

## Evaluation of Ultra Formulations on Yield and Productivity of Rice-Based Cropping Systems in a Semi-Arid Region

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### ABSTRACT

Unpredictable climatic changes and increasing population pressure necessitate agricultural innovations that will enhance crop productivity without expanding cultivated land. Improving yield through efficient nutrient management is essential for ensuring food security and sustainable livelihoods, particularly in semi-arid regions. A two-year field experiment (2022-23 and 2023-24) was conducted to evaluate the performance 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) across four rice-based

cropping systems: Rice-Wheat (CS1), Rice-Raya-Summer Moong (CS2), Rice-Potato-Eggplant (CS3), and Rice-Potato-Tomato (CS4). The experiment was laid out in a split-plot design and the data were analyzed using R software. Results revealed significant improvements in crop yield, rice equivalent yield (REY) and system productivity (SP) under ultra-formulation treatments, particularly T3 and T4. Among the cropping systems, CS3 and CS4 recorded higher productivity due to intensive vegetable cultivation, while CS2 showed moderate productivity with improved nutrient contribution from legumes. The findings highlight the potential of ultra-formulation fertilizers to enhance crop productivity and system performance in diversified rice-based cropping systems under semi-arid conditions.

**Keywords** Rice, Cropping systems, Fertilizers, Yield, System productivity, Regression.

### INTRODUCTION

Over the past four decades, the global population has doubled from 4 to 8 billion and is projected to reach 9.7 billion by 2050 (FAO 2024), intensifying the need to increase food production. Despite technological advances, about 733 million people remained undernourished in 2023, an increase of 152 million since 2019 (FAO 2024). This challenge is further aggravated by stagnating yields, fertilizer overuse, environmental degradation, and rising input costs (Gerard 2024). Sustainable intensification

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through precision nutrient management and diverse cropping systems is therefore essential to enhance productivity without expanding arable land. Balanced and efficient nutrient management plays a crucial role in ensuring crop productivity and sustainability. Fertilizers contribute to over 50% of yield gains in modern agriculture (GECF 2024), and their use is influenced by agro-climatic conditions, irrigation, and crop varieties. Globally, fertilizer consumption increased by 37% between 2000 and 2022, reaching 185 million tonnes, with nitrogen accounting for 58% (FAO 2024).

Crop nutrient requirements vary across growth stages, necessitating synchronized supply of macro- and micronutrients. While N, P and K are essential, elements such as Ca, Mg, Fe, Zn and silicon (Si) also enhance plant growth, stress tolerance, and resilience. Studies show that balanced fertilization and integrated nutrient strategies can increase yields by 31–41%, with even higher gains under optimized management (Ishfaq *et al.* 2023). Approaches such as micronutrient application, deep fertilizer placement, and integration with organic inputs have further improved yield, nutrient use efficiency, and soil health (Baral *et al.* 2024). Silicon has emerged as a beneficial nutrient, particularly in crops like rice and wheat, by enhancing stress tolerance, nutrient availability, and overall productivity (Rahman *et al.* 2021). In this context, ultra-based mineral formulations, derived from natural sources, offer potential as plant enhancers across cropping systems. Therefore, the present study was undertaken to evaluate the impact of ultra – based, silicon nutrient additives on productivity in multi-crop rotations such as rice-wheat, rice-raya-summer moong, rice-potato-eggplant, and rice-potato-tomato systems over time. By integrating advanced formulations like ultra with micronutrient rich strategies and cropping system diversity, we aim to identify sustainable practices that enhance yield outcomes while maintaining or improving soil quality.

## MATERIALS AND METHODS

### Site description

The field experiment was conducted during the 2022-23 and 2023-24 crop seasons at the Research Farm of

the Department of Soil Science, Punjab Agricultural University (PAU), Ludhiana, Punjab, India, located at 30°56'N latitude and 75°52'E longitude with 274 m altitude above mean sea level. The region experiences a semi-arid, subtropical climate, with an average annual rainfall ranging between 700–800 mm.

### Experimental design and fertilizer treatments

The experiment followed a split-plot design, with each plot measuring 30 m<sup>2</sup>, arranged into main plots and sub-plots. The main plot treatments included four maize-based cropping systems: Rice-Wheat (CS1), Rice-Raya-Summer Moong (CS2), Rice-Potato-Eggplant (CS3), and Rice-Potato-Tomato (CS4). The sub-plot treatments consisted of four nutrient management strategies: Recommended Dose of Fertilizers (RDF) as T1, RDF + Ultra Plus 45 as T2, RDF + Ultra Classic 45 as T3, and RDF + Ultra DRC Irrigation as T4. Each treatment combination was replicated thrice in a fixed layout, resulting in a total of 48 treatment units per replication. Crops were irrigated as per their individual water requirements and prevailing weather conditions.

RDF followed PAU recommendations using urea (N), SSP (P<sub>2</sub>O<sub>5</sub>), and MOP (K<sub>2</sub>O), varying by crop. The next three advanced fertilizer formulations from the Duraflex-Ultra product line were: Ultra Classic 45, Ultra Plus 45, and Ultra DRC Irrigation. These products are rich in silicon (approximately 45% SiO<sub>2</sub>), iron, calcium, magnesium, and potassium. Ultra Plus 45 (soil enhancer) and Ultra Classic 45 (soil promoter) are granular, slow-release fertilizers designed to improve soil health by enhancing structure, water retention, microbial activity, and nutrient availability. Ultra DRC Irrigation (flexible use enhancer) is a liquid formulation tailored for fertigation systems (e.g., drip or pivot), containing ultrafine (<10 µm) mineral particles that support efficient nutrient delivery and improved plant uptake under varying moisture regimes (Fertis).

### Agronomical estimations

#### Crop yield

The mean yield of each crop viz: rice, summer moong,

tomato, eggplant, wheat, raya and potato, selected for rice-based cropping systems was calculated in  $q\ ha^{-1}$  according to standardized plot size for two years repeatedly.

### Comparative yield gain analysis

To evaluate the effectiveness of fertilizer treatments over time, comparative yield gain (%) was computed for each treatment (T2, T3, T4) relative to RDF (T1, baseline) treatment across the different cropping system (CS1 to CS4).

$$\text{Yield Gain (\%)} = (\text{Yield treatment} - \text{Yield RDF} / \text{Yield RDF}) \times 100$$

### Rice equivalent yield (REY)

Each cropping system's grain yield was converted into rice equivalent yield (REY) both the year separately based on the crops' minimum support price. The calculation utilized the following formula:

$$\text{Rice Equivalent Yield (REY)} = (\text{YMC} \times \text{PMC} + \text{YSC} \times \text{PSC}) / \text{PMC}$$

Where,

YMC = Main crop yield ( $q/ha$ )

YSC = Secondary crop yield ( $q/ha$ )

PSC = Secondary crop price ( $Rs/q$ )

PMC = Main crop price ( $Rs/q$ )

### Statistical analysis

Data were analyzed using both parametric and non-parametric methods based on dataset characteristics. Crop yield under fertilizer treatments was evaluated using ANOVA, with mean comparisons by LSD at the 5% level (Gomez and Gomez 1984). Yield gains across cropping systems were assessed using the Aligned Rank Transform (ART) method, suitable for factorial designs, and visualized through boxplots (Wobbrock *et al.* 2011).

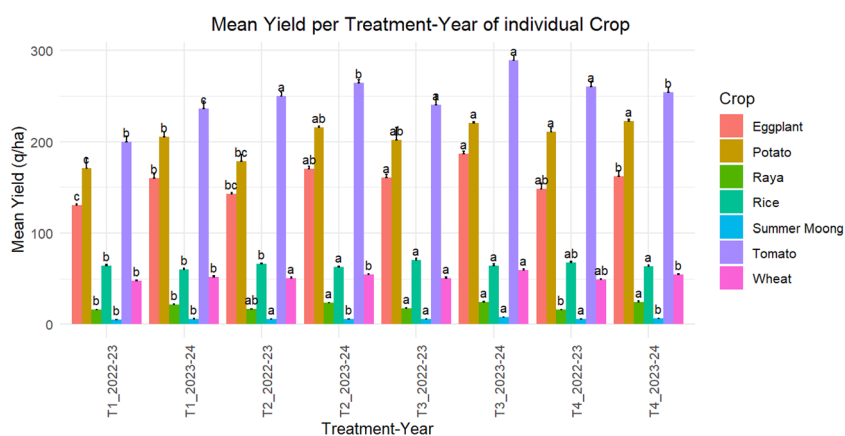
## RESULTS AND DISCUSSION

### Individual crop yield

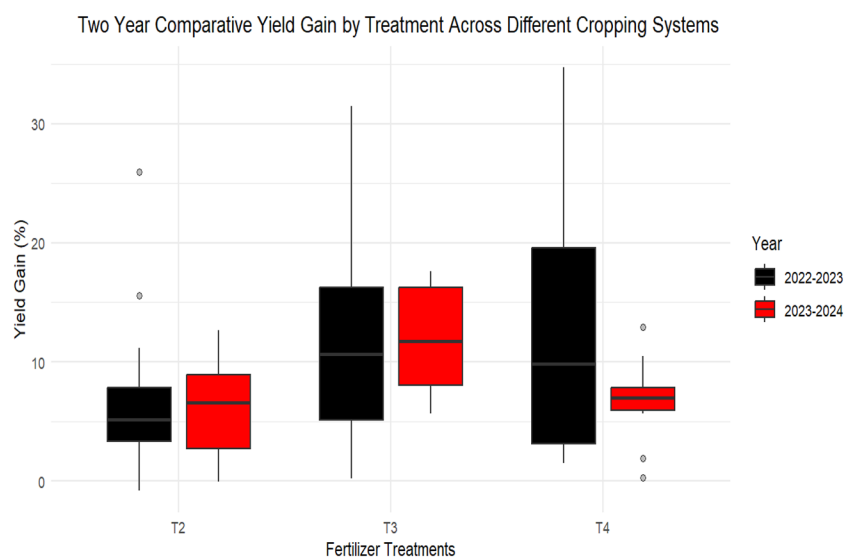
Significant differences ( $p < 0.05$ ) in mean crop yield were observed across treatments over two years (Fig. 1). Treatments T3 and T4 consistently produced higher yields, particularly in 2023-24, indicating positive fertilizer effects over time. Tomato recorded the highest yield ( $289.03\ q\ ha^{-1}$  under T3 in 2023-24), aligning with studies highlighting strong responses to integrated nutrient and silicon application (Zhang *et al.* 2024). In contrast, summer moong showed the lowest yield ( $4.97\ q\ ha^{-1}$  under T1 in 2022-23), likely due to its short duration and sensitivity to stress (Ali *et al.* 2021). Eggplant and potato exhibited moderate yields with improvement in 2023-24, reflecting higher nutrient demand and responsiveness to balanced fertilization (Ali *et al.* 2024). Wheat and rice maintained relatively stable, intermediate yields with slight improvement in the second year, possibly due to improved soil conditions and nutrient build-up under silicon-based fertilization (Sankati *et al.* 2024).

### Comparative yield gain and fertilizer dose

Cropping systems and fertilizer treatments significantly influenced comparative yield gain over both years (Fig. 2). Cropping systems had a stronger effect in 2022-23 ( $F = 13.53$ ,  $p < 0.001$ ) than in 2023-24 ( $F = 3.16$ ,  $p < 0.05$ ), whereas fertilizer effects increased over time ( $F = 3.80$ ,  $p < 0.05$  in 2022-23;  $F = 10.05$ ,  $p < 0.001$  in 2023-24). The interaction between cropping system and fertilizer treatment was non-significant in both years. Treatment T3 showed consistently higher and stable yield gains across seasons, while T2 exhibited moderate gains with low variability. In contrast, T4 showed high variability in 2022-23 but reduced gains and greater consistency in 2023-24. Variability and outliers across treatments suggest seasonal and site-specific influences. Overall, T3 emerged as the most reliable treatment, indicating stable performance under varying conditions. The non-significant interaction suggests that fertilizer responses were consistent across cropping systems, emphasizing the independent effects of both factors. These findings highlight the importance of efficient nutrient management, with T3 identified as a prom-



**Fig. 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.



**Fig. 2.** Comparative yield gain (%) of fertilizer treatments (T2–T4) over RDF baseline across different cropping systems during 2022–23 and 2023–24. Significant differences ( $p < 0.001, 0.05$ ) among treatments were detected using the Aligned Rank Transform (ART) test.

**Table 1.** Effect of fertilizer treatments on rice equivalent yield ( $q\ ha^{-1}$ ) under different cropping systems during 2022–23 and 2023–24.

Fertilizer treatments	Rice equivalent yield ( $q\ ha^{-1}$ )							
	2022–23				2023–24			
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4
T1	110.32 ± 4.62 <sup>s</sup>	124.82 ± 2.09 <sup>efg</sup>	275.30 ± 22.20 <sup>d</sup>	259.94 ± 9.27 <sup>d</sup>	108.55 ± 1.05 <sup>j</sup>	138.74 ± 5.69 <sup>h</sup>	318.12 ± 11.85 <sup>c</sup>	292.65 ± 12.55 <sup>c</sup>
T2	114.51 ± 1.33 <sup>fg</sup>	131.55 ± 2.66 <sup>c</sup>	316.22 ± 2.57 <sup>bc</sup>	270.34 ± 5.31 <sup>d</sup>	115.52 ± 2.32 <sup>j</sup>	145.05 ± 2.81 <sup>gh</sup>	344.59 ± 2.54 <sup>b</sup>	305.96 ± 4.56 <sup>d</sup>

**Table 1.** Continued.

Fertilizer treatments	Rice equivalent yield (q ha <sup>-1</sup> )							
	2022–23				2023–24			
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4
T3	120.29 ± 3.62 <sup>efg</sup>	131.91 ± 2.68 <sup>c</sup>	328.95 ± 10.99 <sup>ab</sup>	302.48 ± 30.11 <sup>c</sup>	124.63 ± 3.98 <sup>i</sup>	155.08 ± 2.52 <sup>f</sup>	361.07 ± 4.83 <sup>a</sup>	322.47 ± 0.52 <sup>c</sup>
T4	117.21 ± 0.30 <sup>efg</sup>	129.59 ± 2.17 <sup>ef</sup>	333.23 ± 5.93 <sup>a</sup>	303.00 ± 5.73 <sup>c</sup>	116.30 ± 0.61 <sup>ij</sup>	151.62 ± 2.50 <sup>fg</sup>	342.60 ± 6.63 <sup>b</sup>	306.61 ± 5.45 <sup>d</sup>
<b>LSD (5%)</b>								
CS (Main)	14.930				9.777			
FT (Sub)	11.311				5.519			
CS×FT (Main×Sub)	16.246				9.095			

Values represent mean ± standard error. Means followed by different letters indicate statistically significant differences at  $p \leq 0.05$  as per LSD. LSD values are given for Cropping System (CS), Fertilizer Treatment (FT), and their interaction (CS × FT).

**Table 2.** Effect of fertilizer treatments on system productivity (kg ha<sup>-1</sup> day<sup>-1</sup>) under different cropping systems during 2022–23 and 2023–24.

Fertilizer treatments	System productivity (kg ha <sup>-1</sup> day <sup>-1</sup> )							
	2022–23				2023–24			
	CS1	CS2	CS3	CS4	CS1	CS2	CS3	CS4
T1	45.97 ± 1.93 <sup>ef</sup>	39.37 ± 0.66 <sup>g</sup>	81.45 ± 6.60 <sup>c</sup>	71.81 ± 2.56 <sup>d</sup>	45.23 ± 0.44 <sup>jk</sup>	43.77 ± 1.80 <sup>k</sup>	94.12 ± 3.50 <sup>c</sup>	80.84 ± 3.47 <sup>f</sup>
T2	47.71 ± 0.56 <sup>e</sup>	41.50 ± 0.84 <sup>fg</sup>	93.56 ± 0.76 <sup>b</sup>	74.68 ± 1.47 <sup>d</sup>	48.13 ± 0.97 <sup>hi</sup>	45.76 ± 0.89 <sup>ijk</sup>	101.95 ± 0.75 <sup>b</sup>	84.52 ± 1.26 <sup>e</sup>
T3	50.12 ± 1.51 <sup>e</sup>	41.61 ± 0.84 <sup>fg</sup>	97.32 ± 3.25 <sup>ab</sup>	83.56 ± 8.32 <sup>c</sup>	51.93 ± 1.66 <sup>g</sup>	48.92 ± 0.80 <sup>h</sup>	106.83 ± 1.43 <sup>a</sup>	89.08 ± 0.14 <sup>d</sup>
T4	48.84 ± 0.13 <sup>e</sup>	40.88 ± 0.69 <sup>g</sup>	98.59 ± 1.76 <sup>a</sup>	83.70 ± 1.58 <sup>c</sup>	48.46 ± 0.25 <sup>h</sup>	47.83 ± 0.79 <sup>hij</sup>	101.36 ± 1.96 <sup>b</sup>	84.70 ± 1.50 <sup>e</sup>
<b>LSD (5%)</b>								
CS (Main)	4.326				2.958			
FT (Sub)	3.191				1.540			
CS × FT (Main×Sub)	4.662				2.680			

Values represent mean ± standard error. Means followed by different letters indicate statistically significant differences at  $p \leq 0.05$  as per LSD. LSD values are given for Cropping System (CS), Fertilizer Treatment (FT), and their interaction (CS × FT).

ising option for enhancing productivity and stability under given agro-climatic conditions (Patel *et al.* 2023).

### Rice equivalent yield (REY) and system productivity (SP)

Significant ( $p < 0.05$ ) variation in system productivity was observed across fertilizer treatments, cropping systems, and their interactions over both years. REY (Table 1) and SP (Table 2) were highest in CS3, followed by CS4. Among treatments, T3 and

T4 consistently outperformed others, particularly in diversified systems. System productivity trends mirrored REY, with the highest value under T3 (106.83 kg ha<sup>-1</sup> day<sup>-1</sup>) in 2023–24, followed by T4, while the lowest was recorded in CS1 (45.23 kg ha<sup>-1</sup> day<sup>-1</sup>). Ultra-formulations significantly enhanced productivity across all systems, likely due to improved nutrient use efficiency and synergistic effects on crop growth. These results align with earlier studies reporting higher system productivity under integrated nutrient management and diversified cropping systems (Sikka *et al.* 2025).

## CONCLUSION

The long-term evaluation showed that T3 maintained comparatively stable and sustained yield advantages over other treatments, reflecting its capacity to support consistent crop performance across seasons. In conclusion, the integration of Ultra fertilizer formulations at appropriate doses with balanced nutrient management strategies can substantially enhance crop yield, system productivity, and long-term sustainability in rice-based cropping systems.

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