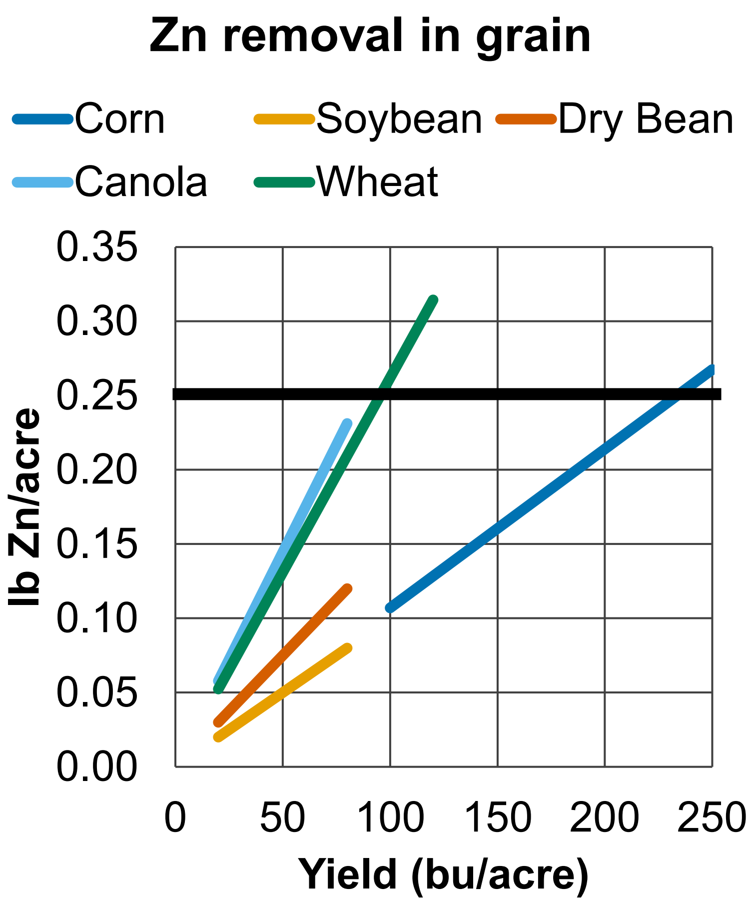
Photographs from Intl. Plant Nutr. Inst.

Zinc crop removal and balance



Zn balance

Crop	Yield bu/acre	Zn rem. lb/acre	Zn add. lb/acre
Corn	200	-0.21	0.25
Soybean	50	-0.05	0
Wheat	80	-0.21	0
Dry Bean	50	-0.08	0.25
		-0.55	**+0.50**

1 quart/acre ZnEDTA (9%) = 0.25 lb Zn/acre

Canola bushel weight: 50 lb/bu, 3000 lb/acre = 60 bu/acre
Dry bean bushel weight: 60 lb/bu, 3000 lb/acre = 50 bu/acre

Micronutrient overview

- Crop responses to micronutrients are very crop- and soil-specific.
  - Some crops are not responsive, while others are VERY responsive—if deficient.
  - Additional factors (e.g., soil pH, soil texture, soil organic matter) should be considered in predicting crop response probability.
- Predicting crop response with soil testing requires local correlation/calibration research.
  - Document if micronutrient deficiency exists under local conditions.
  - Guidelines to predict crop response to fertilization.

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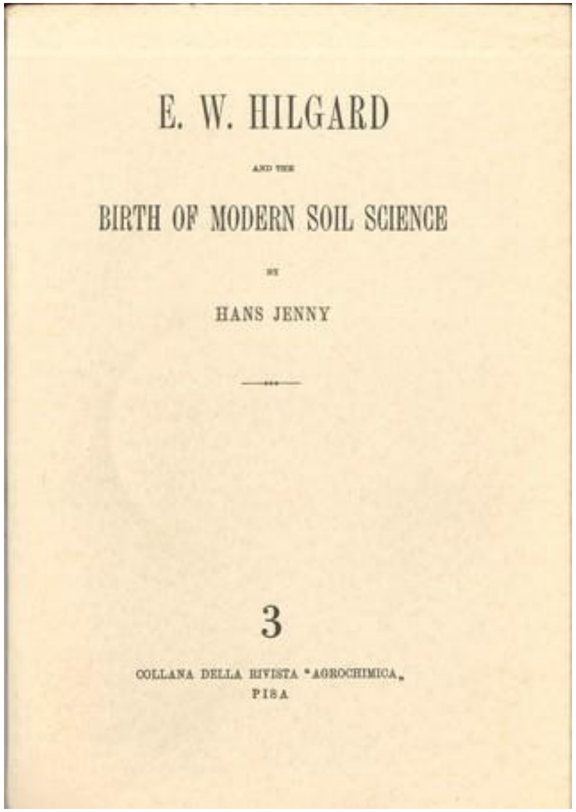
E. W. HILGARD

AND THE

BIRTH OF MODERN SOIL SCIENCE

BY

HANS JENNY

3

COLLANA DELLA RIVISTA "AGROCHIMICA"
PISA

"It is our right to use, but not abuse, the inheritance which is ours, and to hand it down to our children as a blessing, not as a barren, inert incubus, wherewith to drudge through life as a penalty for their fathers' wastefulness.

"That no land can be permanently fertile, unless we restore to it, regularly, the mineral ingredients which our crops have withdrawn.

– E.W. Hilgard (1860), *Report on the Geology and Agriculture of the State of Mississippi*

Thank you for your kind attention!

Are there any questions?

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