

Effect of Ultra Formulations on Soil Nutrient Status in Rice-Based Cropping Systems under Semi-Arid Conditions

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ABSTRACT

Sustainable agricultural production requires nutrient management strategies that maintain soil health while supporting high crop productivity. A two-year field experiment (2022-23 and 2023-24) was conducted to evaluate the influence of three ultra-formulation fertilizers i.e., Ultra Plus 45 (T2), Ultra Classic 45 (T3), and Ultra DRC Irrigation (T4) in comparison with the recommended dose of fertilizers (RDF, T1) under four rice-based cropping systems: Rice-Wheat (CS1), Rice-Raya-Summer Moong (CS2), Rice-Potato-Eggplant (CS3), and Rice-Potato-Tomato (CS4). The experiment followed a split-plot design and soil data were analyzed using R software. Results indicated that ultra-formulation fertilizers significantly improved soil chemical properties compared with the

conventional fertilizer treatment. Soil pH tended to shift toward neutrality under ultra-formulations, while soil organic carbon showed noticeable improvement, indicating enhanced soil quality. The Rice-Raya-Summer Moong system (CS2) contributed to better soil fertility status due to legume inclusion and biological nitrogen fixation. Overall, the integration of ultra-formulation fertilizers with diversified rice-based cropping systems showed promising potential for improving soil health and crop yield in semi-arid environments.

Keywords Cropping system, Ultra-formulations, Soil health, Soil quality, Nutrient management.

INTRODUCTION

Rice-based cropping systems play a vital role in ensuring food security in South Asia, particularly in semi-arid areas where soil nutrient depletion and imbalances are major constraints to sustainable productivity. Continuous cultivation of high yielding varieties with intensive fertilizer use often leads to the decline of soil nutrient reserves and deterioration of soil health, thereby affecting long-term crop productivity and sustainability. In such systems, maintaining optimal soil nutrient status is critical for ensuring efficient nutrient cycling and improved crop performance (Singh *et al.* 2025). Soil nutrient

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dynamics in rice-based systems is strongly influenced by management practices, cropping sequences, and fertilizer inputs. The availability of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) plays a crucial role in determining crop growth, yield, and quality. Among these, nitrogen is a key determinant of plant metabolic processes and grain quality, while phosphorus and potassium regulate energy transfer and stress tolerance in plants. However, conventional fertilization practices often suffer from low nutrient use efficiency due to losses through leaching, volatilization, and fixation, particularly under semi-arid environments (Yuan *et al.* 2024). Therefore, strengthening climate-resilient and sustainable agricultural systems through efficient nutrient management and improved agronomic practices has become essential to ensure food security without expanding cultivated land.

In recent years, advanced fertilizer technologies such as ultra formulations, including nano-fertilizers and silicon-based amendments, have gained attention for their potential to enhance nutrient availability and use efficiency. These formulations improve nutrient uptake by increasing surface area, facilitating controlled release, and enhancing foliar absorption, thereby minimizing nutrient losses, as also reported by Elekhtyar and AL-Huqail (2023). Silicon, though not considered an essential nutrient, has been widely reported to improve nutrient uptake, soil health, and plant resistance to abiotic and biotic stresses in rice-based systems (Cuong *et al.* 2017). Application of silicon fertilizers has been reported to enhance root development, improve antioxidant activity, and strengthen plant defense mechanisms, thereby contributing to improved crop resilience (Verma *et al.* 2022).

The integration of ultra formulations with conventional fertilization strategies has shown promising results in improving soil nutrient status, crop productivity, and sustainability. In this context, the present study was undertaken to evaluate the effect of ultra formulations on soil nutrient status and crop yield of different rice-based cropping systems under semi-arid conditions including rice-wheat, rice-raya-summer moong, rice-potato-eggplant, and rice-potato-tomato rotations.

MATERIAL AND METHODS

Site description

The field study was carried out during the 2022–23 and 2023–24 cropping seasons at the Research Farm of the Department of Soil Science, Punjab Agricultural University (PAU), Ludhiana, Punjab, India. The experimental site is situated at 30°56' N latitude and 75°52' E longitude, at an elevation of approximately 274 m above mean sea level. The area falls under a semi-arid, subtropical climatic zone and receives an average annual rainfall of about 700–800 mm.

Experimental design and fertilizer treatments

The study was conducted using a split-plot experimental design, in which each plot covered an area of 30 m². The experimental layout consisted of main plots and sub-plots. The main plot factor comprised four rice-based cropping systems: Rice–Wheat (CS1), Rice-Raya-Summer Moong (CS2), Rice-Potato-Eggplant (CS3), and Rice-Potato-Tomato (CS4). The sub-plot factor included four nutrient management treatments: the Recommended Dose of Fertilizers (RDF) as T1, RDF combined with Ultra Plus 45 as T2, RDF combined with Ultra Classic 45 as T3, and RDF combined with Ultra DRC Irrigation as T4. Each treatment combination was replicated three times under a fixed experimental layout, resulting in a total of 48 treatment units per replication.

The Recommended Dose of Fertilizers (RDF) followed Punjab Agricultural University (PAU) guidelines, using urea (N), SSP (P₂O₅), and MOP (K₂O), with rates varying by crop and variety. In addition, three Duraflex-Ultra formulations i.e., Ultra Classic 45, Ultra Plus 45, and Ultra DRC Irrigation were evaluated. These silicon-rich products (≈45% SiO₂) also contain essential nutrients (Fe, Ca, Mg, K). Ultra Plus 45 and Ultra Classic 45 are granular slow-release fertilizers that improve soil properties and nutrient availability, while Ultra DRC Irrigation is a liquid fertigation product that enhances nutrient delivery and plant uptake under varying moisture conditions.

Soil chemical analysis

Surface soil samples (0–15 cm) were collected, com-

posited, air-dried, and sieved (2 mm) for analysis. Soil pH and EC were measured in a 1:2 soil-water suspension (Jackson 1967). Available N was estimated by the alkaline KMnO_4 method (Subbiah and Asija 1956), and organic carbon by Walkley and Black (1934). Available P was determined using the Olsen method (Olsen *et al.* 1954), and exchangeable K by ammonium acetate extraction with flame photometry (Merwin and Peech 1951). Nutrient contents were expressed in kg ha^{-1} .

Statistical analysis

The data were statistically analyzed using both parametric and non-parametric approaches based on the nature of data. For individual crop yields under each fertilizer treatment, analysis of variance (ANOVA) was performed followed by Least Significant Difference (LSD) tests at a 5% significance level. To further distinguish each treatment means, LSD post hoc test was applied (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Soil health status

The soil physico-chemical properties were improved over two-year duration (Fig. 1). All parameters except pH were found significantly ($p < 0.05$) different under the influence of different fertilizer treatments and cropping systems. Under CS2 - pH, EC, OC and N were found maximum while under CS3 and CS4, P and K showed maximum values respectively in 2022-23. In 2023-24, under CS2, maximum pH, N, P and K were obtained while under CS4, EC was found maximum. OC showed at par values in CS1 and CS2. Soil pH ranged 4.98-5.38 from slightly acidic

conditions increased to ranged 4.34-6.79, alkalinity conditions in 2023-24. The application of fertilizers consistently for longer period shifted the soil pH towards neutrality likely due to the buffering capacity of the fertilizers, which supplies basic cations through organic matter decomposition, counteracting soil acidity (Howe *et al.* 2024). EC ranged from 150.00 to $441.67 \mu\text{S cm}^{-1}$ was highest under T2 in 2022-23 and ranged from 455.05 to $667.50 \mu\text{S cm}^{-1}$ under T3 in 2023-24, indicating possible salt accumulation due to intensive fertilizer use. EC results increased ion-exchange activity, nutrient cycling, and salt accumulation under T3 and T4, more effectively lead by CS3 and CS4, often linked to excessive application of chemical fertilizers without sufficient leaching or buffering organic inputs (Shrivastava and Kumar 2015, Howe *et al.* 2024). OC, N, P, and K showed highest content as 0.81%, 96.17 kg ha^{-1} , $114.47 \text{ kg ha}^{-1}$, and $163.99 \text{ kg ha}^{-1}$ respectively under T3 but in different cropping systems in 2022-23. In 2023-24, OC displayed highest at par values under T4 and T2 (1.43%) while NPK content were found highest under T4 ($121.26 \text{ kg ha}^{-1}$), T3 ($353.43 \text{ kg ha}^{-1}$), and T2 ($329.95 \text{ kg ha}^{-1}$), respectively. The relatively lower soil OC and NPK content in CS3 and CS4 may be attributed due to the high nutrient demand and rapid uptake associated with these intensive, multi-crop vegetable systems. Crops like potato, eggplant, and tomato have short growth cycles, shallow but efficient root systems, and require substantial nutrient inputs better fulfilled by T2 and T3 for optimal yield. In contrast, CS2 displayed elevated organic carbon and NPK due to the inclusion of legumes (Raya and Summer Moong), which contribute significantly to root biomass and leaf litter, enhance rhizodeposition, and promote symbiotic nitrogen fixation (Peoples *et al.* 2009).

Table 1. Mean yield (q ha^{-1}) of seven crops under four different fertilizer treatments (T1-T4) during 2022-23 and 2023-24. Letters indicate the significant differences (LSD, $p < 0.05$) among treatments in each crop. Bar displays the standard error among replications in each treatment.

Treatment	Eggplant		Potato		Raya		Rice		Summer Moong		Tomato		Wheat	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T1	130 c	160 b	170 c	205 b	10 b	12 b	65 b	60 b	8 b	10 b	200 b	240 c	45 b	50 b
T2	140 bc	170 ab	185 bc	215 ab	15 ab	18 a	75 b	70 a	12 a	15 b	250 a	265 b	48 a	52 b
T3	160 a	185 a	200 ab	220 a	20 a	25 a	72 a	78 a	14 a	18 a	240 a	290 a	50 a	58 a
T4	150 ab	165 b	210 a	225 a	18 b	22 a	78 ab	76 a	15 a	17 b	260 a	255 b	52 ab	55 b

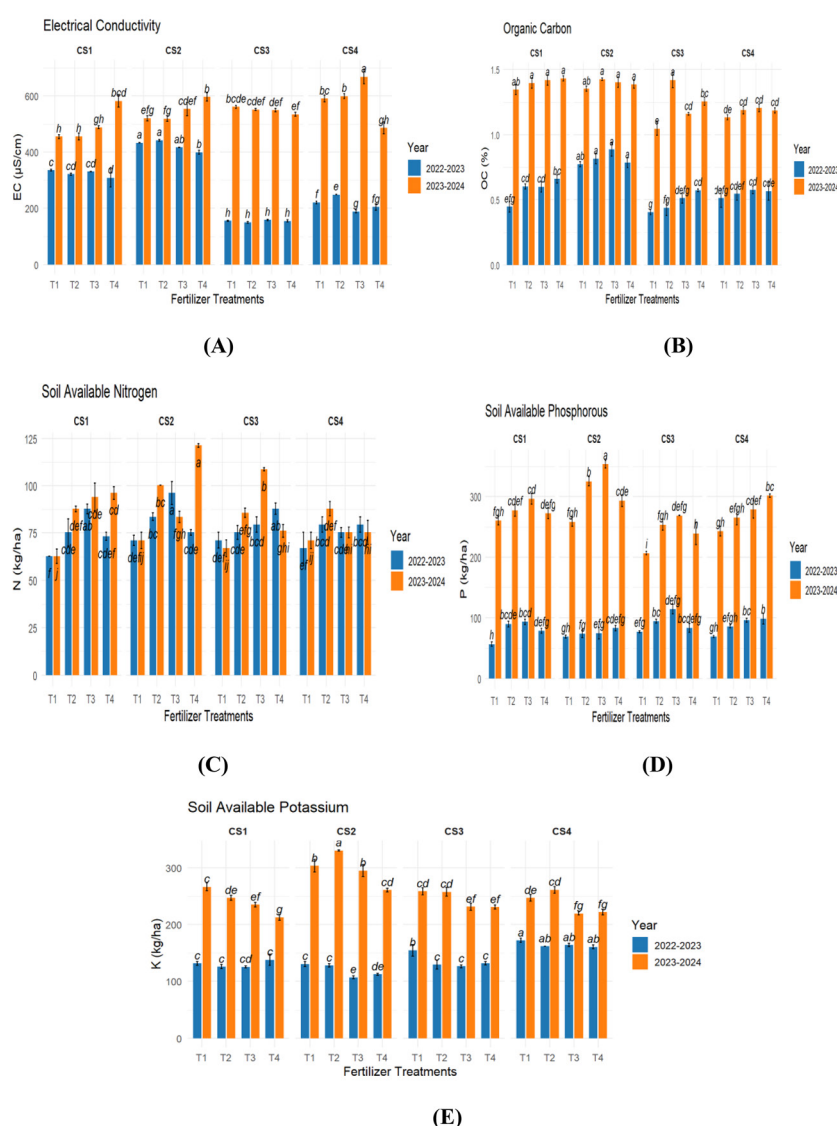


Fig. 1. Soil physico-chemical contents under different fertilizer treatments (T1–T4) across cropping systems (CS1–CS4) during 2022–2023 and 2023–2024. (A) EC – electrical conductivity (B) OC – organic carbon (C) N – nitrogen (D) P – phosphorous (E) K – potassium. Bars represent mean values for each treatment with standard error. Letters indicate statistically significant differences ($p < 0.05$) based on LSD test.

Individual crop yield

Significant differences ($p < 0.05$) were detected in the mean yields of all crops among the different treatments during the two-year study period (Table 1). Treatments T3 and T4 consistently recorded comparatively higher mean yields across crops and were grouped under the statistically superior categories

(‘a’ or ‘ab’), particularly during 2023–24, suggesting a favorable response of crops to fertilizer treatments over time. Among the crops evaluated, tomato produced the highest yield under T3 in 2023–24, with the maximum mean value of 289.03 q ha^{-1} , aligns with earlier findings that tomato responds significantly to integrated nutrient management (chemical and organic inputs) strategies and under silicon (Si) applications

(Zhang *et al.* 2024). Conversely, summer moong recorded the lowest yield under T1 in 2022-23, with a minimum value of 4.97 q ha⁻¹ may be attributed to its short growth cycle, limited nutrient uptake, and high sensitivity to abiotic stress. Similar observations have been reported in pulse crops under conventional nutrient regimes (Ali and Gupta 2012). Wheat and rice, the principal cereal crops, showed moderate yield levels with only slight variation between the two years, indicating their lower sensitivity to fertility gradients compared to vegetables and pulses. Similarly, the moderate yet improved yields observed in eggplant and potato under T3 and T4 respectively, reflect their fulfilment of higher nutrient demand. This trend aligns with earlier studies showing that nitrogen + boron foliar treatments and NPK + foliar nutritional compounds improved both yield and fruit quality in eggplant (Ali *et al.* 2024) and potato (Mona *et al.* 2012), respectively. Moreover, the application of Si significantly improved the morphological, physiological, and biochemical features in Indian Mustard (Pandey *et al.* 2016) supporting the results of present study. Slight yield improvements in 2023-24, especially under T2, T3, and T4, could be attributed to nutrient build-up and better moisture availability under Si-based organic fertilizers (Barão, 2023), potentially enhanced by the application of duraflex-based ultra products.

CONCLUSION

Over the long term, T3 consistently outperformed others with more stable and sustained yield gain. The evaluation of Duraflex-based Ultra fertilizers demonstrated significant improvements in crop yield and soil chemical properties across diverse rice-based cropping systems.

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