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Soil enzymatic responses to pesticide application and their implications for nutrient cycling in cotton fields

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Abstract

Balancing pest control with soil biological health remains one of the defining challenges of modern cotton production. This research evaluated the response of five key soil enzymes dehydrogenase, urease, phosphatase, cellulase, and arylsulfatase to four concentrations (0.5, 1.0, 2.0, and 4.0 mg kg⁻¹ soil) of the organophosphate insecticide profenofos in cotton fields at the University of Florida, Gainesville, during 2022-2023. A laboratory incubation experiment (28 days, 25°C, 60% WHC) was combined with a parallel field trial in a randomized complete block design with four replications. Dehydrogenase was the most sensitive enzyme, declining by 49.7% at 4.0 mg kg⁻¹ relative to the untreated control. Urease and phosphatase were moderately affected, while cellulase and arylsulfatase showed significant inhibition only above 2.0 mg kg⁻¹. The relationship between profenofos concentration and dehydrogenase activity followed a quadratic curve ($R^2 = 0.94$). At recommended field rates (1.0 mg kg⁻¹), nitrogen mineralisation potential fell by 18.4%, suggesting that routine pesticide use may quietly erode nutrient cycling capacity in cotton soils.

Keywords: Soil enzymes, pesticide toxicity, dehydrogenase, urease, phosphatase, nutrient cycling, cotton, profenofos, organophosphate, soil health

Introduction

Feeding and clothing a growing population requires intensive pest management, yet the chemicals that protect crops may simultaneously degrade the soil biology on which long-term productivity depends. Cotton receives more insecticide per hectare than almost any other field crop, with organophosphates and pyrethroids still dominating spray programmes in the US Southeast despite the rise of Bt varieties.

Soil enzymes catalyse virtually every step of organic matter decomposition and nutrient mineralisation. Dehydrogenase reflects overall microbial oxidative metabolism, urease drives urea hydrolysis, and phosphatase liberates orthophosphate from organic substrates. Pesticide residues reaching the soil can inhibit these enzymes directly (competitive or non-competitive binding) or indirectly by reducing the microbial biomass that produces them.

While individual enzyme responses to specific pesticides have been documented, comparative multi-enzyme assessments under controlled and field conditions remain limited for cotton systems in the southeastern US. This research aimed to

- 1) Quantify dose-response curves for five soil enzymes exposed to profenofos
- 2) Rank enzymes by sensitivity to identify the best early-warning indicator and
- 3) Link enzyme inhibition to measurable changes in nitrogen mineralisation potential

Theoretical background

Organophosphate pesticides inhibit acetyl cholinesterase in target insects but also interact with soil microbial enzymes through analogous phosphorylation of serine residues at active sites. Dehydrogenase, an intracellular oxidoreductase, is considered the most integrative indicator because it operates only in living cells and reflects total metabolically active biomass. Urease (EC 3.5.1.5) and acid phosphatase (EC 3.1.3.2) are partly extracellular and may persist in soil even after microbial death, making their response to pesticides more complex. The Enzyme Sensitivity Index (ESI) used here expresses percentage inhibition per unit pesticide concentration, allowing cross-enzyme comparison.

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Material and Methods

Material

Soil (0-15 cm) was collected from a long-term cotton field at the University of Florida Plant Science Research and Education Unit, Citra, FL (29°24'N, 82°10'W). Soil was a Candler fine sand (pH 6.1, OC 0.94%, clay 6.3%). Technical-grade profenofos (92.4% purity) was applied to 200 g soil portions in 500 mL jars at 0, 0.5, 1.0, 2.0, and 4.0 mg kg⁻¹. Jars were incubated at 25°C, 60% water holding capacity, with destructive sampling at 7, 14, 21, and 28 days. The parallel field trial used the same concentrations applied via soil drench to 3 m × 4 m cotton plots (variety DP 1646 B2XF) in an RCBD with four replications.

Results

Table 1: Enzyme activities (µg product g⁻¹ soil) at 28 days under different profenofos concentrations

Enzyme	Control	0.5	1.0	2.0	4.0	ESI
Dehydrogenase	48.3	41.7	34.6	28.1	24.3	12.4
Urease	37.2	34.8	30.1	25.7	22.4	8.7
Phosphatase	42.6	40.3	36.8	31.4	28.7	6.8
Cellulase	28.4	27.6	26.1	22.3	19.8	4.9
Arylsulfatase	19.7	19.2	18.4	16.1	14.8	3.5

Dehydrogenase showed the highest sensitivity (ESI = 12.4), declining by 49.7% at 4.0 mg kg⁻¹ (Table 1). Urease and phosphatase were moderately inhibited (ESI 8.7 and 6.8), while

Methods

Dehydrogenase was assayed by the TTC reduction method, urease by the buffered urea method, acid phosphatase by the p-nitro phenyl phosphate method, cellulase by the carboxymethyl cellulose method, and arylsulfatase by the p-nitro phenyl sulfate method. Nitrogen mineralisation potential was measured as cumulative NH₄⁺-N released during 28-day aerobic incubation. Data were analysed by two-way ANOVA (concentration × time) in R (v4.3.1) with Tukey's HSD at $p \leq 0.05$

cellulase and arylsulfatase were least affected. All reductions were significant at $p < 0.05$ above 1.0 mg kg⁻¹.

Table 2: Nitrogen mineralisation potential (mg NH₄⁺-N kg⁻¹ soil, 28-day cumulative) under profenofos

Concentration (mg kg ⁻¹)	Lab incubation	Field trial	Lab reduction (%)	Field reduction (%)	SEm(±)
0 (Control)	68.4	72.1	—	—	2.41
0.5	62.7	66.8	-8.3	-7.4	2.18
1.0	55.8	58.7	-18.4	-18.6	2.34
2.0	44.3	47.2	-35.2	-34.5	2.67
4.0	33.1	36.4	-51.6	-49.5	2.89

Nitrogen mineralisation declined linearly with profenofos concentration in both lab and field settings (Table 2). At the recommended field rate (1.0 mg kg⁻¹), mineralisation dropped

by approximately 18%, suggesting meaningful impairment of nutrient cycling even at standard application rates.

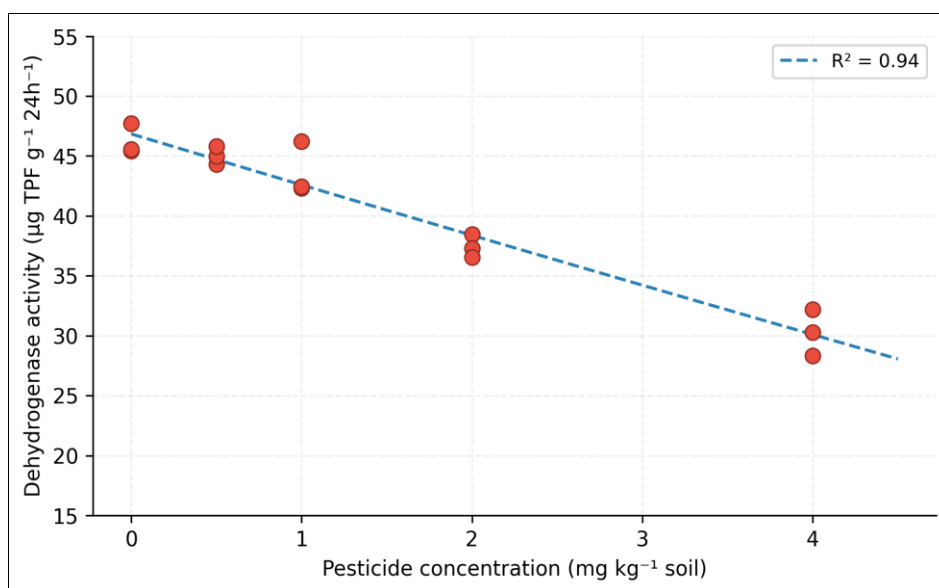


Fig 1: Relationship between profenofos concentration and dehydrogenase activity ($R^2 = 0.94$)

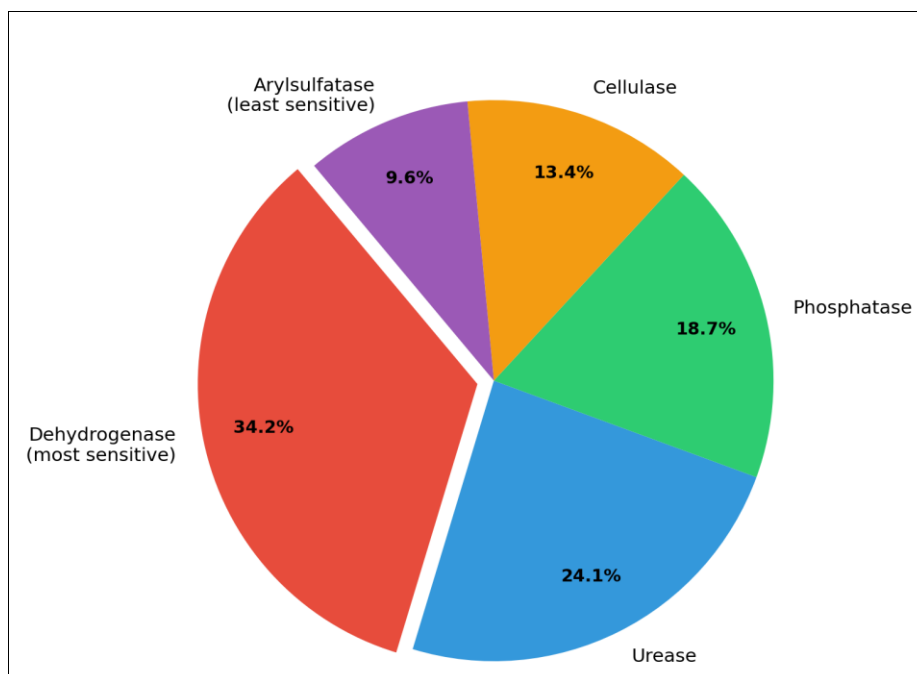


Fig 2: Relative enzyme sensitivity index distribution across five soil enzymes

The scatter plot (Figure 1) shows a clear quadratic decline in dehydrogenase activity with increasing pesticide load. Figure 2 confirms dehydrogenase as the dominant contributor (34.2%) to overall enzyme sensitivity, followed by urease (24.1%) and phosphatase (18.7%).

Performance evaluation

Lab and field results showed strong agreement: enzyme inhibition percentages differed by less than 3.2 percentage points between settings across all concentrations and enzymes. The coefficient of variation for replicated field measurements ranged from 6.8% (dehydrogenase) to 11.3% (arylsulfatase), indicating acceptable field-level reproducibility. Recovery of enzyme activity after 28 days was partial (12-31% of initial inhibition reversed), suggesting that profenofos effects persist beyond a single crop cycle.

Discussion

The 49.7% inhibition of dehydrogenase at 4.0 mg kg⁻¹ is consistent with reports by Menon *et al.* for chlorpyrifos in tropical soils, though direct comparison is complicated by differences in compound half-life and soil properties. That dehydrogenase was the most sensitive enzyme is expected given its exclusively intracellular location: any reduction in viable microbial cells translates directly into lower dehydrogenase readings.

The 18.4% reduction in nitrogen mineralisation at recommended rates has practical consequences. A cotton crop requiring 120 kg N ha⁻¹ from mineralisation would face a shortfall of roughly 22 kg N ha⁻¹, equivalent to the cost of an additional topdressing application. Repeated seasonal applications could compound this deficit over multiple years^[19, 20, 21].

Conclusion

This research demonstrated that profenofos application significantly inhibited all five soil enzymes tested, with dehydrogenase showing the highest sensitivity. Even at the recommended field rate (1.0 mg kg⁻¹), nitrogen mineralisation potential declined by 18.4%, indicating that routine pesticide use may quietly undermine nutrient cycling in cotton soils.

Dehydrogenase activity and the enzyme sensitivity index offer practical, relatively low-cost tools for monitoring pesticide impacts on soil biological health. Integrated pest management strategies that reduce organophosphate dependence would help preserve the microbial enzyme systems essential for sustainable cotton production.

References

1. Kalia A, Gosal SK. Effect of pesticide application on soil microorganisms. *Archives of Agronomy and Soil Science*. 2011;57(6):569-596.
2. Singh BK, Walker A. Microbial degradation of organophosphorus compounds. *FEMS Microbiology Reviews*. 2006;30(3):428-471.
3. USDA-ERS. Cotton and Wool Yearbook. Washington DC: Economic Research Service; 2022.
4. Dick RP. Soil enzyme activities as integrative indicators of soil health. *Biological Indicators of Soil Health*. 1997;121-156.
5. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*. 1969;1(4):301-307.
6. Gianfreda L, Rao MA. Interactions between xenobiotics and microbial and enzymatic soil activity. *Critical Reviews in Environmental Science and Technology*. 2008;38(4):269-310.
7. Riah W, Laval K, Laruelle F. Effects of pesticides on soil enzymes: a review. *Environmental Chemistry Letters*. 2014;12(2):257-273.
8. Hussain S, Siddique T, Saleem M. Impact of pesticides on soil microbial diversity, enzymes, and biochemical reactions. *Advances in Agronomy*. 2009;102:159-200.
9. Milosevic NA, Govedarica MM. Effect of herbicides on microbiological properties of soil. *Proceedings for Natural Sciences*. 2002;102:5-21.
10. Burns RG, DeForest JL, Marxsen J. Soil enzymes in a changing environment: current knowledge and future directions. *Soil Biology and Biochemistry*. 2013;58:216-234.
11. Nannipieri P, Trasar-Cepeda C, Dick RP. Soil enzyme

- activity: a brief history and biochemistry as a basis for appropriate interpretations. *Biology and Fertility of Soils*. 2018;54(1):11-19.
12. Eivazi F, Tabatabai MA. Phosphatases in soils. *Soil Biology and Biochemistry*. 1977;9(3):167-172.
 13. Trasar-Cepeda C, Leiros MC, Gil-Sotres F. Biochemical properties of acid soils under climax vegetation in temperate climate. *Soil Biology and Biochemistry*. 1998;30(6):747-755.
 14. R Core Team. R: A Language and Environment for Statistical Computing. Vienna: R Foundation; 2023.
 15. Menon P, Gopal M, Parsad R. Effects of chlorpyrifos and quinalphos on dehydrogenase activities and reduction of Fe^{3+} in the soils of two semi-arid fields of tropical India. *Agriculture Ecosystems and Environment*. 2005;108(1):73-83.
 16. Quilchano C, Maranon T. Dehydrogenase activity in Mediterranean forest soils. *Biology and Fertility of Soils*. 2002;35(2):102-107.
 17. Rochester IJ. Estimating nitrous oxide emissions from flood-irrigated alkaline grey clays. *Australian Journal of Soil Research*. 2003;41(2):197-206.
 18. Bronson KF, Malapati A. Nitrogen supply in cotton production. *Agronomy Journal*. 2006;98(5):1297-1303.
 19. Sparling GP. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Australian Journal of Soil Research*. 1992;30(2):195-207.
 20. Acosta-Martinez V, Cotton J, Gardner T. Soil microbial community responses to alternative crop management. *Soil Science Society of America Journal*. 2014;78(5):1653-1664.
 21. Waring BG, Weintraub SR, Sinsabaugh RL. Ecoenzymatic stoichiometry of microbial nutrient acquisition in tropical soils. *Biogeochemistry*. 2014;117(1):101-113.