Exploring the link between soil and human health: lessons from Rodale Institute's long-term trials

Rodale Institute, Kutztown, PA

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www.rodaleinstitute.org

The soil health and human health connection begins to emerge

JI Rodale

Organic Gardening and Farming Magazine, 1942

Eve Balfour founded the Soil Association in England in 1946

JI founded the Soil and Health Association (Rodale Institute) in 1947

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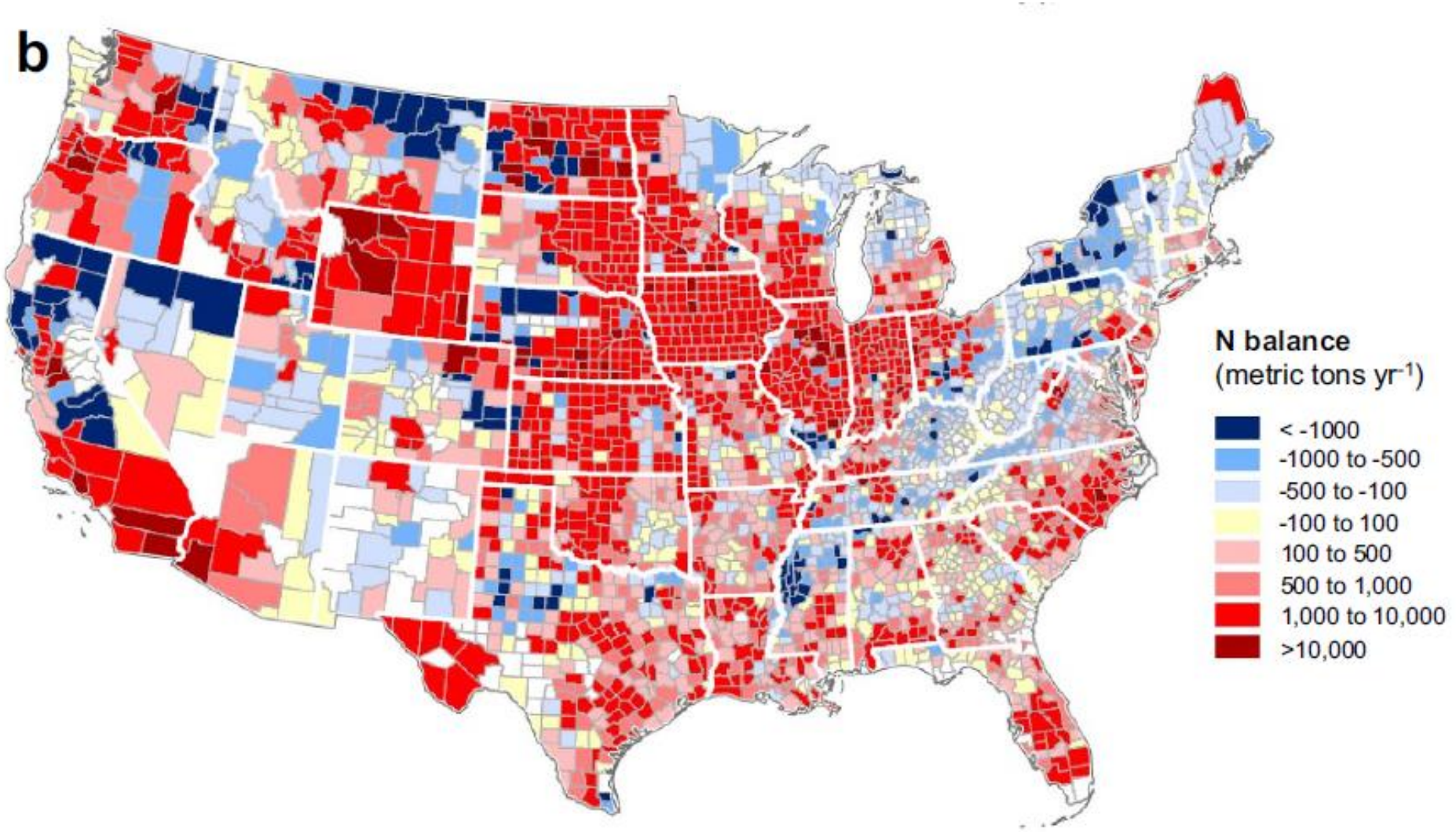
HEALTHY SOIL = HEALTHY FOOD = HEALTHY PEOPLE

Chronic Disease in the US
> 45% of the population

Cost of chronic disease, 2015 - 2050

$95,000,000,000,000

Chen et al. 2018. The macroeconomic burden of noncommunicable diseases in the United States: Estimates and projections. PLOS ONE.



Massive nitrogen loading in major crop production areas of the United States

Roy et al. 2021. *Environmental Research Letters*

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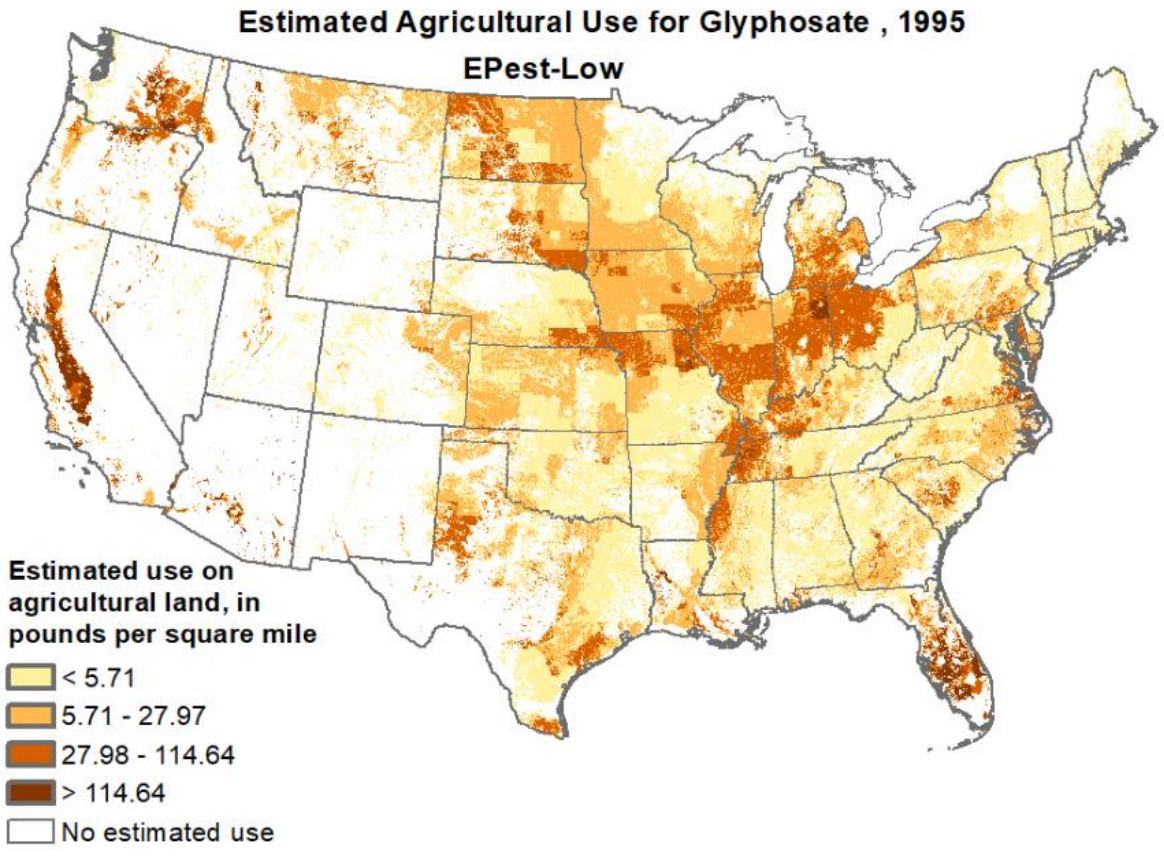
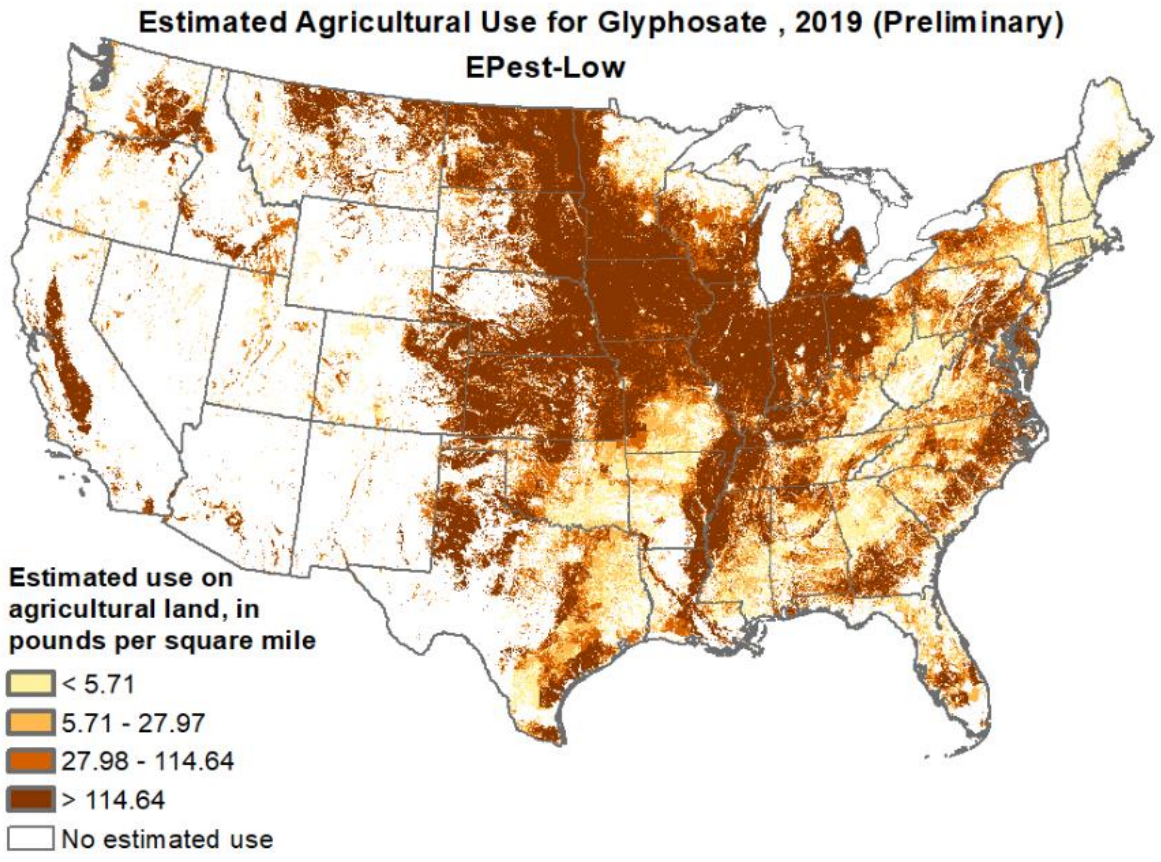
Glyphosate

1995



1995 ~ 25 million lbs. applied annually

2019



1995 ~ 275 million lbs. applied annually

Over 70% of water samples had glyphosate
Over 80% of Americans have glyphosate in their body

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United States Geological Society – National Water Quality Assessment. 2023

Pesticides and Cancer

All Cancer Rates attributed to agricultural use areas similar to All Cancer Rates from smoking

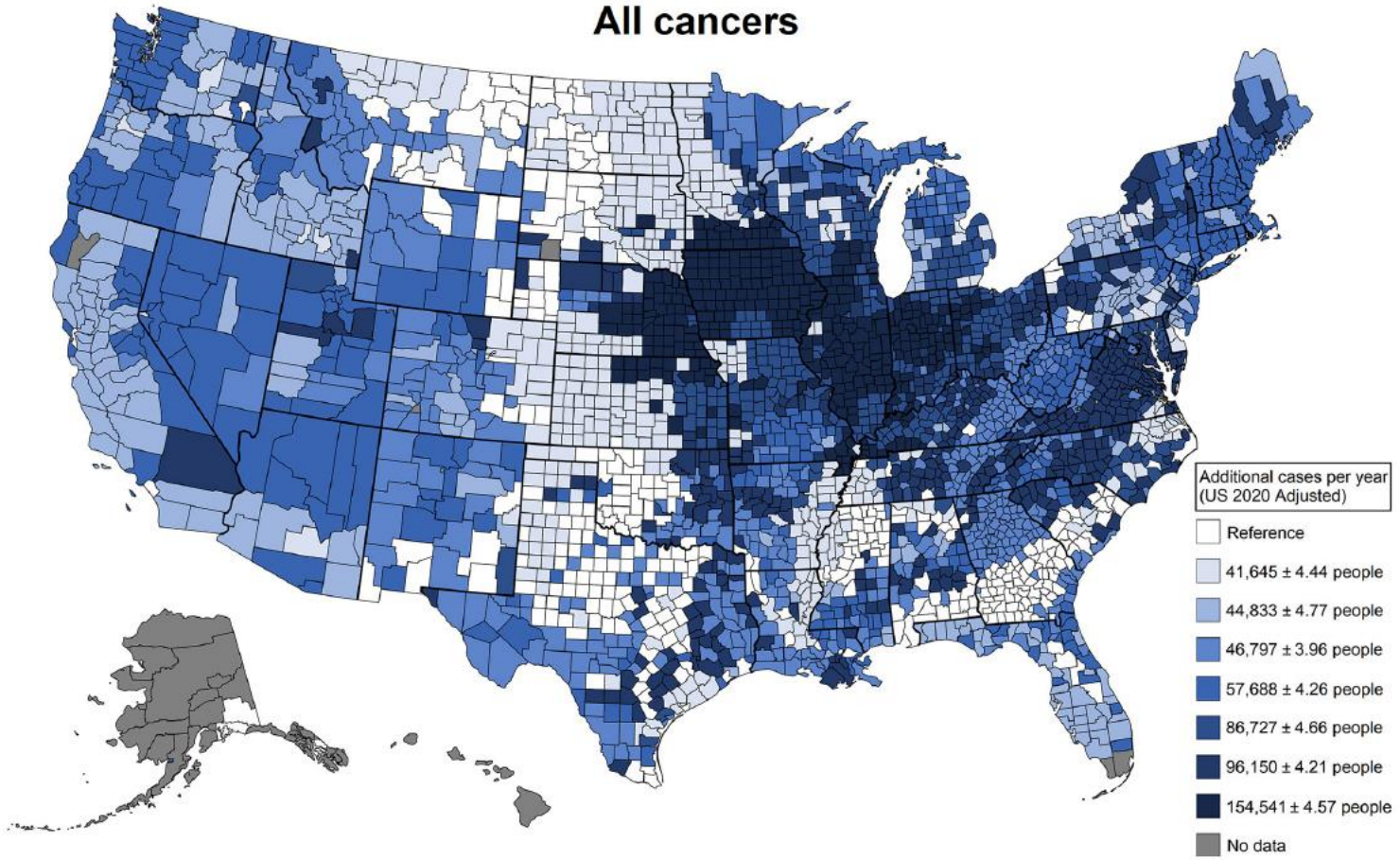

FIGURE 4
Additional cancer cases in a single year that can be attributed to differences in agricultural pesticide use patterns. These patterns of use were defined by latent class analysis; estimates were derived from generalized linear models adjusted for agricultural land use, total population, the Social Vulnerability Index, and smoking rates. This plot contrasts the counties that have the least risky use of agricultural pesticides with the counties that have the riskiest use of agricultural pesticides.

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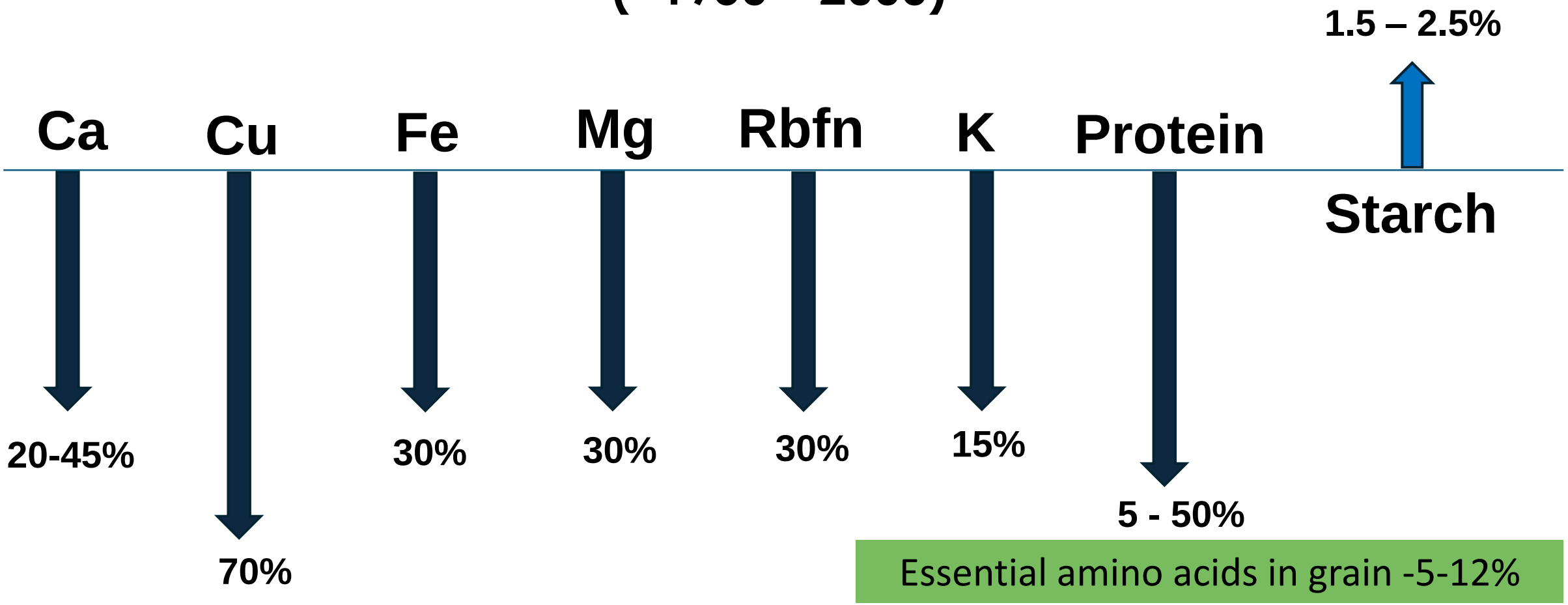
Gerken et al. 2024. Frontiers in Cancer and Society

Nutritional Decline in our Food (~1950 – 2000)



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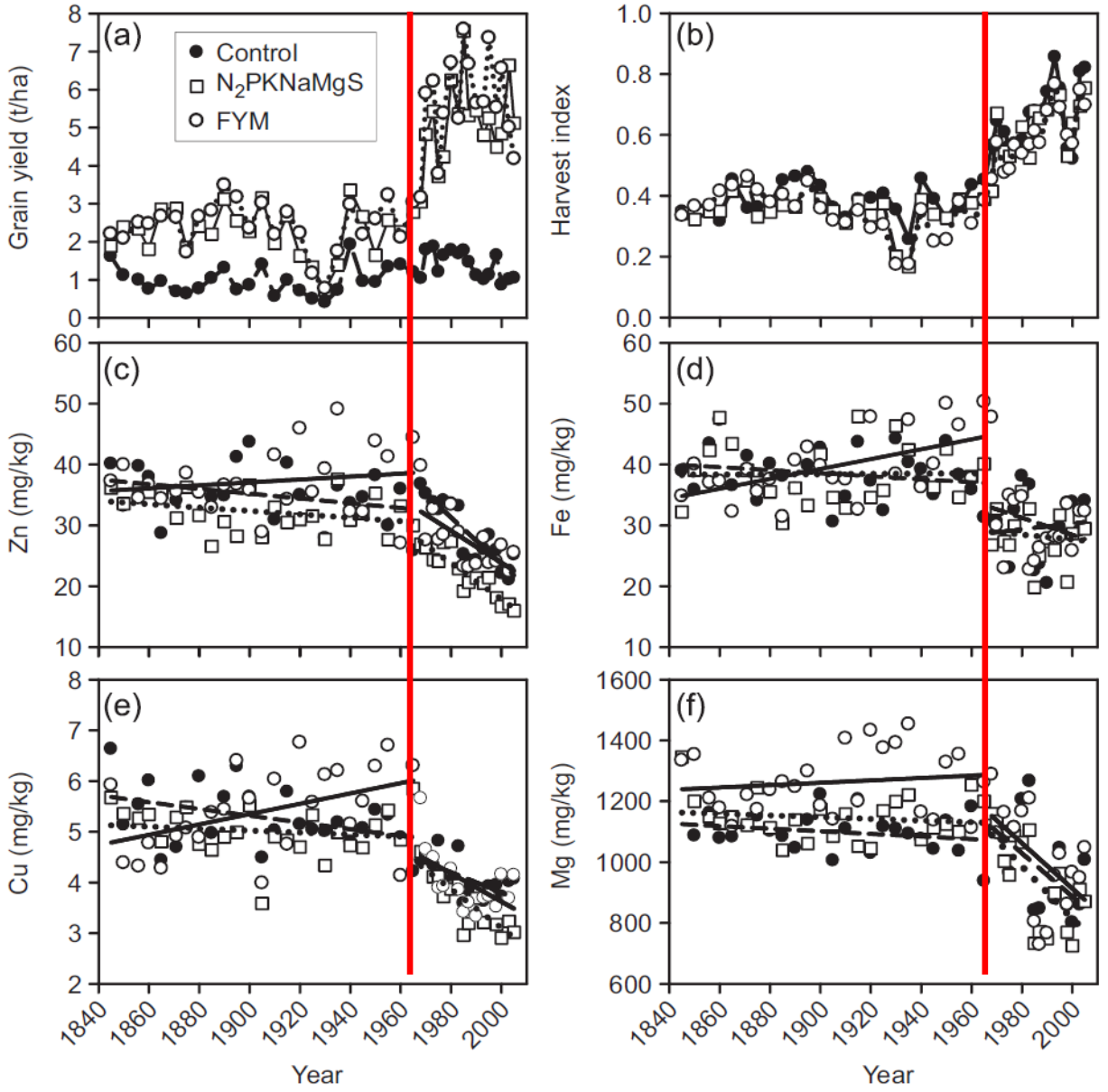
David Thomas, 2003: Davis et al. 2004: Davis et al. 2009; Scott et al. 2006; Simmonds 1995

Wheat grown in the long-term Broadbalk Wheat Trial at Rothamsted Research, UK

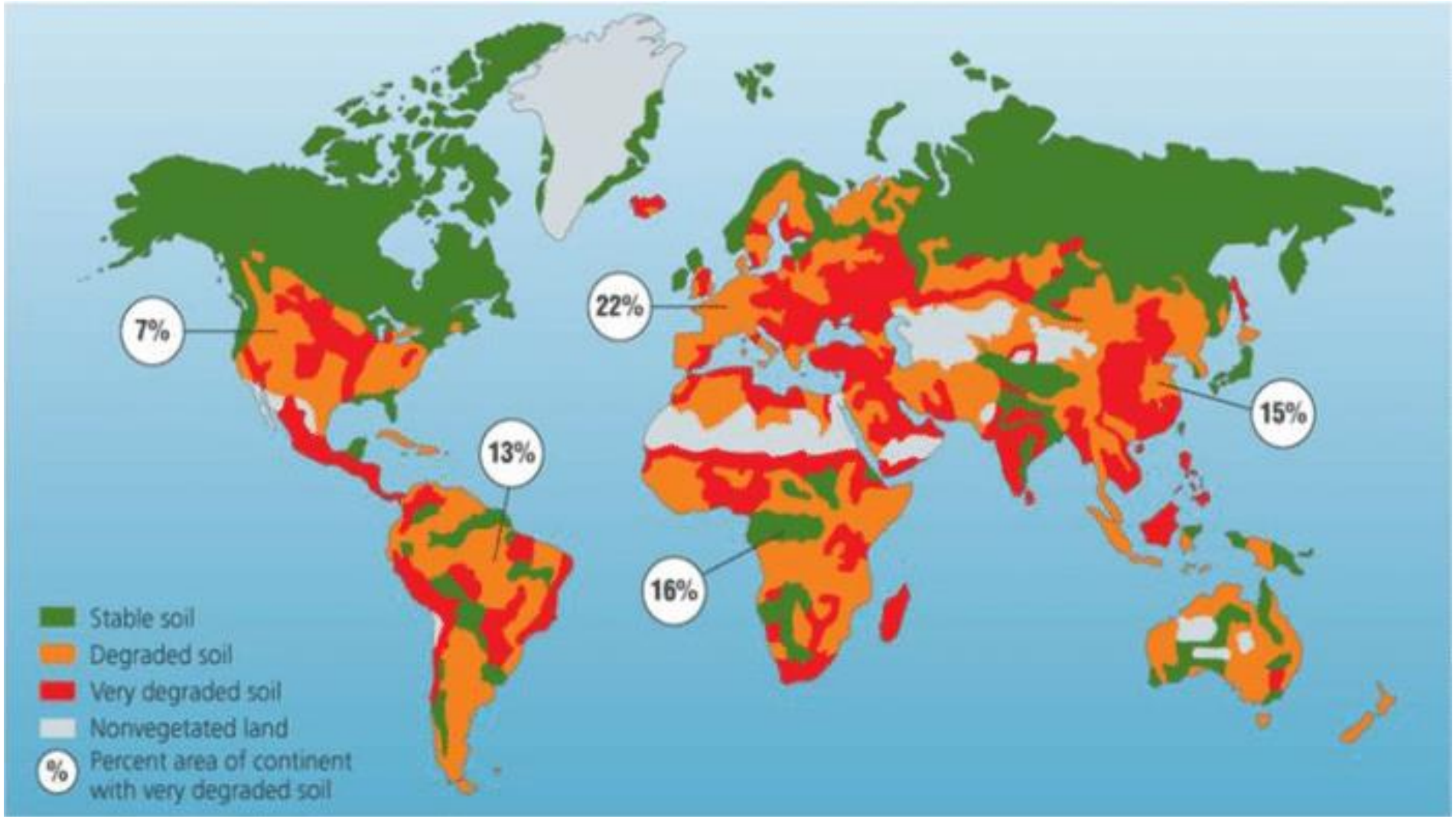
Traditional Wheat Semi-dwarf Wheat

Photo: William Cunningham (U. of Minnesota) and Mary Ann Cunningham (Vassar College)



Fan et al. 2008. *Journal of Trace Elements in Medicine and Biology*.

Global Soil Degradation



United Nations Environment Programme (UNEP), 2002
Status of the world's soil resources (UN FAO), 2015

Could organic farming that improves soil health be a solution to improve nutritional quality of crops?

And improve human health?

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Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses

- **4x higher pesticide residues in conventional crops.**
- **Higher cadmium, nitrate, and nitrite in conventional cereals.**
- **Lower protein, amino acid, and fiber in organic cereals.**
- **Higher total antioxidant activity in organic crops.**

Many of these compounds have previously been linked to a reduced risk of chronic diseases, including CVD and neurodegenerative diseases and certain cancers, in dietary intervention and epidemiological studies.

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Marcin Baranski et al. 2014. British Journal of Nutrition

Farming Systems Trial

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THE DIFFERENT SYSTEMS

ORGANIC MANURE

This system represents an organic dairy or beef operation. It features a long rotation including both annual feed grain crops and perennial forage crops. The system's fertility is provided by leguminous cover crops and periodic applications of manure or composted manure. This diverse rotation is also the primary line of defense against pests.

ORGANIC LEGUME

This system represents an organic cash grain system. It features a mid-length rotation consisting of annual grain crops and cover crops. The system's sole source of fertility is leguminous cover crops and the rotation provides the primary line of defense against pests.

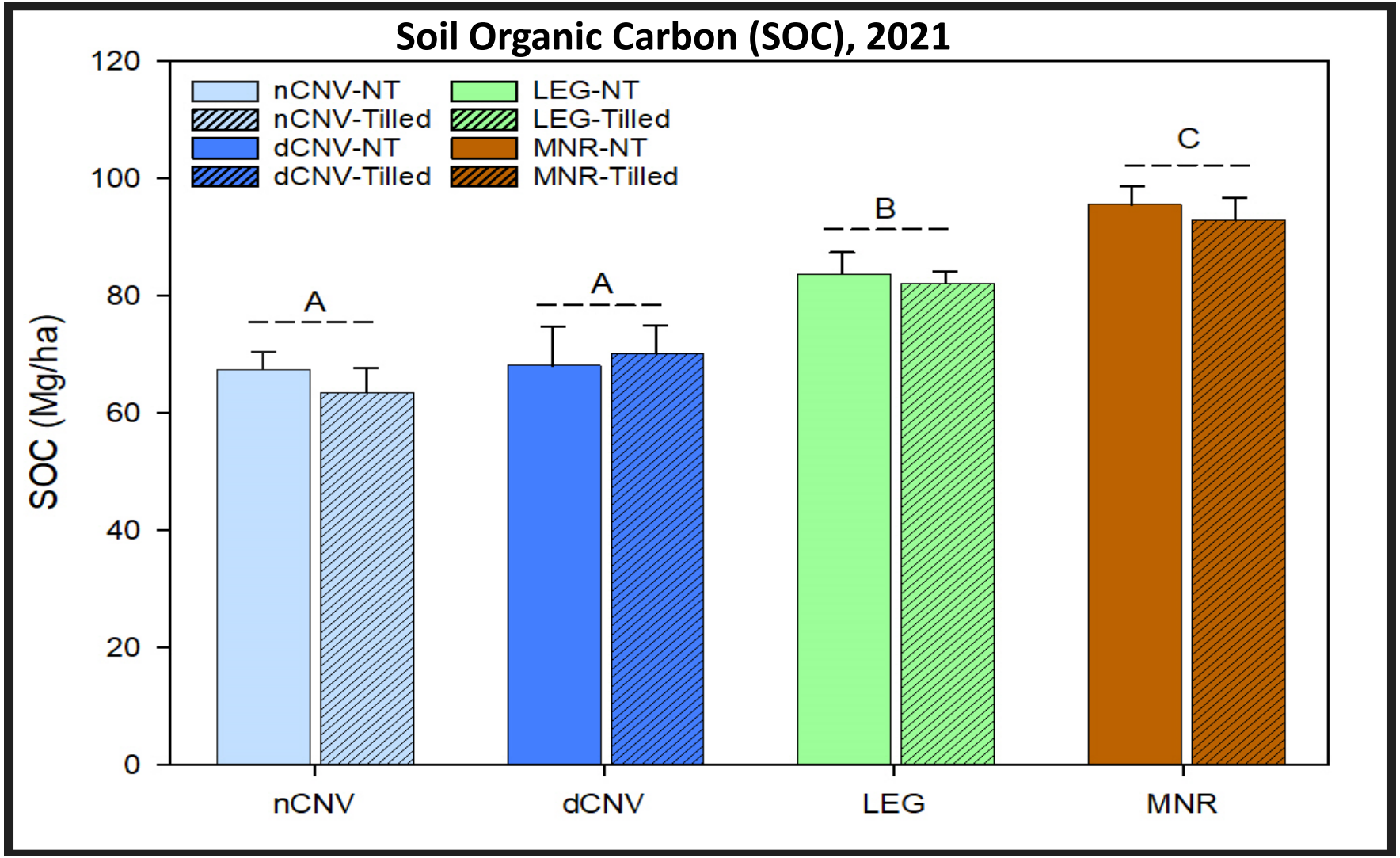
CONVENTIONAL SYNTHETIC

This system represents the majority of grain farms in the U.S. It relies on synthetic nitrogen for fertility, and weeds are controlled by synthetic herbicides selected by and applied at rates recommended by Penn State University Cooperative Extension. In 2008, genetically modified (GM) corn and soybeans were added to this system.

NO-TILL SYSTEMS

Each of the major systems was divided into two in 2008 to compare traditional tillage with no-till practices. The organic systems utilize our innovative no-till roller/crimper, and the no-till conventional system relies on current, widespread practices of herbicide applications and no-till-specific equipment.

Farming Systems Trial



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Orgnically managed soils are healthier than conventional

Farming Systems Trial

Article

Reducing Tillage Affects Long-Term Yields but Not Grain Quality of Maize, Soybeans, Oats, and Wheat Produced in Three Contrasting Farming Systems

Kirsten Ann Pearsons [1], Emmanuel Chiwo Omondi [2], Brad J. Heins [3], Gladis Zinati [1], Andrew Smith [1] and Yichao Rui [1,*]

	Maize			Wheat			Oats [1]		Soybeans		
Response	CNV	LEG	MNR	CNV	LEG	MNR	LEG	MNR	CNV	LEG	MNR
Protein [2], %	7.2 [c]	7.5 [b]	8.1 [a]	12.9 [a]	11.4 [b]	11.4 [b]	12.9	12.8	39.0 [b]	40.4 [a]	39.7 [ab]
Fat [3], %	3.79 [ab]	3.69 [b]	3.90 [a]	1.78	1.87	1.89	5.42	5.32		-	
Starch, %	73.9 [a]	73.4 [ab]	72.5 [b]	65.7 [c]	66.9 [b]	67.7 [a]	44.5	44.6		-	
Ash, %	1.43	1.45	1.46	2.04 [a]	1.80 [b]	1.74 [b]	3.49	3.49		-	
NEg [4]	1.52 [a]	1.51 [b]	1.52 [ab]	1.40 [b]	1.42 [a]	1.41 [a]	1.33	1.34	1.90 [b]	1.91 [ab]	1.91 [a]
NEl [5]	2.076 [a]	2.066 [b]	2.074 [ab]	1.96 [b]	1.97 [a]	1.97 [a]	1.89	1.90	2.48 [b]	2.49 [ab]	2.49 [a]
NEm [6]	2.203 [a]	2.191 [b]	2.202 [a]	2.07 [b]	2.08 [a]	2.08 [a]	1.98	1.99	2.672	2.683	2.682
TDN [7], %	88.22 [a]	87.82 [b]	88.10 [ab]	84.6 [b]	85.0 [a]	84.8 [ab]	79.73	80.17	97.0	97.4	97.3
Ca, ppm	159	152	185	537	504	487	1520	1460		-	
K, %	0.405	0.399	0.394	0.439	0.435	0.428	0.500 [a]	0.473 [b]		-	
Mg, %	0.103 [b]	0.104 [ab]	0.109 [a]	0.133 [a]	0.134 [a]	0.121 [b]	0.157	0.154		-	
P, %	0.299	0.296	0.307	0.376 [a]	0.380 [a]	0.352 [b]	0.414	0.389		-	
S, ppm	916	924	952	1430 [a]	1330 [b]	1340 [b]	1700	1900		-	

[1] Only in LEG and MNR systems; [2] Protein = crude protein (%); [3] Fat = crude fat (%); [4] net energy for growth Mcal kg^{-1}; [5] net energy for lactation Mcal kg^{-1}; [6] net energy for maintenance Mcal kg^{-1}; [7] TDN = total digestible nutrients

Protein levels highest in Organic Manure Maize, Conventional Wheat, and Organic Legume Soybean

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Pearsons et al. 2022. *Sustainability*

Farming Systems Trial

Soil Chemical Indicators, Farming Systems Trial, 2019

Systems	pH	Total N %	P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg	S mg/kg
Conventional	6.13 b	0.29 b	6.02 b	84.81	1241.00 b	111.29 b	7.63 b
Legume	5.90 b	0.29 ab	6.21 b	90.83	1183.81 b	87.50 c	10.65 a
Manure	6.18 a	0.32 a	8.54 a	99.10	1542.88 a	130.69 a	10.60 a
System	< 0.001	< 0.01	< 0.01	NS	< 0.001	< 0.001	< 0.001
Tillage	NS	NS	0.06	NS	NS	NS	NS
System x Tillage	NS	NS	NS	NS	NS	NS	NS

Sampling Date – November 11, 2019

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Farming Systems Trial

Wheat Nutrients, 2019

Wheat, 2019

	---------- mg per 100g ----------							
Systems	Ca	Fe	K	Mg	Zn	B_6	Protein	Kcal
Conventional	31.45	2.55	351.39	120.76 B	2.84	0.26 A	12.19 A	363.57 A
No-Till	33.60	2.64	356.25	121.33	2.89	0.26	12.20	364.00
Tillage	29.85	2.48	347.74	120.33	2.81	0.27	12.19	363.25
Legume	34.16	2.52	353.06	119.35 B	2.66	0.24 B	10.52 B	359.75 B
No-Till	29.58	2.45	346.04	117.66	2.66	0.23	10.27	359.25
Tillage	38.74	2.59	360.09	121.03	2.65	0.24	10.77	360.25
Manure	31.92	2.73	364.02	130.03 A	2.76	0.23 B	10.80 B	356.63 C
No-Till	33.09	2.79	374.44	132.32	2.79	0.23	10.70	357.38
Tillage	30.76	2.67	353.61	127.74	2.74	0.23	10.89	355.88
System	NS	0.0514	NS	***	NS	***	***	***
Tillage	NS	NS	NS	NS	NS	NS	NS	NS
System x Tillage	*	NS	NS	NS	NS	NS	NS	NS

Conventional wheat received 60 kg/ha of ammonium nitrate – explains higher Vitamin B_6 and Protein

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Toward a nutrient density score

Nutrient density = nutrient concentration (g, mg, µg) divided by energy (kcal)

PLUS

meets nutritional values needed to sustain a *thriving* life.

Example: Nutritional Quality Index (NQI)

$$\textbf{NQI} = \frac{\textbf{Sample nutritional value (mg/g)}}{\textbf{Reference Daily Value (mg)}} \div \frac{\textbf{Sample caloric value (kcal/g)}}{\textbf{2000 kcal}} = \textbf{> or < 1}$$

DRI values are Daily Recommended Intake values from tables from the National Academy of Sciences Food and Nutrition Board, https://ods.od.nih.gov/Health_Information/Dietary_Reference_Intakes.aspx

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Adam Drewnowski. 2005. *The American Journal of Clinical Nutrition*

Toward a nutrient density score

Wheat, 2019

FARMING SYSTEMS TRIAL

Systems	Mean NQI (13 Nutrients)	Naturally Nutrient Rich (7 nutrients plus fiber)	Calorie For Nutrient (13 Nutrients)
Conventional	2.355 a	1.355 a	8.72 a
Organic Legume	1.914 b	1.276 b	10.54 b
Organic Manure	2.10 a	1.336 a	9.61 a
P-value	< 0.05	< 0.01	< 0.05

- **Ca**, Cu, Cr, **Fe**, **K**, **Mg**, Mn, Mo, Na,P, **Zn**, **B_6**, **Total Protein**
- Need to add additional vitamins and antioxidant compounds

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Vegetable Systems Trial
Nutrient Density - Winter squash

CNV = Conventional, ORG = Organic, BP = Black Plastic (high tillage), RT = Reduced Tillage

Overall mean winter squash NQI with cropping systems, Rodale Institute, 2020-2022

System	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Vit B6	Vit C	Proteins
CNV	3.11	3.85	**1.26 b**	**2.30 b**	**0.50 b**	2.06	**4.71 b**	0.92	**3.40 b**	**3.77**	**0.80 b**
ORG	3.22	4.07	**1.63 a**	**2.56 a**	**0.61 a**	2.24	**6.40 a**	1.00	**3.61 a**	**3.44**	**0.97 a**

Overall mean winter squash NQI with management practices, Rodale Institute, 2020-2022

Management	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Vit B6	Vit C	Proteins
BP	**2.67 b**	**3.70 b**	**1.27 b**	2.34	0.54	1.96	**5.15 b**	0.93	**3.72 a**	3.81	0.94
RT	**3.65 a**	**4.23 a**	**1.61 a**	2.51	0.57	2.34	**5.95 a**	0.98	**3.30 b**	3.39	0.83

- **ORGANIC**: An increase in Ca, Mg, Fe, Cu, Vitamin B6 and proteins.
- **Reduced tillage**: An increase in P, K, Ca, and Cu.
- These nutrients play important roles in energy production, enzyme regulation, scavenging reactive oxygen and free radicals.

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Vegetable Systems Trial
Nutrient Density – 'Lehigh' Potatoes

Overall mean VST potato 'Lehigh' NQI with cropping systems, Rodale Institute, 2020-2022

System	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Vit B6	Vit C	Proteins
CNV	2.82	**2.83 b**	0.16	**2.10 b**	0.92	2.12	**4.92 b**	1.13	**3.52 b**	4.98	**1.44 b**
ORG	2.83	3.24 a	0.15	2.45 a	0.92	2.11	5.35 a	1.10	3.78 a	4.91	1.52 a

Overall mean VST potato 'Lehigh' NQI with management practices, Rodale Institute, 2020-2022

Management	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Vit B6	Vit C	Proteins
BP	**2.92 a**	3.06	0.16	**2.32 a**	**0.87 b**	2.14	5.25	1.11	3.72	**4.63 b**	1.48
RT	**2.72 b**	3.02	0.15	**2.21 b**	0.96 a	2.09	5.02	1.12	3.58	5.26 a	1.49

- **ORGANIC**: An increase in K, Mg, Cu, Vitamin B6 and proteins.
- **Reduced tillage**: An increase in Fe and Vitamin C.
- These minerals such as Mg important in K and Ca transport and coordination of neuromuscles.

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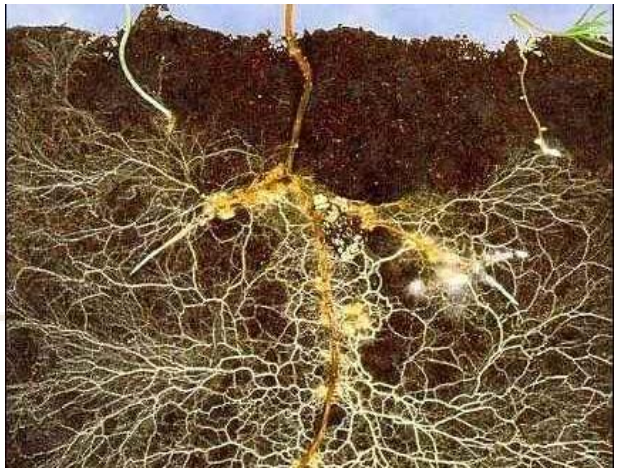
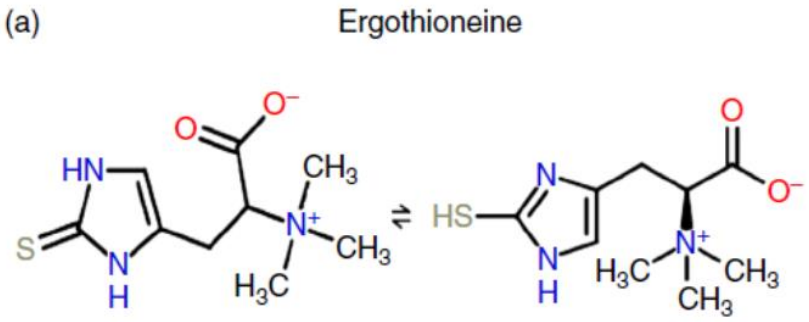
Ergothioneine





- Amino acid only produced by fungi or fungi-like bacteria
- Not synthesized by plants but attained through our diet
- Antioxidant, anti-inflammatory, cardiovascular disease and neurodegenerative??

Longitudinal Consumption of Ergothioneine Reduces Oxidative Stress and Amyloid Plaques and Restores Glucose Metabolism in the 5XFAD Mouse Model of Alzheimer's Disease

Clayton A. Whitmore 1,2, Justin R. Haynes 1,2, William J. Behof 1,2, Adam J. Rosenberg 1,2 ,Mohammed N. Tantawy 1,2, Brian C. Hachey 3, Brian E. Wadzinski 4, Benjamin W. Spiller 4, Todd E. Peterson 1,2, Krista C. Paffenroth 4,5, Fiona E. Harrison 5,6,7 , Robert B. Beelman 8, Printha Wijesinghe 9, Joanne A. Matsubara 9 and Wellington Pham 1,2,5,7,10,11,12,13,*

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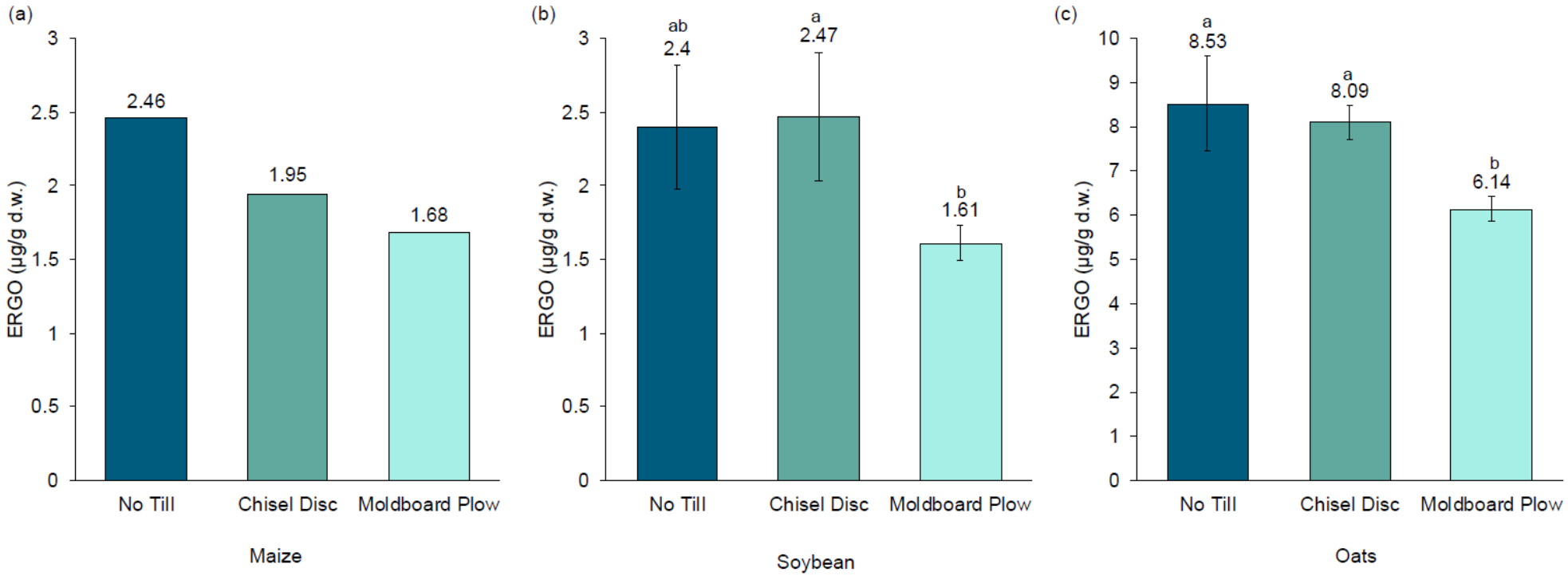
pharmaceuticals

Article *agronomy*

Soil Disturbance Impact on Crop Ergothioneine Content Connects Soil and Human Health

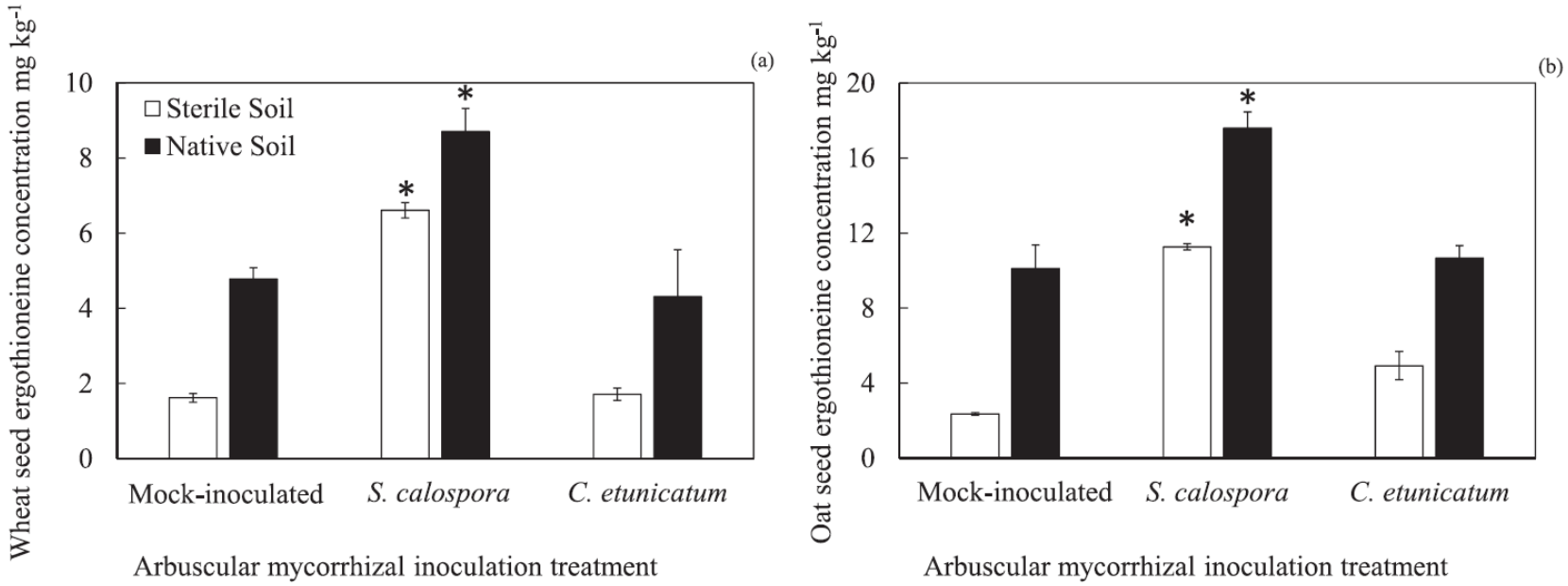
Robert B. Beelman [1,*], John P. Richie, Jr. [2], Allen T. Phillips [3], Michael D. Kalaras [1], Dongxiao Sun [4] and Sjoerd W. Duiker [5]



Linking soil health to human health: Arbuscular mycorrhizae play a key role in plant uptake of the antioxidant ergothioneine from soils

Plants People Planet PPP Open Access

Joseph E. Carrara[1] | Steven J. Lehotay[1] | Alan R. Lightfield[1] | Dongxiao Sun[2] | John P. Richie Jr[3] | Andrew H. Smith[4] | Wade P. Heller[1]



Specific arbuscular mycorrhizal fungi play a role in uptake or biosynthesis of ergothioneine

Farming Systems Trial

PENNSTATE HERSHEY
Milton S. Hershey Medical Center

Ergothioneine

----- mg per kg ------

Main Treatment	Tillage	Oats 2014	Oats 2017	Wheat 2019
Conventional	No Till	10.43 a	12.83 a	3.29 a
	Tilled	8.33 ab	9.32 b	2.12 ab
Legume	No Till	6.913 b	6.55 bc	1.42 b
	Tilled	6.618 b	4.85 c	1.31 b
Manure	No Till	8.49 ab	4.36 c	1.46 b
	Tilled	5.75 b	3.70 c	1.46 b
	System	NS	NS	***
	Tillage	*	**	NS
	SystemxTillage	NS	NS	NS

Conventional wheat received 60 kg/ha ammonium nitrate top dressed in spring

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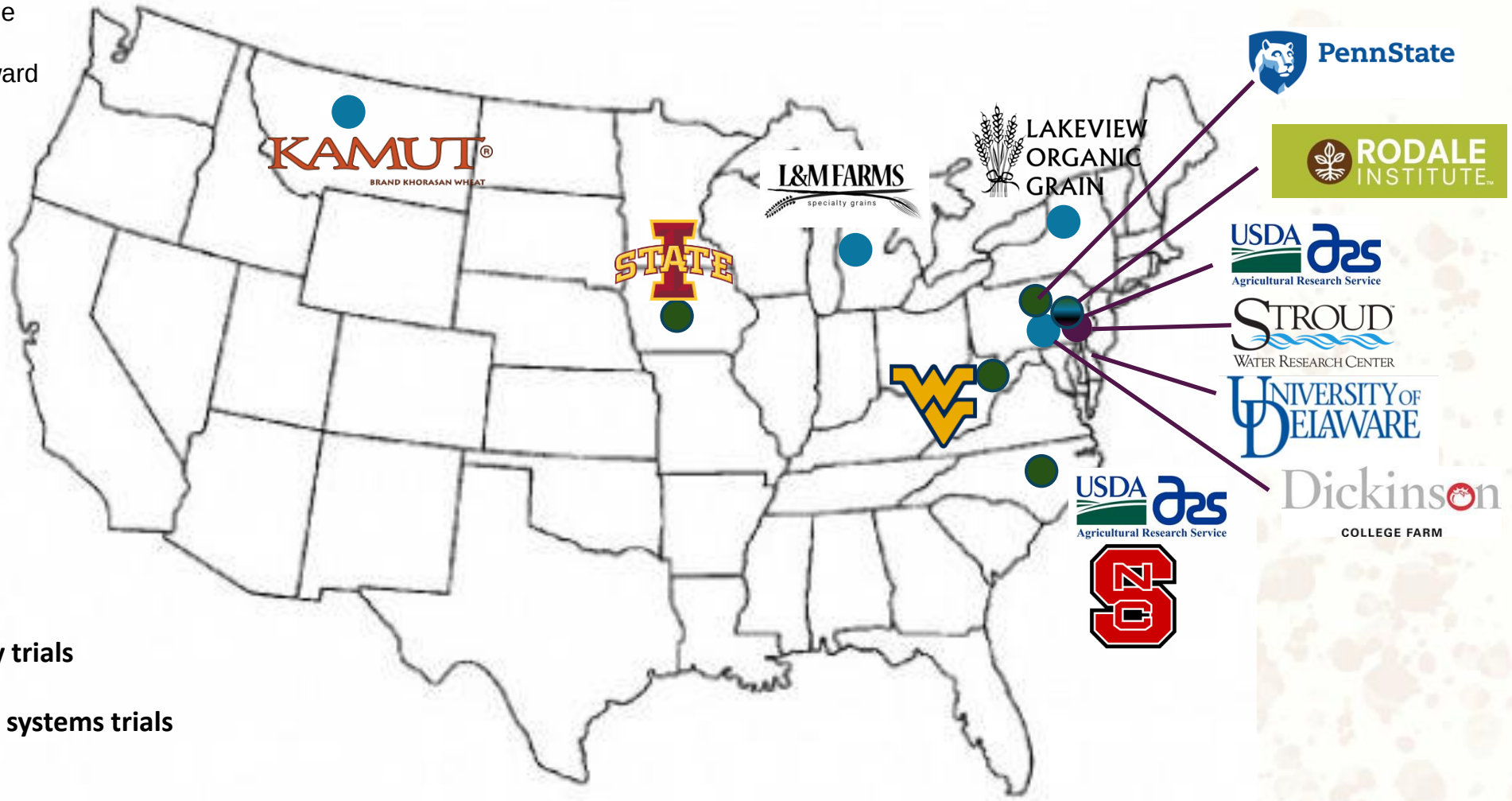
Exploring the Link Between Soil and Human Health: Protein, Protein Quality and the Nutraceutical Amino Acid Ergothioneine

This project is funded by the Foundation for Food and Agricultural Research – Award #CA20-SS-0000000152

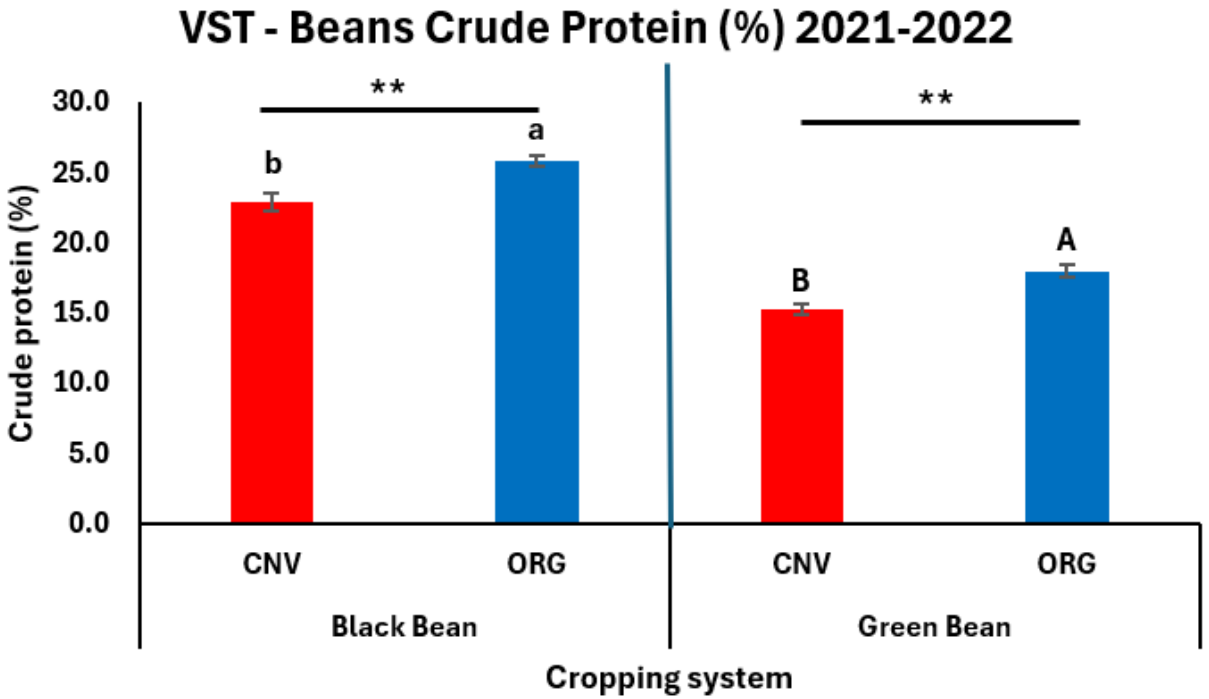


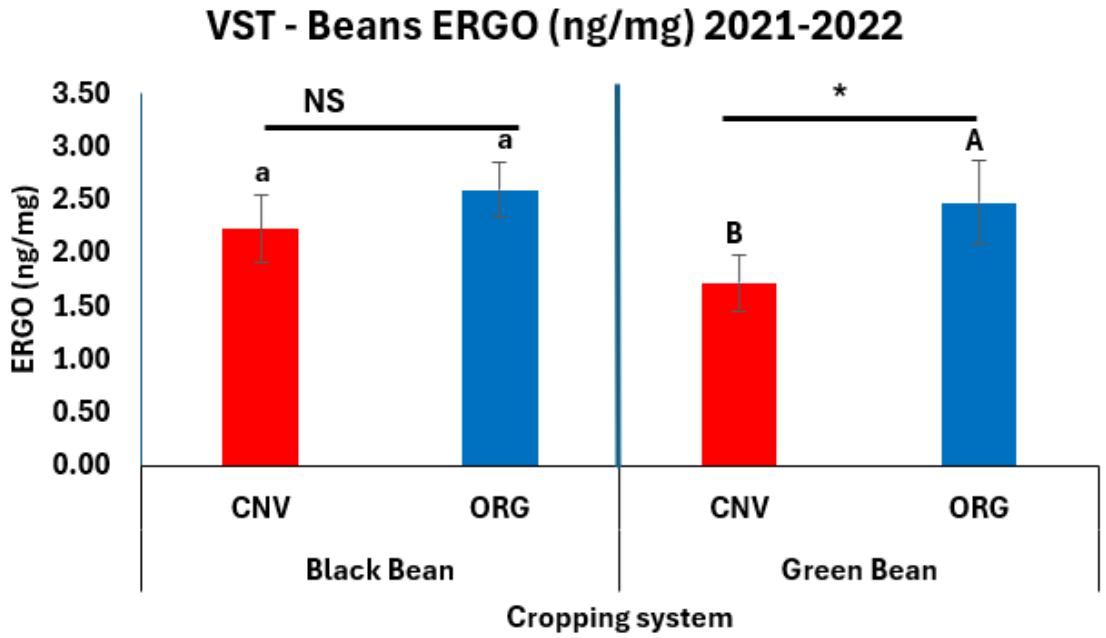
On-farm wheat variety trials

Long-term agricultural systems trials

In partnership with

Vegetable Systems Trial
Ergothioneine - Black Bean and Green Bean (*Phaseolus vulgaris*)

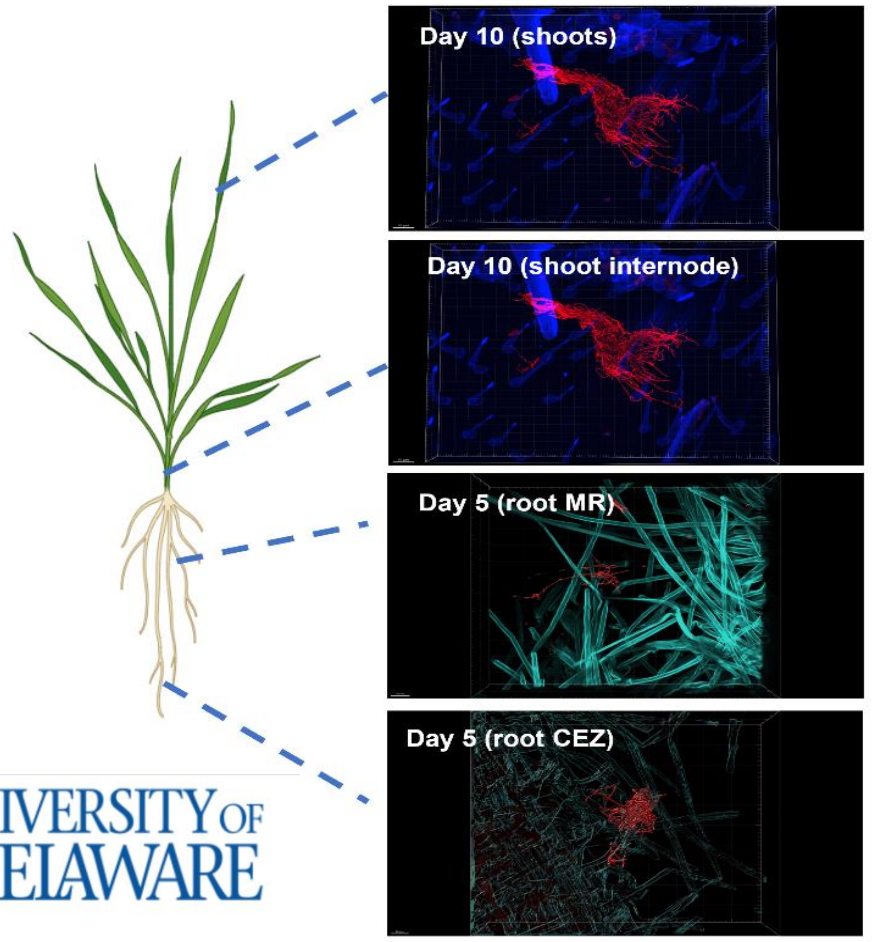




- Crude protein levels in black beans **>>** green beans.
- Crude protein levels ORG > CNV.
- ERGO concentration in ORG green bean > CNV green beans.

Current and Future Research Directions

- **Publish multi-year results**
- **More in-depth nutrient analysis – expand measurement of phytonutrients**
- **Explore microbial basis of phytonutrient concentrations**



Streptomyces coelicolor colonization in *in vitro* grown wheat plants. Post inoculation, plants were imaged for *S. coelicolor* colonization in roots and shoots. The red in the micrograph shows the presence of live *S. coelicolor*.

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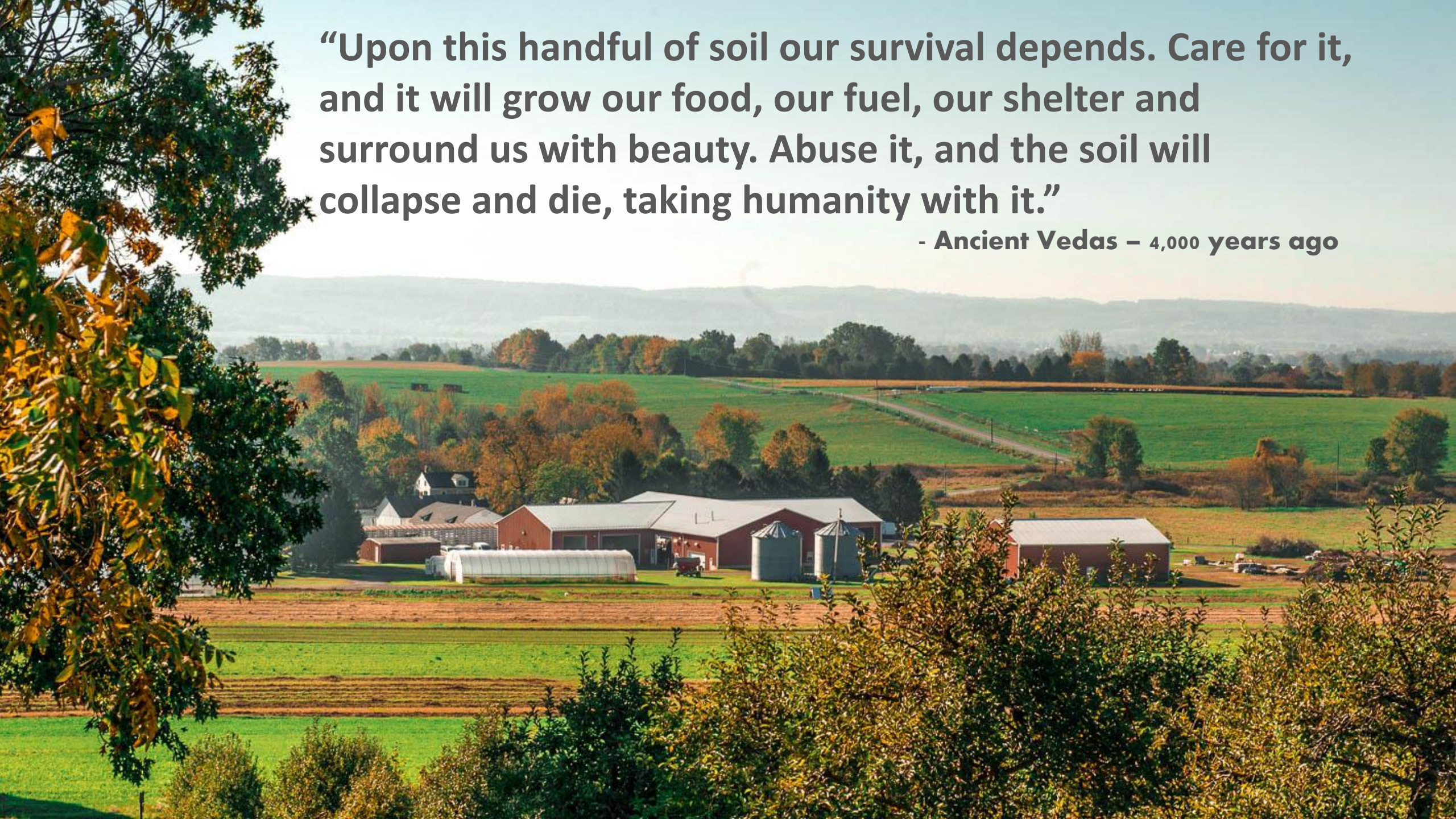
“Upon this handful of soil our survival depends. Care for it, and it will grow our food, our fuel, our shelter and surround us with beauty. Abuse it, and the soil will collapse and die, taking humanity with it.”
- Ancient Vedas – 4,000 years ago