Food for Thought: Heavy Metals and Field Crops

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N P K
Greater yield in the field
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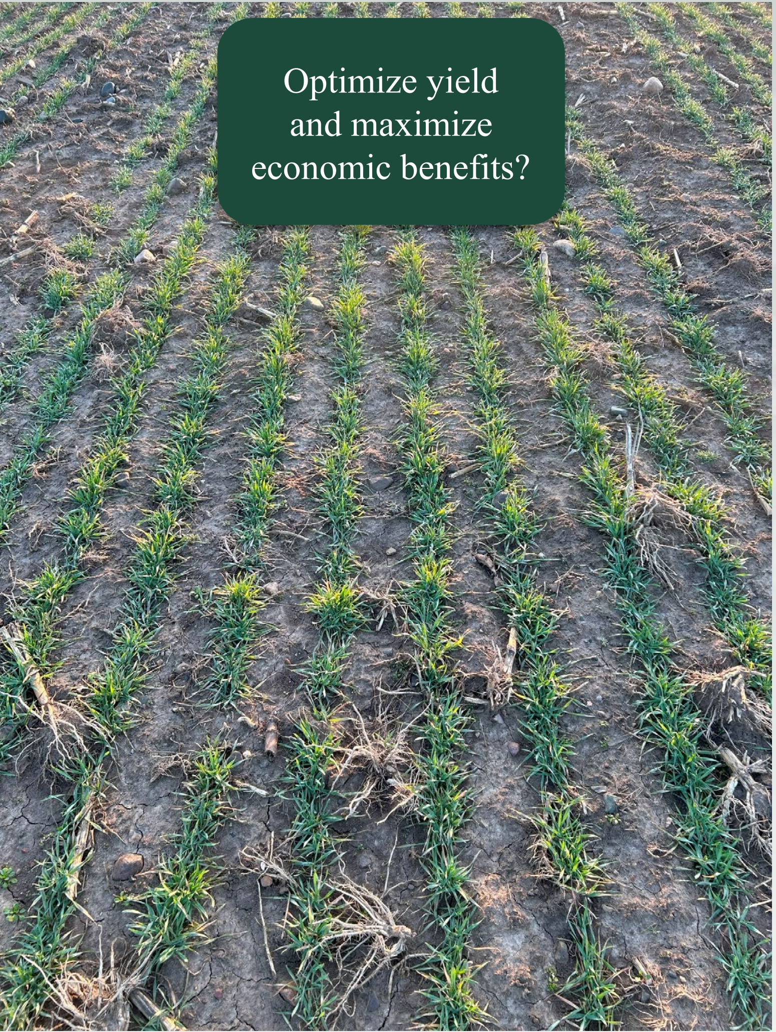


Optimize yield and maximize economic benefits?

Safe and healthy food

2021 Congressional Staff Report - high levels of **arsenic (As) 90-180 ppb, cadmium (Cd) 20-260 ppb, and lead (Pb) 10-352 ppb** found in store-bought infant foods.

Metals and Metalloids

- Ubiquitous in agricultural ecosystems
  - Both toxic and nutritional metals
  - Uptake through soil
  - Transfer through food chain and dietary intake
- Both lack of AND excess can lead to adverse health effects
- Entire metallome may require mgmt. to enhance nutrition and food safety

Closer to Zero Action Plan (US FDA)

- Reduce exposure to heavy metals from foods eaten by infants and young kids to LOWEST levels possible (will extend to other consumers)
- 2021: Govt report on high levels of As, Cd, and Pb found in infant foods and potential neurocognitive impairment from these metals
- <u>FDA will set maximum action levels for these metals in food which will impact both grower and processor</u>

Health risks of As, Pb, and Cd exposure

- As concentration > 5 ppb “showed significant reductions in Full Scale IQ, Working Memory, Perceptual Reasoning and Verbal Comprehension scores.” [1]
- Neurological effects from high levels of Pb exposure during early childhood include learning disabilities, behavior difficulties, and lowered IQ.[4]
- Cd uptake from carrot roots was 12x more for children (> 5x for men, 8x for women). [2] Cd exposure negatively affected children’s full-scale IQ, particularly among boys (↓ 7 points). [3]

Table III. Health risk assessments for Spelter residents consuming radish, carrot, spinach, and lettuce grown on gardens close to smelter facility

Elements	Regulatory limit			Radish			Carrot			Spinach			Lettuce		
	Men	Women	Children	Men	Women	Children	Men	Women mg kg^{-1} y^{-1}	Children	Men	Women	Children	Men	Women	Children
Pb[a]	1·30	1·30	1·30	0·41	0·58	0·90	0·80	1·12	1·75	0·11	0·15	0·23	0·29	0·40	0·63
Zn[b,c]	57·35	58·40	57·03	4·90	6·86	10·72	40·67	56·94	89	8·18	11·46	17·90	52·83	73·96	115·57
Cd[a,c]	0·36	0·36	0·36	0·07	0·10	0·16	2	3	4·59	0·19	0·27	0·41	0·44	0·61	0·96
Cu[d]	4·69	6·57	5·02	0·09	0·13	0·20	1·36	1·90	3	0·10	0·16	0·22	1·35	1·90	2·96

[a]Villatoro-Pulido *et al.* (2009).
[b]Rucker & Storms (2002).
[c]World Health Organization (2007).
[d]Stern (2010).

[1] Wasserman, G. A., Liu, X., LoIacono, N. J., Kline, J., Factor-Litvak, P., van Geen, A., ... & Graziano, J. H. (2014). A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren. Environmental Health, 13, 1-10.
[2] Roy, M., & McDonald, L. M. (2015). Metal uptake in plants and health risk assessments in metal-contaminated smelter soils. Land degradation & development, 26(8), 785-792.
[3] Gustin, K., Tofail, F., Vahter, M., & Kippler, M. (2018). Cadmium exposure and cognitive abilities and behavior at 10 years of age: a prospective cohort study. Environment international, 113, 259-268.
[4] Food and Drug Administration, Lead in Food, Foodwares, and Dietary Supplements (online at www.fda.gov/food/metals-and-your-food/lead-food-foodwares-and-dietary-supplements) (accessed Mar. 11, 2024)

Why the Concern Now?

- Increased regulatory scrutiny concerning food consumed by infants and young children with arsenic (As), cadmium (Cd), and lead (Pb)
- Gerber (Nestle) initiated meetings
  - Investigated affected fields and identify problem:
  - Fields tested prior to plant
    - Soils with high HM and low pH already excluded
    - Hotspots exist where crops accumulate higher rates than soils contain (high tissue levels despite non-contaminated sites)
    - Crop rejection
    - WHY?

Existing (Pre-Plant) Steps to Mitigate Risk

- Fields tested for Persistent Organic Pollutants (POPs) – 1960's
- Fields tested for HM's – early 2000's
- Restricting fields biosolids applications within ~3 years
  - Questions persist on time interval – PFAS?
- Ascertain field history
- Solar sites?

Why Grower Concerns?

- 1/1/24: California-Baby food products sold or made in state must be tested for HM's
- 1/1/25: California-HM results must post on manufacturer's website; HMs > threshold must have QR code on package
- Other commodity concerns
- To ensure safe food supply, need to understand what drives HM uptake
  - What are HM crop uptake patterns?

Why Grower Concerns?

- Complex issue –
  - **NOT DRIVEN SIMPLY BY PRESENCE of HM**
  - Crop species, soil type, topography, climate variability all impact
  - Collaboration across entire food chains
    - Growers need to understand where and how to grow specific crops
    - Processors must understand where to source certain foods and processing methods
    - Consumers need education and awareness

USDA-AFRI Grant: "How Food Crops Become Contaminated with HM's"

- Focuses on 2 baby foods (carrots and wheat) - Both common ingredients in baby food and large prod. areas in MI
- **How can growers mitigate HM uptake?**
  - Long-term, breeding efforts may prevail
    - Sweet potato: variety specific, root biomass, CA1 gene expressed or not
- Can we use soil amendments to immobilize HMs or foliar sprays of metal uptake inhibitors as targeted intervention?
  - Can we decrease the bioavailable fraction of HMs by sorption, complexation, precipitation, ion exchange, etc….

Objectives

- Evaluate the effectiveness of individual and combined soil amendments in mitigating plant uptake of heavy metals
- Assess plant uptake patterns and the spatiotemporal variability of heavy metal (As, Pb, and Cd) uptake from soil and winter wheat grain
- Varietal differences

Fig. 1: Organic amendments and inorganic fertilizers, L-R: dairy compost, gypsum, urea, ag. lime, biochar, ZnSO4

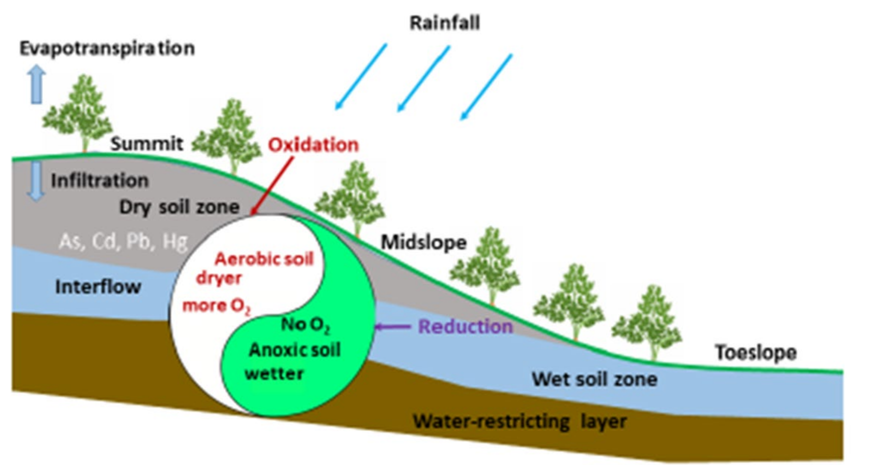


Fig. 2. Field topography as a critical macroscale parameter controlling soil water dynamics and the mobilization and plant uptake of heavy metals.

Mitigating Uptake and Bioavailability of Heavy Metals in Winter Wheat using Inorganic Fertilizers and Organic Amendments

- One-way RCBD with 4 replications with 100 lbs. N/A at green-up except for check and N trt's

Treatments	Aim	Amount, timing and applications
Check (negative control)	----	NA
EDDS (positive control) (35% in 100mL of water)	Increase HM uptake	2mmol / L, 30 GPA at Feekes 5, + 1 week, + 2 weeks
Inorganic Fertilizer		
Agricultural lime (32% Ca)	Soil pH	2 tons/A, pre-plant broadcast
Gypsum (23.3% Ca and 18.6% S)	Cation substitution	1 ton/A, pre-plant broadcast
N rates (low, medium, high) (46-0-0)	Growth dilution/concentration	50 lbs N, 100 lbs N, 150 lbs N /A at green-up
Zinc sulfate granular (35%, 19.5% S) foliar (4.5% S, 10% Zn)	Direct element competition	10 lbs Zn/A, pre-plant broadcast 1 pint/A, foliar at Feekes 9
Organic amendments		
Dairy compost	Active OM	5 tons/A fresh weight, pre-plant broadcast
Wood-based biochar	Inert OM	2 tons/A dry, pre-plant broadcast

Measurables Collected

- **Growth**
  - Tiller population (1ft^2) at Feekes 4
  - Head counts (1ft^2) at Feekes 11
  - Peduncle length at Feekes 11
  - Plant height at Feekes 11
  - Grain yield (bu./A)
- **Elemental Analysis (macro, micro, heavy metals)**
  - Agronomic inputs (organic amendments and inorganic fertilizers)
  - Biomass at Feekes 4
  - Flag leaf tissue at Feekes 9
  - Grains at harvest
  - Bulk soil samples at Feekes 4 and harvest

Tillers [Feekes 4]

Head density (1ft^2) [Feekes 11.1]

Calculations

- **Correlation analysis** among bulk soil and plant tissue elements with As, Cd, and Pb
- **Plant uptake factor:** PUF = element $_{(ppb)}$ in biomass / element $_{(ppb)}$ in soil
  - Capacity of wheat to absorb heavy metals from soil
  - >1 = increased plant uptake and easily absorbed from soil
  - <1 = env. better? Remains in soil and not translocated to plant
- **Translocation index of heavy metals** (Movement of heavy metals from soil to plant)

TI = element $_{(ppb)}$ in biomass / (element $_{(ppb)}$ in biomass + element $_{(ppb)}$ in soil)

2024 Pre-plant soil analysis

Soil pre-plant nutrient concentrations (0 – 8 inch.) and soil nitrate levels (0-12 inch, Lansing, MI, 2024. ‡

Soil pH	OM	CEC	Preplant Soil nitrate	Soil As	Soil Cd	Soil Pb
	—%—	—meq 100g^{-1}—	—NO_3^- kg^{-1} soil—	——ppm——		
7.1	2.3	10	3	**5.5**	**0.46**	**13.5**
Avg. US soil conc.				5.2	0.20	16.0

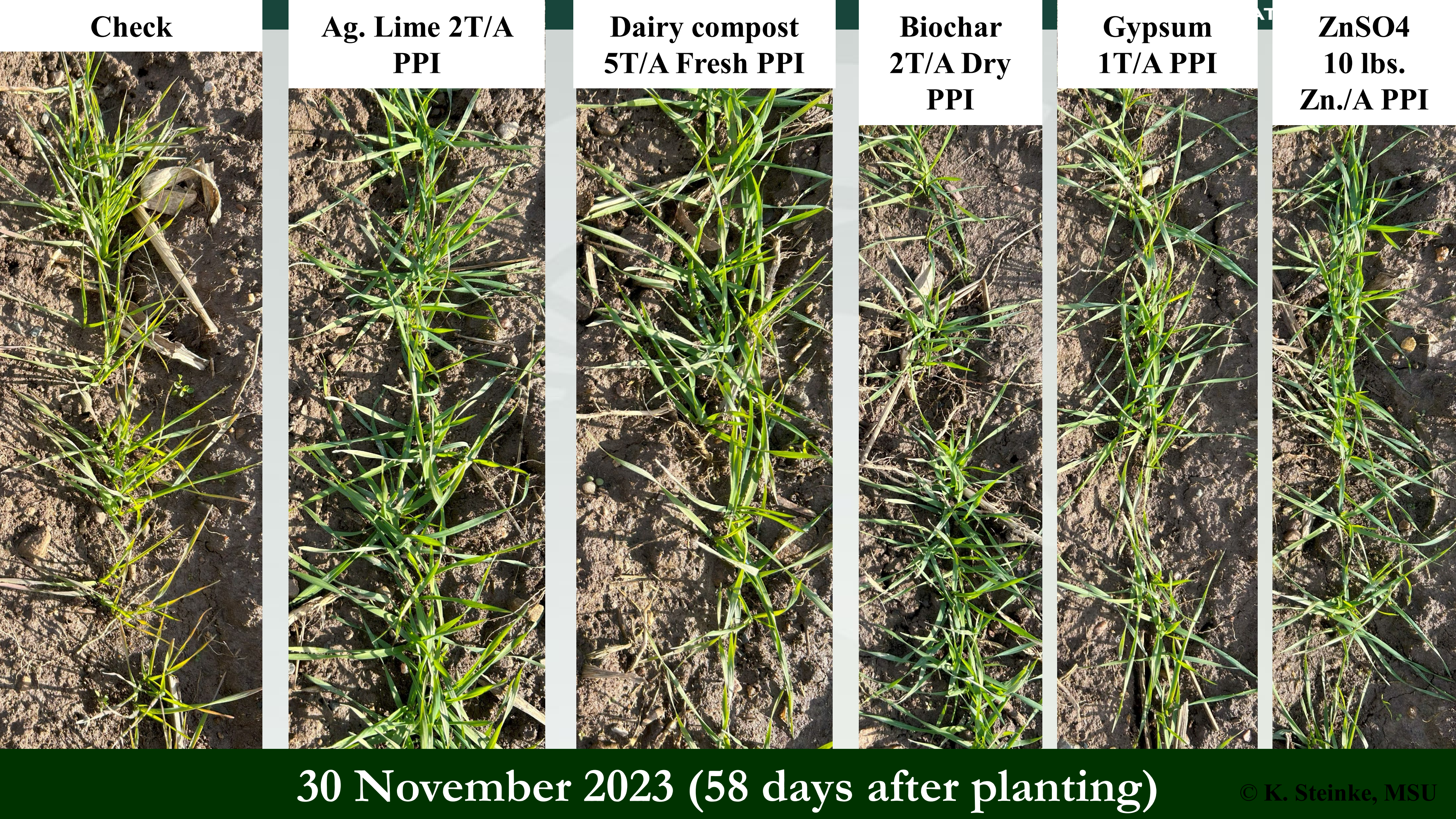
‡ Conover loam soil (*Fine-loamy, mixed, active, mesic Aquic Hapludalfs*).

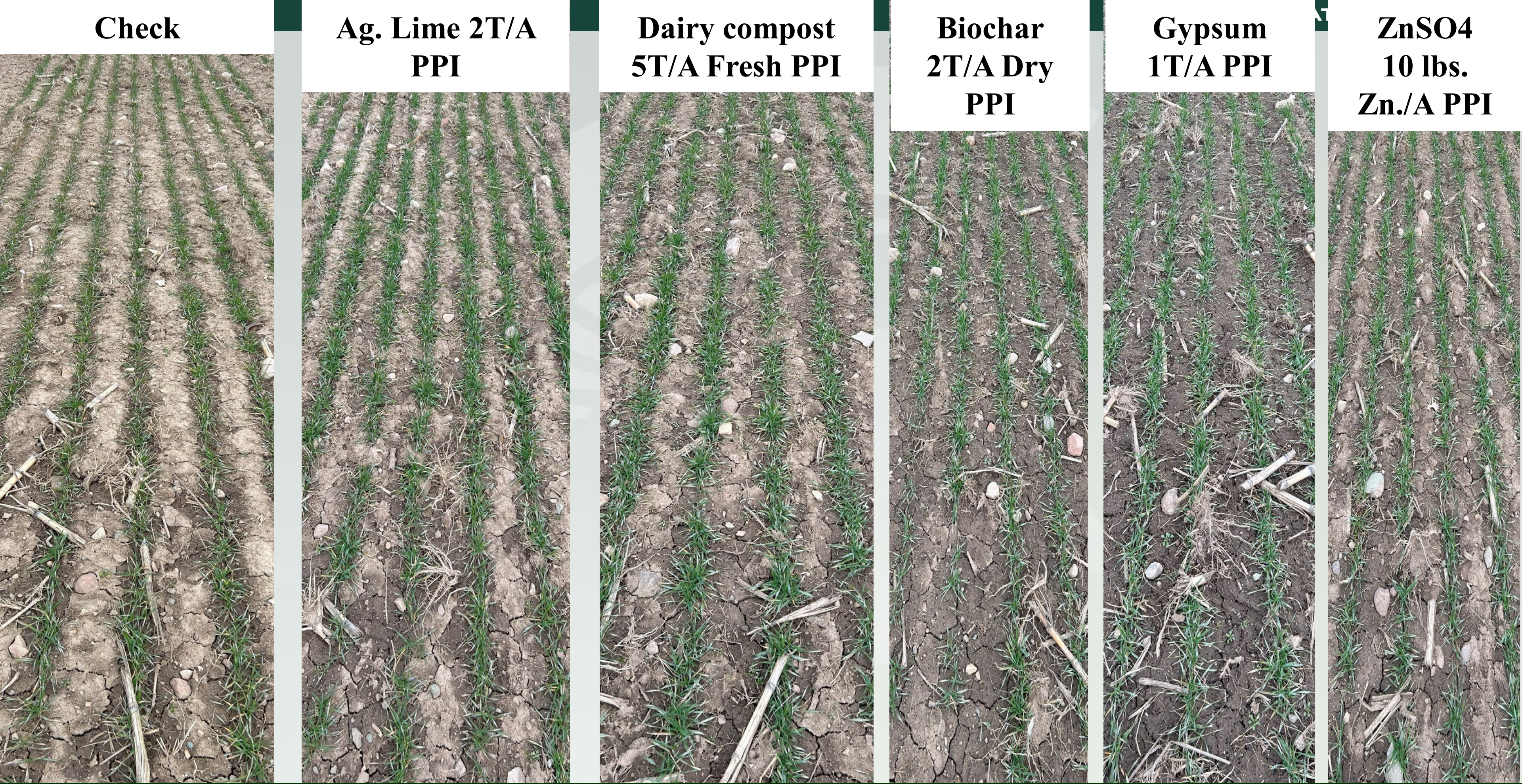
- Neutral soil pH
- Above critical Bray P1 level
- Below critical soil K and Zn levels

2025 Pre-plant soil analysis

Soil pH	OM	CEC	Bray P1	Exch. K	Exch. Mg	Exch. S	Total As	Total Cd	Total Pb
	—%—	—meq kg soil—	ppm						
7.3	2.6	12.7	50	116	380	5	1.41	0.29	12.7
			[a] 22-37	[b]120-170			[c]0.39	[d]0.48	[e]400

[a] Mehlich 3-P optimal levels 30-50 ppm, converted to Bray P1 by dividing by 1.35. [b]Mehlich 3-K optimal levels 120-170 ppm.
[c,d,e] US EPA screening level, https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact#:~:text=Table%201:%20Background%20Heavy%20Metal,Metal:%20Molybdenum


Check
Ag. Lime 2T/A PPI
Dairy compost 5T/A Fresh PPI
Biochar 2T/A Dry PPI
Gypsum 1T/A PPI
ZnSO4 10 lbs. Zn./A PPI
30 November 2023 (58 days after planting)
© K. Steinke, MSU



13 February 2024 (135 days after planting)

In-season: Tiller count at FK 4

Treatment[1]	Tillers per sq. ft.
Ag. lime	130
Dairy Compost	149
Biochar	116
Gypsum	123
ZnSO4 (g)	138
Ammonium sulfate (starter fert only)	142
P > F (0.05)	0.1896
Check	115

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at PPI.

10 April 2025

Dairy compost @ 5T/A PPI

Biochar @ 2T/A PPI

In-season: Plant height at FK11

Treatment[1]	cm.
Ag. lime	68.8 bc
Dairy Compost	70.5 abc
Biochar	70.2 abc
Gypsum	67.7 c
ZnSO4 (g)	69.9 abc
Low N at FK 4	64.3 d
Mid N at FK 4	70.4 abc
High N at FK 4	72.2 a
EDDS chelate	70.8 ab
P > F (0.05)	**<.0001**
Check	48.3

[1] All plots received ammonium sulfate as a starter fertilizer and green-up N fertilizer except the check plots and N treatments. ZnSO4 was applied as PPI granular and FK 9 foliar

01 June 2025

High N @ FK 4

Low N @ FK 4

In-season: Head length at FK11

Treatment[1]	mm.
Ag. lime	71.0 bc
Dairy Compost	70.6 c
Biochar	68.5 c
Gypsum	70.9 bc
ZnSO4 (g)	71.1 bc
Low N at FK 4	71.1 bc
Mid N at FK 4	76.4 a
High N at FK 4	74.4 ab
EDDS chelate	71.7 bc
P > F (0.05)	**0.0007**
Check	53.8

[1] All plots received ammonium sulfate as a starter fertilizer and green-up N fertilizer except the check plots and N treatments. ZnSO4 was applied as PPI granular and FK 9 foliar

01 June 2025

Mid N @ FK 4 | Biochar

In-season: Head density at FK11

Treatment[1]	Spikes per sq ft.
Ag. lime	85
Dairy Compost	91
Biochar	82
Gypsum	79
ZnSO4 (g)	77
Low N at FK 4	57
Mid N at FK 4	72
High N at FK 4	93
EDDS chelate	84
P > F (0.05)	0.0650
Check	44

[1] All plots received ammonium sulfate as a starter fertilizer and green-up N fertilizer except the check plots and N treatments. ZnSO4 was applied as PPI granular and FK 9 foliar

23 May 2025

High N @ FK 4

Low N @ FK 4

Grain yield

Treatment[1]	Bu/A
Ag. lime	102.4 a
Dairy Compost	106.5 a
Biochar	107.4 a
Gypsum	113.7 a
ZnSO4 (g,l)	103.8 a
Low N at FK 4	77.9 b
Mid N at FK 4	106.7 a
High N at FK 4	113.1 a
EDDS chelate	107.5 a
P > F (0.05)	**0.0005**
Check	32.4

[1] All plots received ammonium sulfate as a starter fertilizer and green-up N fertilizer except the check plots and N treatments. ZnSO4 was applied as PPI granular and FK 9 foliar

19 May 2025

Gypsum vs. Low N

Elemental analysis: FK4 BIOMASS

Treatment[1]	Total As	Total Cd	Total Pb
		ppm	
Check	0.199	0.274	0.597
Ag. lime	0.231	0.232	0.665
Dairy Compost	0.194	0.221	0.555
Biochar	0.182	0.250	0.538
Gypsum	0.204	0.345	0.636
ZnSO4 (g)	0.187	0.449	0.556
Ammonium sulfate (starter fert only)	0.177	0.213	0.582
P > F (0.05)	0.8999	0.5373	0.9688

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

Elemental analysis: FK4 SOIL

Treatment[1]	Total As	Total Cd	Total Pb
	ppm		
Check	2.58	0.196	10.7
Ag. lime	2.67	0.205	11.1
Dairy Compost	2.61	0.195	10.9
Biochar	2.70	0.189	10.5
Gypsum	2.63	0.197	10.9
ZnSO4 (g)	2.44	0.230	11.5
Ammonium sulfate (starter fert only)	2.49	0.205	11.1
P > F (0.05)	0.9687	0.2803	0.1419
US EPA Screening level	[a]0.390	[b]0.480	[c]400

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

[a,b,c] US EPA screening level, https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact#:~:text=Table%201:%20Background%20Heavy%20Metal,Metal:%20Molybdenum

Elemental analysis: FK4 PUF

Treatment[1]	Total As	Total Cd	Total Pb
	PUF = FK 4 biomass/FK 4 soil		
Check	0.068	1.50	0.056
Ag. lime	0.086	1.12	0.057
Dairy Compost	0.074	1.08	0.050
Biochar	0.070	1.32	0.051
Gypsum	0.080	1.74	0.059
ZnSO4 (g)	0.084	2.06	0.052
Ammonium sulfate (starter fert only)	0.072	1.02	0.053
P > F (0.05)	0.8877	0.4355	0.9968

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

Elemental analysis: FK9 FLAG LEAF

Treatment[1]	Total As	Total Cd	Total Pb
	ppm		
Check	0.012	0.142	0.029 b
Ag. lime	0.013	0.172	0.052 b
Dairy Compost	0.014	0.170	0.044 b
Biochar	0.012	0.185	0.053 b
Gypsum	0.013	0.135	0.061 b
ZnSO4 (g)	0.013	0.195	0.059 b
Low N at FK 4	0.012	0.149	0.049 b
Mid N at FK 4	0.012	0.119	0.051 b
High N at FK 4	0.013	0.141	0.116 a
EDDS chelate	0.012	0.179	0.026 b
P > F (0.05)	0.5760	0.7284	**0.0489**

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

Elemental analysis: FK9 SOIL

Treatment[1]	Total As	Total Cd	Total Pb
	ppm		
Check	2.54	0.203	10.9
Ag. lime	2.53	0.214	11.3
Dairy Compost	2.64	0.208	11.1
Biochar	2.83	0.203	11.3
Gypsum	2.56	0.209	11.6
ZnSO4 (g)	2.54	0.211	11.4
Low N at FK 4	2.54	0.214	11.8
Mid N at FK 4	2.39	0.210	11.4
High N at FK 4	2.35	0.221	11.5
EDDS chelate	2.45	0.214	11.8
P > F (0.05)	0.7769	0.9945	0.7707
US EPA Screening level	[a]0.390	[b]0.480	[c]400

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

[a,b,c] US EPA screening level, https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact#:~:text=Table%201:%20Background%20Heavy%20Metal,Metal:%20Molybdenum

Elemental analysis: FK9 PUF

Treatment[1]	Total As	Total Cd	Total Pb
	PUF = FK 9 flag leaf/FK 4 soil		
Check	0.005	0.650	0.0027 b
Ag. lime	0.005	0.827	0.0045 b
Dairy Compost	0.005	0.847	0.0040 b
Biochar	0.004	0.922	0.0048 b
Gypsum	0.005	0.643	0.0053 b
ZnSO4 (g)	0.005	0.944	0.0053 b
Low N at FK 4	0.005	0.690	0.0043 b
Mid N at FK 4	0.005	0.564	0.0045 b
High N at FK 4	0.006	0.598	0.0100 a
EDDS chelate	0.005	0.860	0.0022 b
P > F (0.05)	0.2825	0.6554	**0.0369**

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 granular was applied at planting. As, Cd, Pb were analyzed using ICP-QQQ-MS.

Elemental analysis: HARVEST GRAIN

Treatments	Total As	Total Cd	Total Pb
	ppm		
Check	0.001	0.038	0.005
Ag. lime	0.001	0.036	0.002
Dairy compost	0.001	0.034	0.002
Biochar	0.001	0.036	0.004
Gypsum	0.001	0.038	0.005
ZnSO4	0.001	0.034	0.006
Low N	0.001	0.033	0.003
Mid N	0.001	0.037	0.006
High N	0.001	0.041	0.005
EDDS chelate	0.001	0.041	0.004
FDA action level	**Not established**	**Not established**	**0.01**
P > F (0.05)	0.1650	0.6272	0.5224

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 was applied granularly at planting and foliarly at FK 9. As, Cd, Pb were analyzed using ICP-QQQ-MS.

Elemental analysis: HARVEST SOIL

Treatments	Total As	Total Cd	Total Pb
	ppm		
Check	2.47	0.212	10.9 cd
Ag. lime	2.56	0.200	10.9 cd
Dairy compost	2.44	0.205	10.4 d
Biochar	2.62	0.206	11.3 abc
Gypsum	2.46	0.209	10.8 cd
ZnSO4	2.32	0.227	11.0 bcd
Low N	2.62	0.208	11.1 abcd
Mid N	2.40	0.222	11.1 abcd
High N	2.33	0.235	11.7 ab
EDDS chelate	2.37	0.249	11.8 a
P > F (0.05)	0.7577	0.3729	**0.0337**
US EPA Screening level	**[a]0.390**	**[b]0.480**	**[c]400**

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 was applied granularly at planting and foliarly at FK 9. As, Cd, Pb were analyzed using ICP-QQQ-MS.
[a,b,c] US EPA screening level, https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact#:~:text=Table%201:%20Background%20Heavy%20Metal,Metal:%20Molybdenum

Elemental analysis: HARVEST PUF

Treatments	Total As	Total Cd	Total Pb
	PUF = Harvest grain/Harvest soil		
Check	0.0004	0.183	0.0007
Ag. lime	0.0006	0.181	0.0003
Dairy compost	0.0004	0.168	0.0045
Biochar	0.0004	0.177	0.0004
Gypsum	0.0004	0.183	0.0005
ZnSO4	0.0003	0.150	0.0007
Low N	0.0003	0.160	0.0003
Mid N	0.0005	0.165	0.0008
High N	0.0004	0.164	0.0006
EDDS chelate	0.0004	0.166	0.0003
P > F (0.05)	0.3110	0.8331	0.5658

[1] All treatments were applied pre-plant incorporated (PPI), except ammonium sulfate, which was applied as a topdress. All plots received ammonium sulfate as a starter fertilizer, except the check plots. Only ZnSO4 was applied granularly at planting and foliarly at FK 9. As, Cd, Pb were analyzed using ICP-QQQ-MS.
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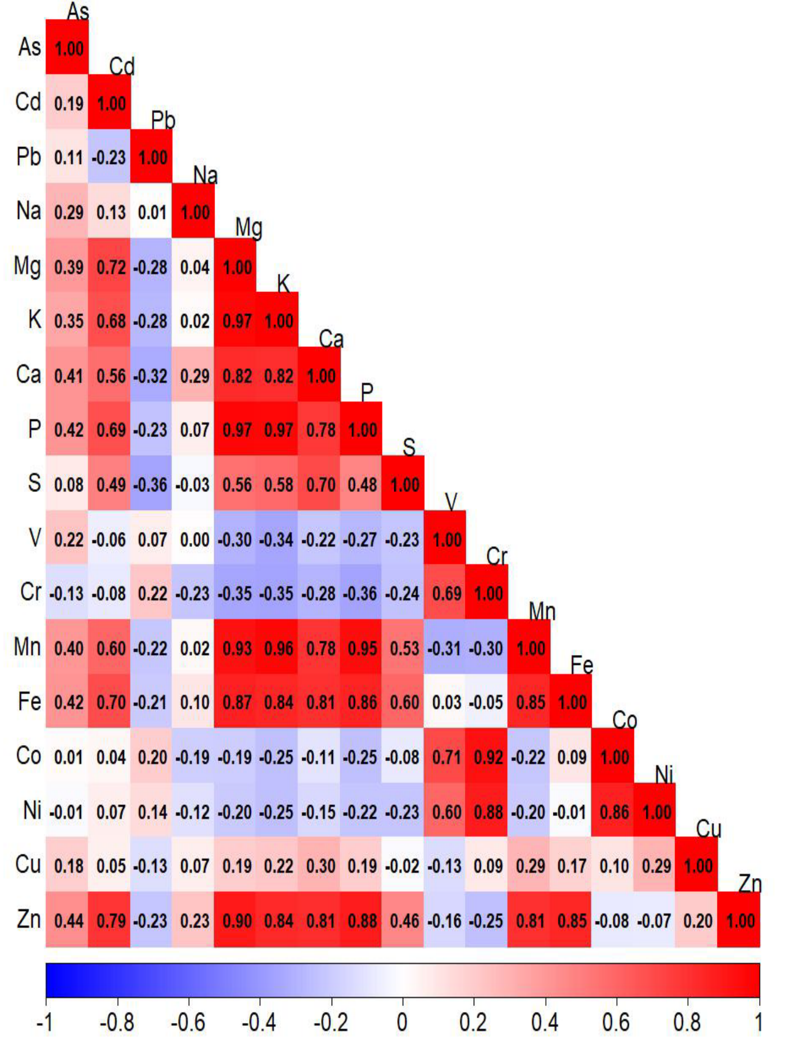


Grain As, Cd, Pb vs. grain elements

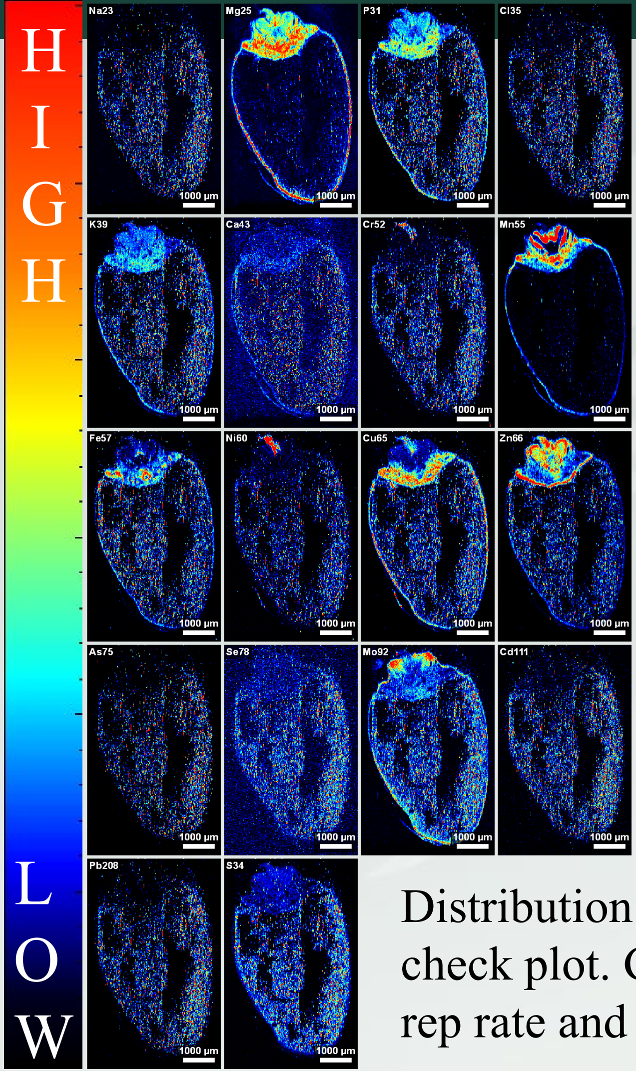
Grains elements

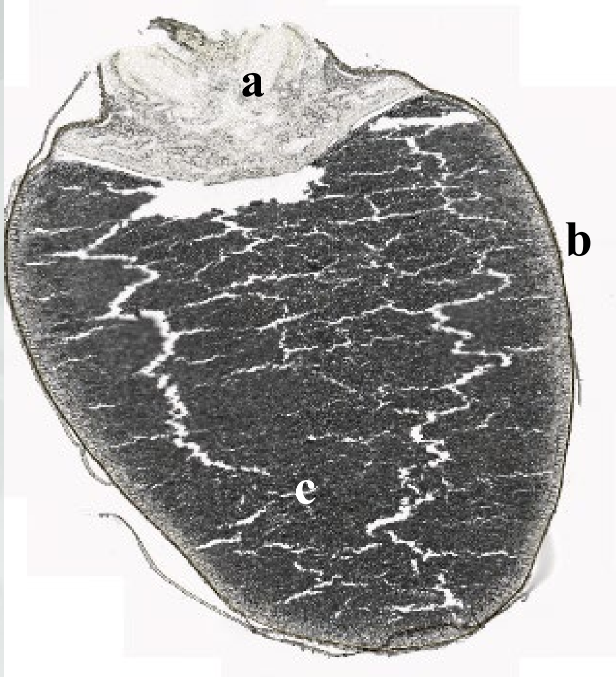
As: weak (+) correlations

Cd: moderate-strong (+) corr with Mg, K, Ca, P, S, Mn, Fe, Zn

Pb: weak (-) correlations

Pearson correlation test among grains elements ($p < 0.05$). Grains elements including arsenic (As), cadmium (Cd), lead (Pb), sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), phosphorus (P), sulfur (S), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn).





Microscopic image of winter wheat grain (20 µm) using ZEISS Axioscan 7 Microscope Slide Scanner

a. germ

b. bran

c. endosperm

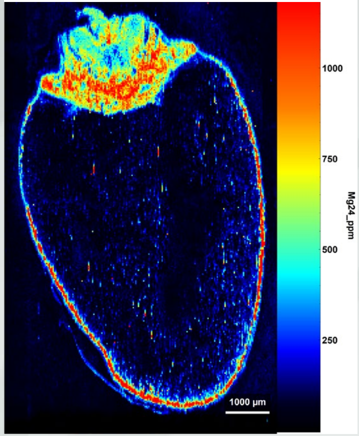
Distribution of elements in the winter wheat grain from check plot. Grain was imaged at 20µm spot size, 125Hz rep rate and 90% laser power using LA-ICP-TOF-MS.

Grain from check plot

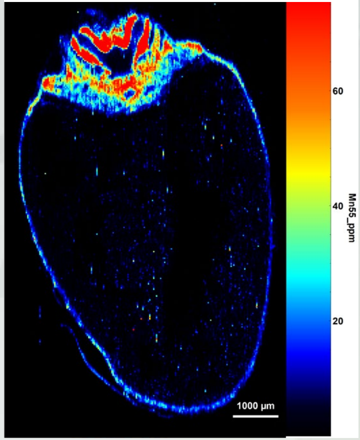
Microscopic image of winter wheat grain (20 µm) using ZEISS Axioscan 7 Microscope Slide Scanner

The scale in the images (left) are in ppm or mg/kg sample

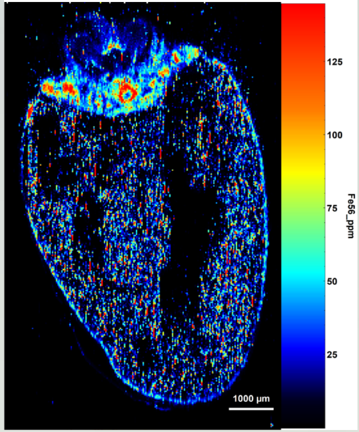
Mg



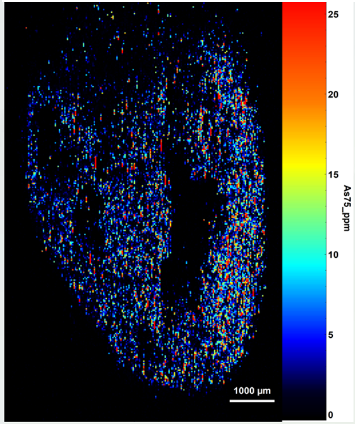
Mn



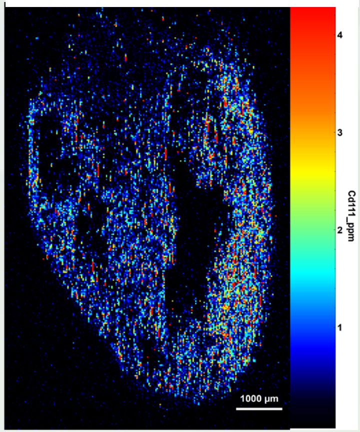
Fe



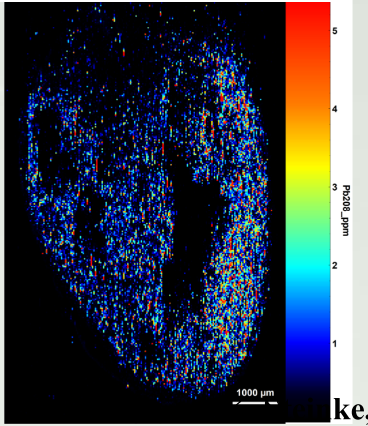
As



Cd



Pb



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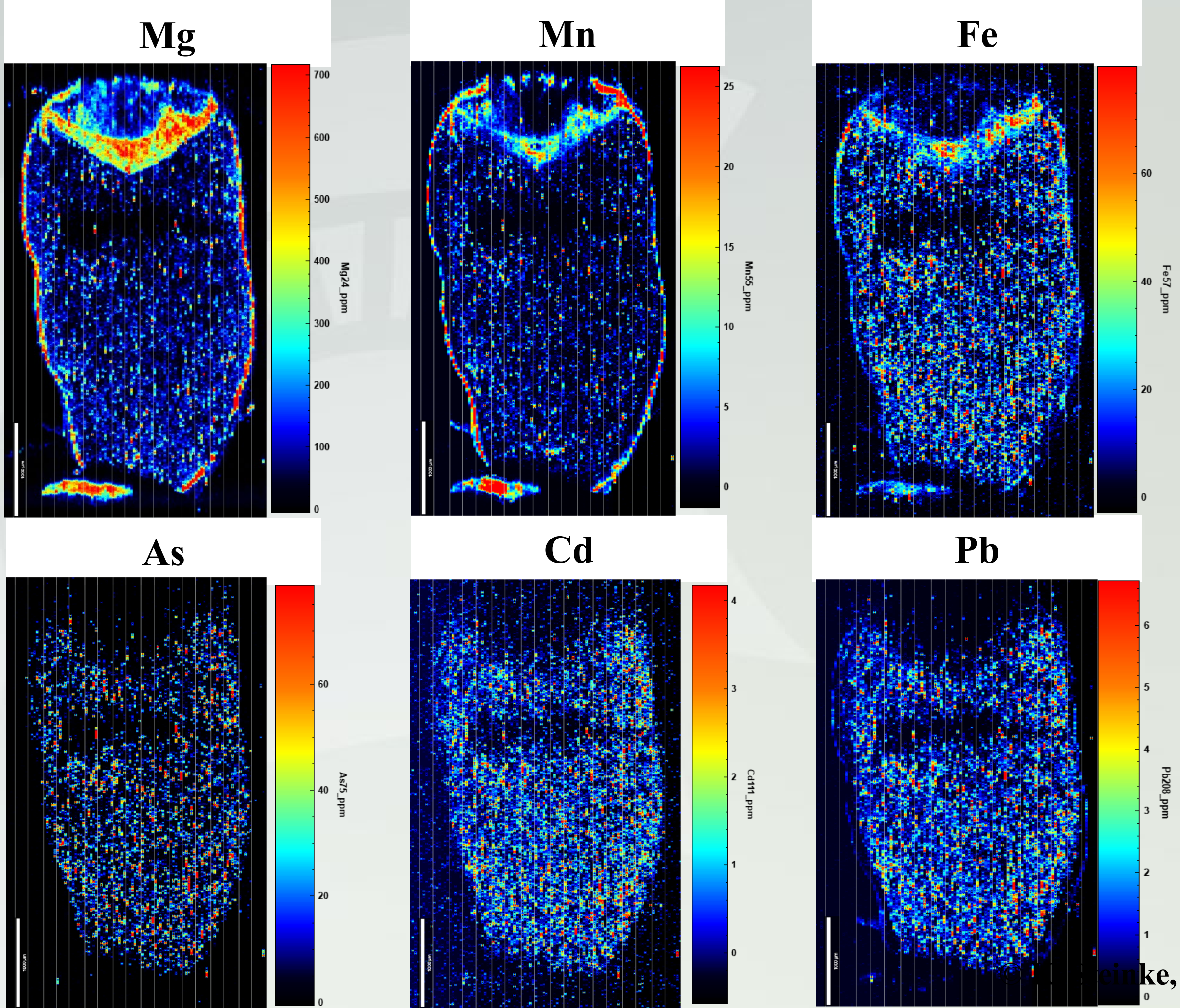
EDDS Chelate 2mmol/L at FK 5, + 1wk, + 2wk

Microscopic image of winter wheat grain (20 µm) using ZEISS Axioscan 7 Microscope Slide Scanner

The scale in the images (left) are in ppm or mg/kg sample



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Year 1: 2024 Amendment Trial Recap

- Pre-plant soil: Neutral soil pH, below soil K, above soil P, 5.5 ppm As, 0.46 ppm Cd, 13.5 ppm Pb
- Weather: Dry autumn (-53%), Warm wetter winter (+34%), Dry spring (-56%), Normal summer
- Grain yield: 18.2-109.2 bu./A, avg = 83.6 bu./A
- FK4 PUF: for Cd $ZnSO_4$ <1.0, for As < DL, for Pb = 0.1
- FK9 Flag leaf: all soil amendments reduced As by 86-144 ppb
- Harvest grain: Check, Ag. lime, Gypsum, $ZnSO_4$ <10 ppb
- Harvest soil: 2.3-3.0 ppm As, 0.20-0.27 ppm Cd, 9.5-10.3 ppm Pb
- Harvest PUF: As, Cd, Pb < 1.0 but Biochar, $ZnSO_4$, Low N, Mid N, EDDS reduced Cd PUF

Year 2: 2025 Preliminary Amendment Trial Results

- Pre-plant soil: Neutral soil pH, above soil P, below soil K, 1.4 ppm As, 0.29 ppm Cd, 12.7 ppm Pb
- Weather: Dry warm autumn, Warm wet winter, Dry spring, Dry summer
- Grain yield: 27.1-127.5 bu./A, avg = 97.2 bu./A (+17% vs. 2024)
- FK4 PUF: Cd > 1.0 with ZnSO4 (highest), As and Pb < 1.0
- FK 9 PUF: As, Cd, Pb < 1.0 but High N had greatest Pb PUF
- Harvest grain: all treatments <10 ppb Pb
- Harvest soil: 2.1-2.6 ppm As, 0.20-0.25 ppm Cd, 10.4-11.8 ppm Pb
- Harvest PUF: As, Cd, Pb < 1.0 but Dairy compost had highest Pb PUF

Year 2: 2025 Slope Trial

Elemental analysis: HARVEST

Slope	Soil Moisture -%-	Grain ppm			Soil ppm		
		Total As	Total Cd	Total Pb	Total As	Total Cd	Total Pb
Toeslope	10.3	0.002 a	0.037 b	0.001	2.10 a	0.136 a	8.21 a
Midslope	10.2	0.001 b	0.052 a	0.002	1.72 b	0.140 a	7.86 a
Summit	8.9	0.001 b	0.054 a	0.000	1.51 b	0.114 b	6.12 b
P > F (0.05)	**0.0712**	**0.013**	**0.0067**	0.1628	**0.0023**	**0.0001**	**<0.0001**
FDA/US EPA		**Not established**	**Not established**	**0.01**	**[a]0.390**	**[b]0.480**	**[c]400**

Slope	PUF		
	Total As	Total Cd	Total Pb
Toeslope	0.001 a	0.270 c	0.0002
Midslope	0.001 a	0.367 b	0.0003
Summit	0.000 b	0.477 a	0.0000
P > F (0.05)	**0.0006**	**0.0019**	0.7583

[a,b,c] US EPA screening level, https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact#:~:text=Table%201:%20Background%20Heavy%20Metal,Metal:%20Molybdenum

Year 2: 2025 Slope Trial Results

- Weather: Dry warm autumn, Warm wet winter, Dry spring, Dry summer
- FK4 PUF: all slope had Cd PUF > 1.0 with Summit (highest, 2.71), both As and Pb PUF < 1.0
- FK 9 PUF: Midslope and Summit had Cd PUF > 1.0, both As and Pb PUF < 1.0
- Harvest grain: slope position < FDA action level (10 ppb)
- Harvest PUF: As, Cd, Pb < 1.0

2025 WHEAT VARIETY TRIAL

Planted: 19 September 2024
Sample collected before harvest: 09 July 2025
Planting rate: 1.5 million per A.

One-way RCBD (3 reps)
5 Tall-statured SRWW varieties
5 Semi-dwarf SRWW varieties
Control: MCIA ‘Marlin’, MCIA ‘Wharf’
90 lbs. N and 20 lbs. S (4/7/25); 30 lbs. N (4/24/25)

					GRAIN (ppb)			STRAW (ppb)		
Varieties	Classification [1]	GY (bu./A)	SY (T./A)	PH (cm)	As	Cd	Pb [2]	As	Cd	Pb
MI21R0058	T	56.9 cd	3.2	86.2 bc	4.0	58.7	13.5	33.5	162.4	57.6
MI20R0210	SM	63.4 bcd	2.4	81.9 d	2.0	43.8	7.3	20.1	101.8	43.6
FS 606	T	54.0 de	2.5	92.5 a	2.4	60.7	22.9	25.3	141.9	33.2
MCIA Jonah	T	66.1 bc	2.7	89.3 ab	2.2	53.0	8.8	35.3	139.7	91.0
AgriMAXX 545	SM	77.1 a	2.6	87.0 bc	1.4	46.9	4.7	31.2	125.6	66.2
FS 745	SM	62.9 bcd	2.5	87.1 bc	1.3	67.4	2.8	30.4	173.9	57.8
MCIA .357	SM	42.9 e	1.9	74.5 e	1.0	66.2	13.9	36.7	188.9	73.4
DF 144 R	SM	72.5 ab	2.3	86.1 bc	1.6	44.8	2.7	24.3	127.3	52.9
Dyna-Gro 9422	T	67.9 ab	2.7	88.2 b	1.5	60.0	28.6	23.3	184.9	37.9
Dyna-Gro 9570	T	68.4 ab	3.4	89.4 ab	1.0	52.0	14.2	23.1	147.6	44.9
MCIA Wharf	Control	69.7 ab	2.6	77.6 e	3.0	48.1	8.8	31.7	119.4	29.9
MCIA Marlin	Control	53.1 ed	2.3	83.5 cd	2.0	72.4	10.3	46.7	164.5	77.8
P > F (0.05)		**0.0005**	0.0831	**<.0001**	0.2054	0.2464	0.4106	0.2794	0.4594	0.4401

[1] Based on the 2024 MSU Variety trial. T- tall (≥ avg. 81 cm.), SM – semi-dwarf (< 81 cm.). [2] FDA action level for Pb: 10 ppb
PH – Plant height, SY – Oven-dried straw weight (1 sq. ft. sample) converted to T/A

	Grain PUF			Straw PUF			Translocation Factor		
Variety	**As**	**Cd**	**Pb**	**As**	**Cd**	**Pb**	**As**	**Cd**	**Pb**
Tall-statured	0.0004	0.25 a	0.0023 a	0.008	0.57	0.006	0.009	0.94	0.007
Semi-dwarf	0.0006	0.22 b	0.0018 b	0.008	0.68	0.005	0.008	0.79	0.007
[1] P-values	0.1696	**0.0367**	**0.0235**	[2] 0.92	0.0892	0.4124	[2] 0.7019	0.1042	0.3453
Control 'MCIA Marlin'	0.0006	0.34	0.0013	0.014	0.76	0.008	0.015	1.1	0.009
Control 'MCIA Wharf'	0.0009	0.19	0.0007	0.009	0.47	0.003	0.009	0.67	0.003

[1] Wilcoxon rank sum exact test
[2] Two-sample t-test

Grain PUF = grain ppm / soil ppm
Straw PUF = straw ppm/soil ppm
Translocation factor = grain + straw ppm / soil ppm

2025 Variety Trial Results

- 50% out of 12 selected varieties > FDA action grain Pb level 10 ppb.
- Grain uptake factor As, Cd, Pb < 1.0
- Grain uptake factor for Cd and Pb: Tall varieties > semi-dwarf varieties
- Straw uptake factor for As, Cd, and Pb: Tall varieties vs. semi-dwarf varieties = NS
- Translocation factor for As, Cd, and Pb: Tall varieties vs. semi-dwarf varieties = NS
- Weak negative correlation of Grain Cd and Pb with grain yield and straw yield.

Implications to Consider

- Using science to establish HM FDA action values
  - 10 ppb (non-root crops) or 20 ppb (root crops) Pb
  - No action values As or Cd
- Know contents of what you apply
  - Fresh market crops, SH practices, etc.
- Other chemical interactions at play?
  - Cl and Cd (hard acids/bases; soft acids/bases)
- Opportunity? Fear the unknown but can we use to support US food quality compared to other crop sources

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Thank you!

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Soil Fertility and Nutrient Management

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