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SOILS: WHERE FOOD BEGINS

Micronutrient management adaptations to climate change: Extrapolations from findings on copper and zinc chemistry in semi-arid to arid climate of the United States

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Background

- Micronutrients are critical to crop health and productivity.
- Copper and zinc are vital in enzyme activation, chlorophyll formation, carbohydrate and protein syntheses.
- Chemistry vary with climate and soil characteristics (temporally and spatially).
- Climate change (variability in weather patterns) compounds nutrient management problems.
- Climate–smart practices are inevitable.
- Fertilizer shortage, wars, pandemic, and environmental deterioration call for need to maximize natural soil and crop potential.

Cu and Zn Chemistry: Reactions and Interactions

Soil Reactions

- Complexation
- **Ion Exchange**
- Adsorption
- **Desorption**
- Precipitation
- **Dissolution**
- Acid-Base Equilibria

Copper	Zinc
Cu^{2+}	Zn^{2+}
Soil pH: -	**Soil pH: -**
Texture: Poor in coarse texture	Soil OM: - or +
Soil OM: Strong OM-Cu-Clay complex	**Interaction with other nutrients, e.g., Cu^{2+}, Fe^{2+}, Mn^{2+} inhibit Zn^{2+} High P affects Zn uptake**
Interaction with other nutrients, e.g., High P, Zn, and Fe lowers root Cu absorption	Climate and soil condition, e.g., cold weather induces deficiency; flooding may as well under acid soil ($ZnFe_2O_4$)

Study Site Significance

USA

Texas

- **Site:** Lubbock, TX (Located in the Southern High Plains, USA)
- **Climate:** Semi-arid to Arid
- **Rainfall:** 18.65 inches ~ 470 mm (111-year average); 2022 so far (3.96 inches)
- **Mean Annual Temp:** ~ 16 °C
- **Soil:** Mostly pH 7.52 to 8.39; aridic; thermic
- **Aquifer:** Ogallala
- **Agriculture:** 30-40% of US cotton
- **Challenges of SHP:** Drought, wind erosion, hail, salinity, declining aquifer, water quality, micronutrient deficiency

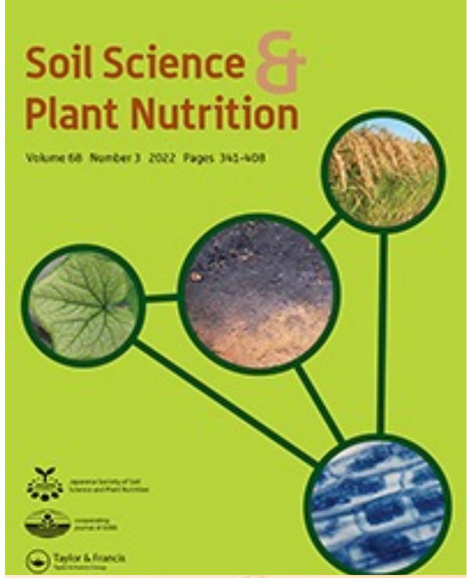
Objectives

1. **Draw inferences from two previous studies:**

   - Udeigwe et al. (2016). Copper micronutrient fixation kinetics and interactions with soil constituents in semi-arid alkaline soils. *Soil Science and Plant Nutrition*, *62*(3), 289-296. https://doi.org/10.1080/00380768.2016.1197046

   - Udeigwe et al. (2017). Plant-available zinc fixation kinetics in semi-arid alkaline soils of the Southern High Plains. *Archives of Agronomy and Soil Science*, *63*(4), 553-564. https://doi.org/10.1080/03650340.2016.1227068

2. **Extrapolate the findings from the referenced studies to the management of these micronutrients in a time of climate change.**



Methodology: Soil Sampling and Tests

- **Soil Samples:** Six different production sites in West Texas, USA at 0 -15 cm and 15 -30 cm depths (for a total of 12 soil samples).
    - Amarillo 1
    - Amarillo 2
    - Pullman
    - Acuff
    - Pyron
    - Mansker

- **Soil Tests**
    - Soil pH
    - Electrical Conductivity (EC)
    - OM
    - % $CaCO_3$
    - Total Carbon (TC), Total Nitrogen (TN)
    - Exchangeable Cations
    - Particle Size Analysis
    - DTPA Extractable Cu, Fe, Mn, and Zn
    - Total Elemental Analysis

Methodology: Kinetic Modeling

Approach

- DTPA extraction was conducted at a specified interval over a period of approximately 90 days.
- Extracts were analyzed for micronutrients using ICP-OES
- Data was fitted to various kinetic models: zero, first, second, and power functions.
- All statistical analyses were conducted using Statistical Analysis Software (SAS, ver. 9.3).

Kinetic Models

	Kinetic model	Equation	Parameter
1	Zero order	$q_t = q_0 - k_0 t$	k_0, zero-order rate constant (mg kg^{-1} day^{-1})
2	First order	$\ln q_t = \ln q_0 - k_1 t$	k_1, first-order rate constant (day^{-1})
3	Second order	$1/q_t = 1/q_0 + k_2 t$	k_2, second-order rate constant [(mg $kg^{-1})^{-1}$ day^{-1}]
4	Power function	$q_t = at^b$	a, initial reaction magnitude constant [(mg kg^{-1} $(day^{-1})^b$] and b, reaction rate constant

[a] q_0 and q_t are the amount of micronutrient at times zero and t, respectively.

Results: Soil Characteristics

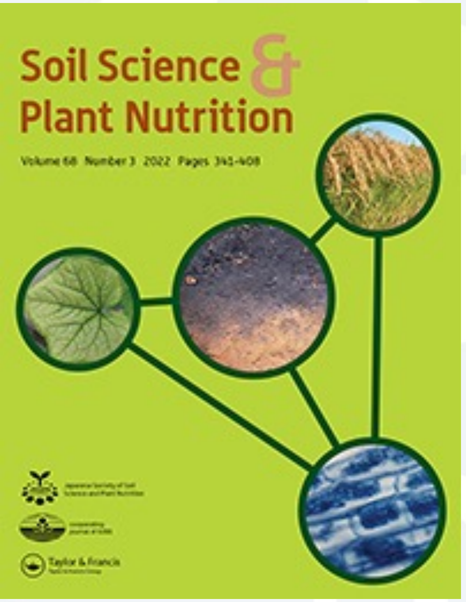
Table 1. Soil classification, identification and selected properties of the studied semi-arid alkaline soils of the Southern High Plains, USA.

Series (classification)	Sample identification	Sampling location	pH	EC	OM	$CaCO_3$	Clay	Sand	Silt	Textural class*
				$dS\ m^{-1}$	%					
Pyron (Fine, mixed, superactive, thermic Typic Argiustolls)	S_a	32.7211°N,	7.52	0.22	1.56	2.34	32.8	39.9	27.3	CL
	S_b	100.8386°W	8.02	0.24	1.57	4.16	33	38.7	28.3	CL
Acuff (Fine-loamy, mixed, superactive, thermic Aridic Paleustolls)	O_a	33.8403°N,	8.39	0.35	1.31	4.68	29.7	49.1	21.3	SCL
	O_b	101.6999°W	8.36	0.27	1.43	4.55	37.6	50.7	11.7	SC
Amarillo (Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs)	$A1_a$	33.5935°N,	8.18	0.23	1.7	1.95	26	61.1	12.9	SCL
	$A1_b$	101.9058°W	8.24	0.21	1.35	1.17	24.7	61.7	13.6	SCL
	$A2_a$	33.6058°N,	8.32	0.17	0.59	0.46	19.4	72.4	8.2	SL
	$A2_b$	101.9073°W	8.3	0.17	0.75	0.65	23.2	65.7	11.1	SCL
Pullman (fine, mixed, superactive, thermic Torrertic Paleustolls)	P_a	34.05901°N,	8.07	0.24	1.05	2.41	17.8	74.9	7.4	SL
	P_b	101.4773°W	8.35	0.22	0.93	5.59	24	64.2	11.8	SCL
Mansker (coarse-loamy, carbonatic, thermic Calcidic Paleustolls)	M_a	34.1261°N,	8.12	0.27	1.63	0.98	27.9	56.5	15.6	SCL
	M_b	101.5899°W	8.2	0.25	1.24	0.13	41.9	40.9	17.2	C

EC, electrical conductivity; OM, organic matter; $CaCO_3$, calcium carbonate; SCL: sandy clay loam; SC: sandy clay; SL: sandy loam; CL: clay loam; C: clay; a = 0–15 cm; b = 15–30 cm.

Environmental Characteristics: Semi arid to arid, drought, wind erosion, hail, salinity, declining aquifer, water quality, micronutrient deficiency

Results & Discussion: Cu Kinetics (90 d)

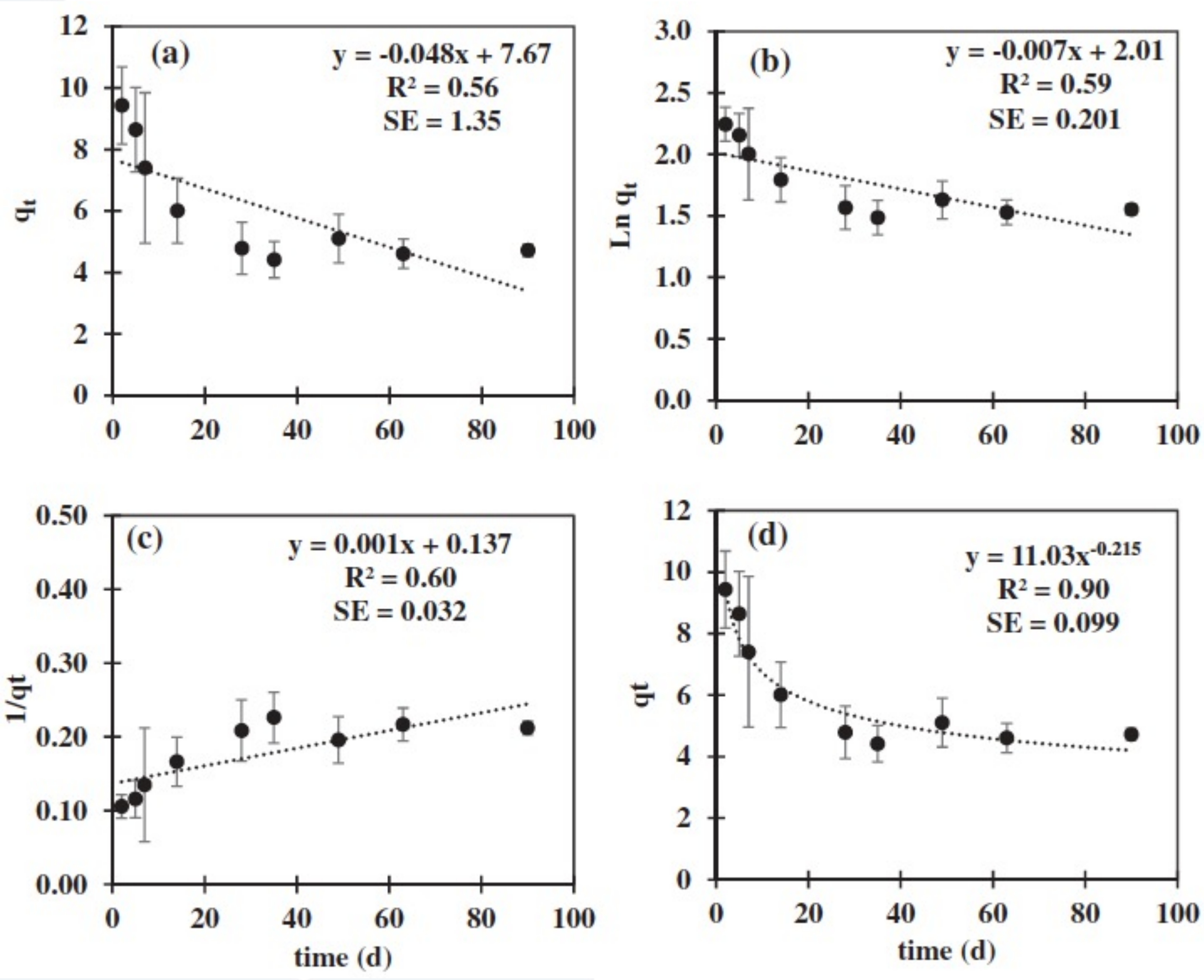


Zero Order

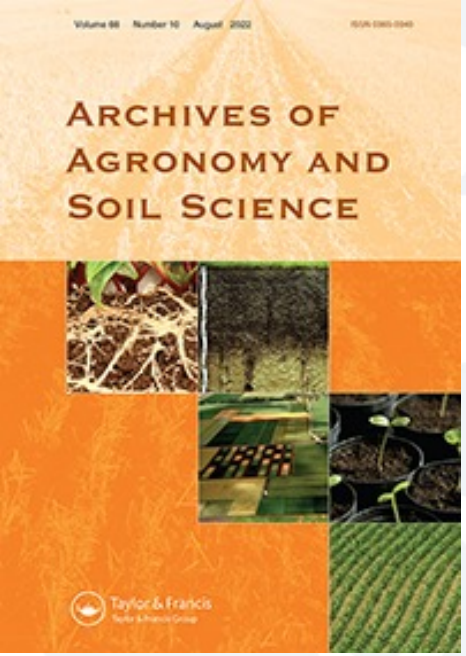
First Order

Second Order

Power Function



Results & Discussion: Zn Kinetics (90 d)

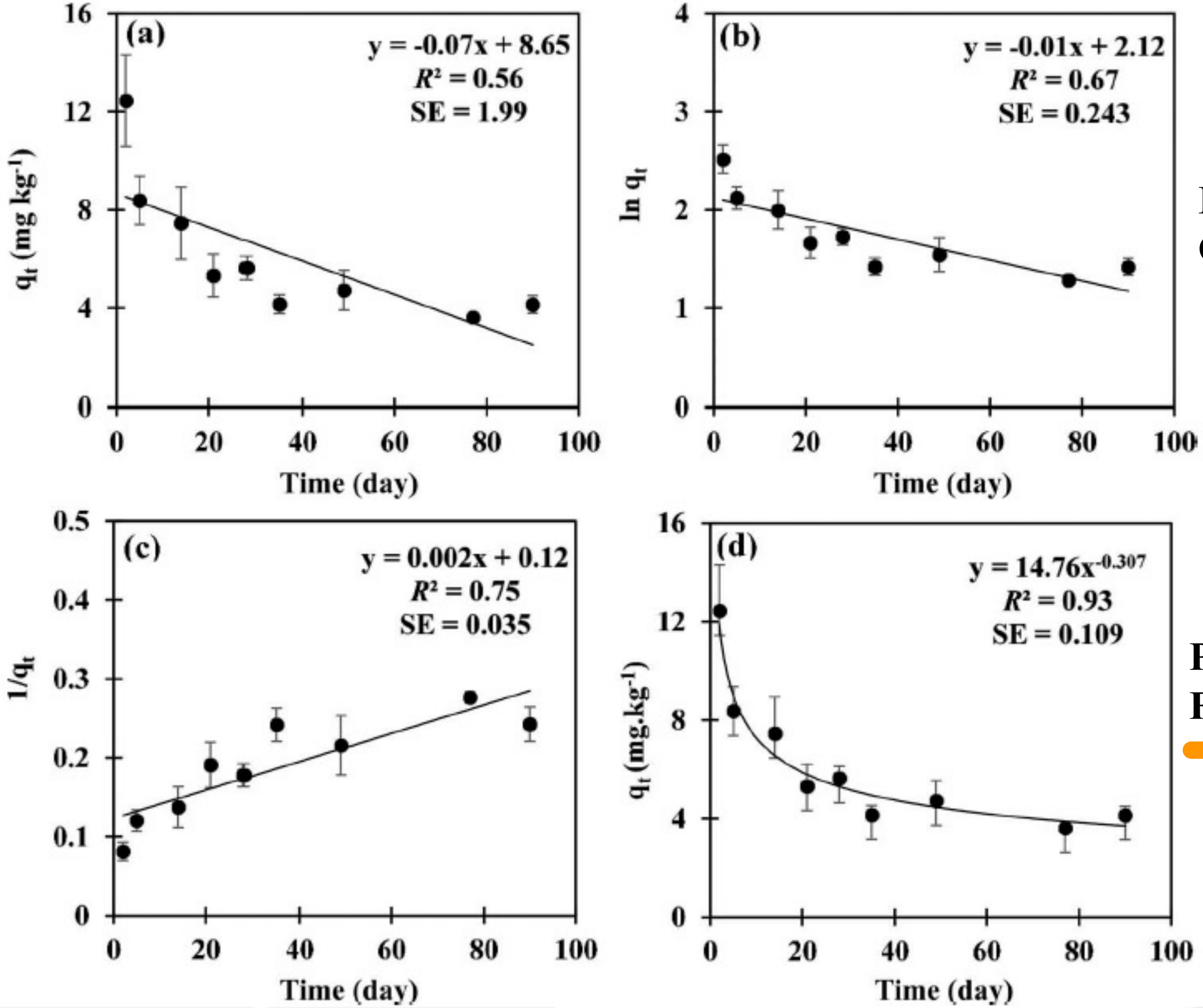


Zero Order

First Order

Second Order

Power Function



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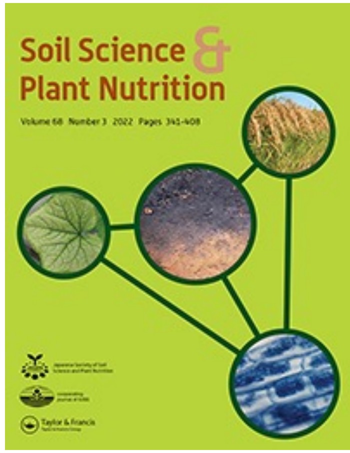
Results & Discussion: Cu and Zinc Micronutrients



- Most Cu (80%) was fixed within the first 14 days
- **Short term (14 days) Cu fixation controlled by OM + pH**
- Long term (90 days) Cu fixation controlled by pH and pH + $CaCO_3$.
- **Cu Fixation within 35 d better described by second order model (R^2=0.98)**
- Cu Fixation within 90 d better described by power function model (R^2=0.90)

- **Most Zn (57%) was fixed within the first 14 days**
- Zinc fixation within 90 d showed a weak +trend with pH and Total P
- **Zn Fixation kinetic (35 d) better described by second order model (R^2=0.91)**
- Zn fixation (90 d) better described by the power function model (R^2=0.93)
- **Reaction rates for Zn higher (more rapid fixation) in the subsurface soils**

Conclusion and Recommendations

- Timing is critical (most Cu and Zn fixed within 14 days)
- **Chelated compounds of Cu and Zn should be used (supported by a comparative study)**
- Foliar application recommended given interactions with soil constituents
- **Organic residue incorporation is encouraged (relevant to soil recovery, productivity, and sustainability**
- Think regenerative….cover cropping, rotation, mulching, conservation tillage, waste incorporation…
- **Biotechnology (biostimulants) incorporation to maximize natural plant and soil potentials is more paramount now.**

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Thank you!

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