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Yield Response, Economic Returns and Nutrient-Use Efficiency under STCR-Based Fertilizer Management in Mustard

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A B S T R A C T

This study evaluates mustard responses to STCR-based fertilizer management, incorporating soil-test–based prescriptions and farmyard manure (FYM) across a range of treatments. The experimental framework aimed to quantify yield response and response ratios, nutrient-use efficiencies, and the economic implications of different fertilizer regimens. Among the treatments, the yield-target strategy of 22 q ha−1 (YT 22 q ha−1; T8) produced the highest grain yield, surpassing the conventional yield target of 6 t ha−1 (T5) and other regimens. Treatments based on STCR doses generally outperformed conventional inorganic schedules, with FYM-inclusive programs yielding greater grain production than sole chemical fertilization. The observed yield gains translated into superior gross return and net return for the yield-target STCR approach, although the benefit–cost ratio (B:C) varied with input costs, indicating a trade-off between maximizing yield or net benefit and achieving economic efficiency per unit input. The response ratio (grain yield per unit nutrient applied) varied among treatments, with T7 and T2 leading in efficiency despite high absolute yields for T8, suggesting that yield targets interact with base fertilization to shape nutrient-use efficiency. Nitrogen emerged as a primary driver of both yield and profitability, consistent with STCR principles that align nutrient supply with crop demand. Across nutrients (N, P, K), use efficiencies were higher under STCR prescriptions than under blanket applications, and FYM generally enhanced nutrient recovery, though its impact on per-unit efficiency depended on dose and interaction with mineral inputs.

Introduction

India stands as a leading global producer of rapeseed and mustard, accounting for a substantial share of the world's oilseed area and contributing prominently to national and regional food security. India ranks among the top producers, with production levels trailing only China in the global ranking and driven by large expanse of cultivated land under oilseed crops. Mustard, an important oilseed, is valued for its high nutrient content, with oil yield ranging broadly from about 37 to 49 percent depending on cultivar, management, and environmental conditions. The crop's nutritional profile and economic significance underscore the importance of

optimizing nutrient management to maximize yield, quality, and resource-use efficiency under diverse agroecologies (Kumar *et al.,* 2008). Rapeseed and mustard are energy-dense oilseed crops that often confront limited nutrient supply, making efficient nutrient management essential. Across general requirements and, in particular, for micronutrients, the crop demands substantial inputs that must be supplied in appropriate quantities to realize its yield potential.

Estimated nutrient needs for achieving 1 tonne of mustard seed per hectare fall within: nitrogen 80–120 kg $ha^{-1,}$ phosphorus 12.4–42.7 kg ha^{-1}, potassium 20–40 kg ha^{-1}, sulfur 12–20 kg ha^{-1}, zinc 0.1 kg ha^{-1}, and boron 0.036 kg ha^{-1}, with values reported by Chand *et al.,* (2021). Under resource-constrained conditions, such substantial requirements may remain unmet, contributing to persistent productivity gaps (Priyamedha *et al.,* 2015). Integrated nutrient management that combines organic sources (e.g., farmyard manure, vermicompost) with inorganic fertilizers (N, P, K, and S) offers a pathway to enhance nutrient availability, synchronization with crop demand, and overall system sustainability. The effectiveness of these integrated strategies depends on the balance among input types, timing, soil health, and local agro-ecological context, underscoring the need for region-specific optimization (Graham *et al.,* 2017).

In recent years, site-specific fertilization approaches that consider soil-test data have gained traction as a means to optimize nutrient supply, enhance yield, and improve nutrient-use efficiency (NUE). Among these, soil-test–level–driven prescriptions under the STCR (short-term fertilizer recommendations) framework aim to synchronize fertilizer inputs with crop nutrient requirements, thereby reducing losses and environmental footprints while maintaining profitability. Integrating organic inputs, such as farmyard manure (FYM), with mineral fertilizers is a core principle of integrated nutrient management (INM). FYM can augment soil physical and biological properties, improve nutrient mineralization, and potentially enhance NUE. However, the agronomic and economic outcomes of FYM-inclusive STCR strategies are highly context dependent, influenced by soil type, climate, and input costs. Several studies across cereals and oilseeds have reported yield gains and improved nutrient recovery under integrated approaches, yet findings vary with the rate and timing of FYM application, and with the baseline fertility status of the soil. Despite evidence supporting yield-targeted fertilization, there remains a need to quantify how different STCR-based regimens, with and without FYM, influence mustard yield, response efficiency, and economic viability under contemporary market conditions. This study aims to (i) evaluate yield responses and response ratios to diverse fertilizer regimens anchored in STCR prescriptions, (ii) assess the total cost of cultivation, gross and net returns, and (iii) quantify nutrient-use efficiencies (NUE, PUE, KUE) under AY practices, including FYM integration. By clarifying the agronomic and economic trade-offs, this work seeks to inform on-farm management decisions that promote sustainable mustard production in [region/country], with implications for nutrient stewardship and resource-use efficiency in intensifying cropping systems.

Material and Methods

Study Area

Raipur, the capital of Chhattisgarh, is located near the center of the state (approximately 21°16′ N, 81°60′ E) at an average elevation of 289.6 meters above mean sea level. The IGKV Instructional Farm lies in the eastern part of Raipur, adjacent to National Highway 6, at approximately 20°04′ N, 81°39′ E, with an altitude of about 293 meters above mean sea level.

Soil Characteristics

The soil employed in the study was analyzed for key physical and chemical properties. The texture comprised 26.4% sand, 28.8% silt, and 44.8% clay, indicating a clay-dominant soil. The soil water-holding capacity was 39.48%, with porosity of 41.32%. The pH was measured at 7.4, indicating a near-neutral soil environment, and the electrical conductivity (EC) was 0.18 dS m^{-1}, reflecting low to moderate soluble salt content.

Experimental details

The experiment was conducted using a factorial randomized block design (FRBD) with three replications. The trial comprised 16 treatment combinations, including a set of control and nutrient management options with and without farmyard manure (FYM).

Method of Plant Analysis

Dried straw and grain were grinded and used for

following chemical analysis Nitrogen content was determined by KEL plus unit methods as described by Chapman and Pratt, (1961). Phosphorus in the diacid extract of plant samples was estimated by vanadomolybdo phosphoric yellow colour method using spectrophotometer at 420nm wave length as described by Jackson (1973). Potassium in the diacid extract of plant samples was determined using flame photometer as per the method described by Jackson (1973).

Statistical Analysis

All field and laboratory observations were recorded systematically and organized for analysis. The experiment was laid out as a factorial randomized block design (FRBD) with appropriate replication. Data were subjected to analysis of variance to assess treatment effects. When the F-test indicated significant effects, mean comparisons were performed using the standard error of the mean (SEM) and critical difference (CD) at the 5% probability level.

Results and Discussion

Yield response and response ratio of mustard

The responses of mustard to fertilizer regimens and farmyard manure (FYM) are detailed in Figure 3.1. The highest grain yield was achieved under T8, followed by T5, T7, T2, and T3. The STCR-based dose aiming at 22 q ha^{-1} produced a superior response compared with the conventional yield target of 6 t ha−1 (T5). Treatments incorporating soil-test–based fertilizer applications yielded higher responses than those receiving inorganic fertilizer alone. FYM-enhanced fertilizer programs generated greater grain yields than sole chemical fertilizer, underscoring the benefits of integrated nutrient management. These outcomes align with prior work by Bhaduri & Gautam (2013), Ahmed *et al.,* (2015), and Keram *et al.,* (2012), which reported enhanced yields with integrated nutrient strategies.

The response ratio for mustard (Fig. 3.1) was significantly influenced by fertilizer treatment and FYM. Across treatments, FYM applications increased the nutrient-use efficiency and grain yield relative to fertilizer-only regimes. The response ratio—defined as kg grain per kg nutrient applied—was highest for T7 and followed by T2, T5, T8, and T6. The STCR dose for T7 yielded a higher response than T8 and T5, indicating that yield targets can differentially shape efficiency metrics depending on the interaction with baseline fertilizer regimens. While T8 achieved high absolute yields, its response ratio was comparatively lower than the RDF-based target due to the larger fertilizer input. These patterns corroborate earlier findings (Ahmed *et al.,* 2015) that STCR-based prescriptions can optimize both yield and nutrient use efficiency, supporting the adoption of targeted fertilizer strategies complemented by organic amendments for sustainable mustard production.

Efficiency of fertilizer nutrients for mustard

The efficiencies of applied nutrients (N, P, and K) were assessed for mustard under both FYM-inclusive and FYM-free regimens (Fig.3.2). Nitrogen use efficiency (NUE) was highest under soil-test–based fertilization targeting yield, with and without FYM, and outperformed other fertilizer regimens, including the RDF-based treatment (T5). This outcome reflects the STCR approach, which optimizes nutrient supply by aligning applications with crop demand, thereby maximizing nutrient recovery relative to blanket applications. FYM generally enhanced nutrient-use efficiency across nutrients, illustrating the benefit of integrated nutrient management.

Phosphorus use efficiency (PUE) varied widely (0.05–0.40). Imbalanced fertilization, such as the full P dose without concurrent N (as in T3), reduced PUE, whereas STCR-based prescriptions achieved higher P efficiencies, both with and without FYM, by leveraging available soil P and fertilizer-derived P. The elevated PUE in several treatments was associated with higher native soil P and improved fertilizer utilization.

Potassium use efficiency (KUE) was higher under STCR-based programs relative to blanket applications; however, in some cases, KUE appeared inflated by high baseline soil K, which can mask true efficiency gains. These findings align with reports from Sahu *et al.,* (2017), who observed comparable patterns of nutrient-use efficiencies under soil-test–driven and organic-inclusive strategies in high-density wheat systems at Raipur. Overall, the results support the superiority of STCR-based prescriptions, particularly when integrated with FYM, for maximizing nutrient-use efficiencies and ensuring sustainable nutrient management in mustard cropping systems.

Total cost of cultivation and gross return for mustard

Total cost of cultivation and gross return (Fig.3.3) were influenced by fertilizer management and FYM. Among treatments, the highest cost of cultivation occurred with T5 (N120 P60 K40), while the highest gross return was achieved by T8 due to the greater input level. Gross return followed the pattern T8 > T5 > T7. Incorporation of FYM enhanced gross returns over sole inorganic fertilizer applications, highlighting the economic benefits of integrated nutrient management. The yield-targeted STCR-based regimen at 22 q ha^{-1} delivered the greatest gross return among all treatments, underscoring the cost–benefit potential of precision nutrient management. In the absence of nitrogen fertilization, both yield and gross return declined markedly, reaffirming nitrogen as a critical driver of mustard productivity and profitability. While references to maize IPNS guidelines (e.g., Parihar *et al.,* 2015) and other studies (Ahmed *et al.,* 2015) illustrate broader applicability of yield-targeting fertilizer prescriptions, their direct transfer to all soil types requires region-specific validation. Practically, these results advocate incorporating soil testing, STCR-based doses, and FYM to optimize economic returns while sustaining soil fertility in rice–wheat or mustard systems.

In this study, economic performance of mustard under the STCR-based fertilizer management was best with the yield-target treatment of T8: YT 22 q/ha. This treatment consistently produced the highest net return and the superior cost–benefit outcome compared with other fertilization strategies (Figs. 3.4 and 3.5.). Yield targets that aligned with an attainable higher grain output enabled greater economic gains, underscoring the advantage of targeted nutrient application in optimizing both productivity and profitability.

Among the nutrient management options, inorganic fertilizer regimens at equivalent or higher nutrient levels generally outperformed sole FYM in terms of net return, yet the incremental benefit of adding FYM to mineral fertilizer did not translate into higher B:C ratios in all cases. Specifically, while FYM improved net returns relative to some inorganic-only treatments, the calculated benefit–cost ratio tended to decline when FYM was incorporated with inorganic fertilizer (relative to inorganic fertilizer alone). This finding suggests a potential trade-off between maximizing yield (and absolute net benefit) and achieving the most favorable economic efficiency per unit cost when farm inputs include organic amendments. It is consistent with the notion that, under limited resource conditions, the marginal economic advantage of incorporating FYM may depend on the balance between input costs and yield response.

The ranking of treatments by B: C ratio showed that T8 yielded the highest return efficiency, followed by T7 and T5. However, the superiority of higher-yield targets did not always align with the best economic efficiency when FYM was used; in some combinations, the FYM-inclusive schemes reduced the B: C ratio relative to fertilizer-alone approaches. This pattern aligns with earlier reports that emphasize yield or net benefit as primary drivers of profitability, while cost efficiency may pivot on input costs and resource use efficiency. These observations are in line with prior studies. Benbi *et al.,* (2006) reported that yield-target-based fertilizer formulations produced higher yields, net benefits, and B: C ratios compared with farmers' practice. Deshmukh *et al.,* (2012) also documented similar advantages of yield-target-based nutrient management. The current results extend these findings to the context of mustard under the STCR framework, reinforcing the potential of yield-targeting strategies to enhance economic returns while highlighting the nuanced role of organic amendments in modulating cost efficiency.

This study demonstrates that STCR-based fertilizer management, particularly the yield-target regimen of 22 q ha−1 (T8), can substantially enhance mustard productivity and economic returns under the tested conditions. Across treatments, T8 delivered the highest grain yield and the most favorable economic outcome, evidenced by the greatest gross return and net return, supporting the premise that precise yield-targeting fertilization outperforms conventional or farmers' practice regimes.

The integration of FYM with inorganic fertilizer generally boosted grain yield and gross return relative to inorganic fertilizer alone, underscoring the value of integrated nutrient management for sustaining soil fertility while sustaining profitability. However, the observed benefits to cost efficiency were context-dependent: in several cases, the inclusion of FYM reduced the B: C ratio compared with inorganic-only schemes due to differences in input costs and local price dynamics. These findings highlight a trade-off between maximizing absolute yield or net benefit and achieving optimal input-use efficiency.

Fig.1 Response ratio of fertilizer in mustard

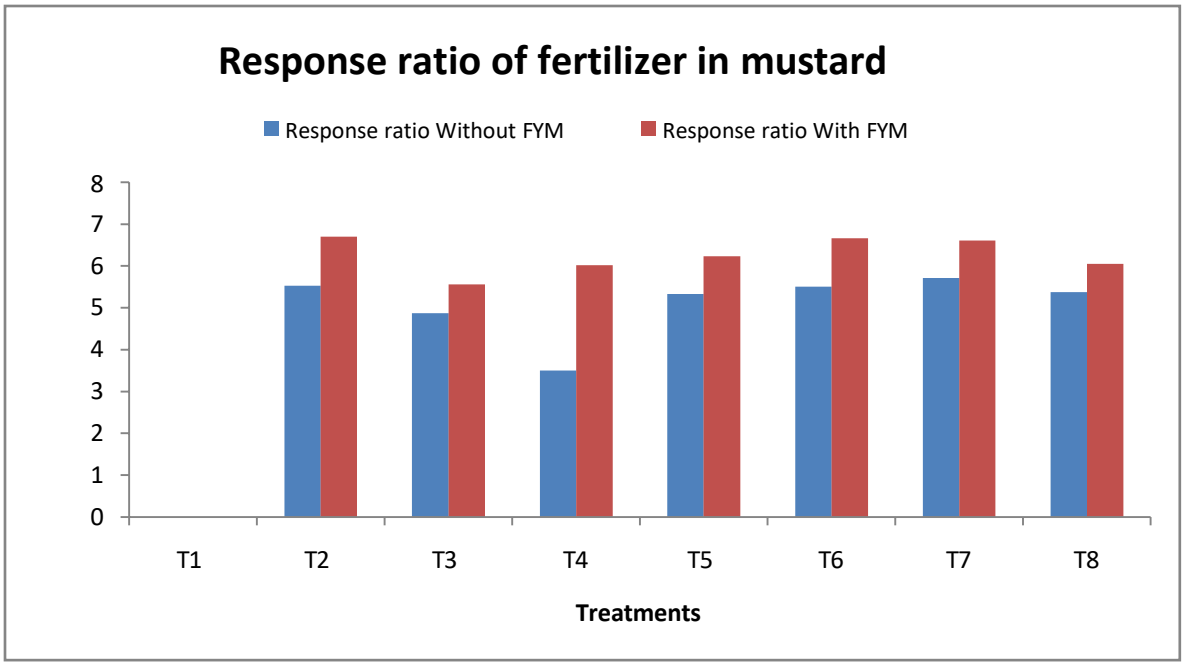


Fig.2 Fertilizer efficiency of mustard

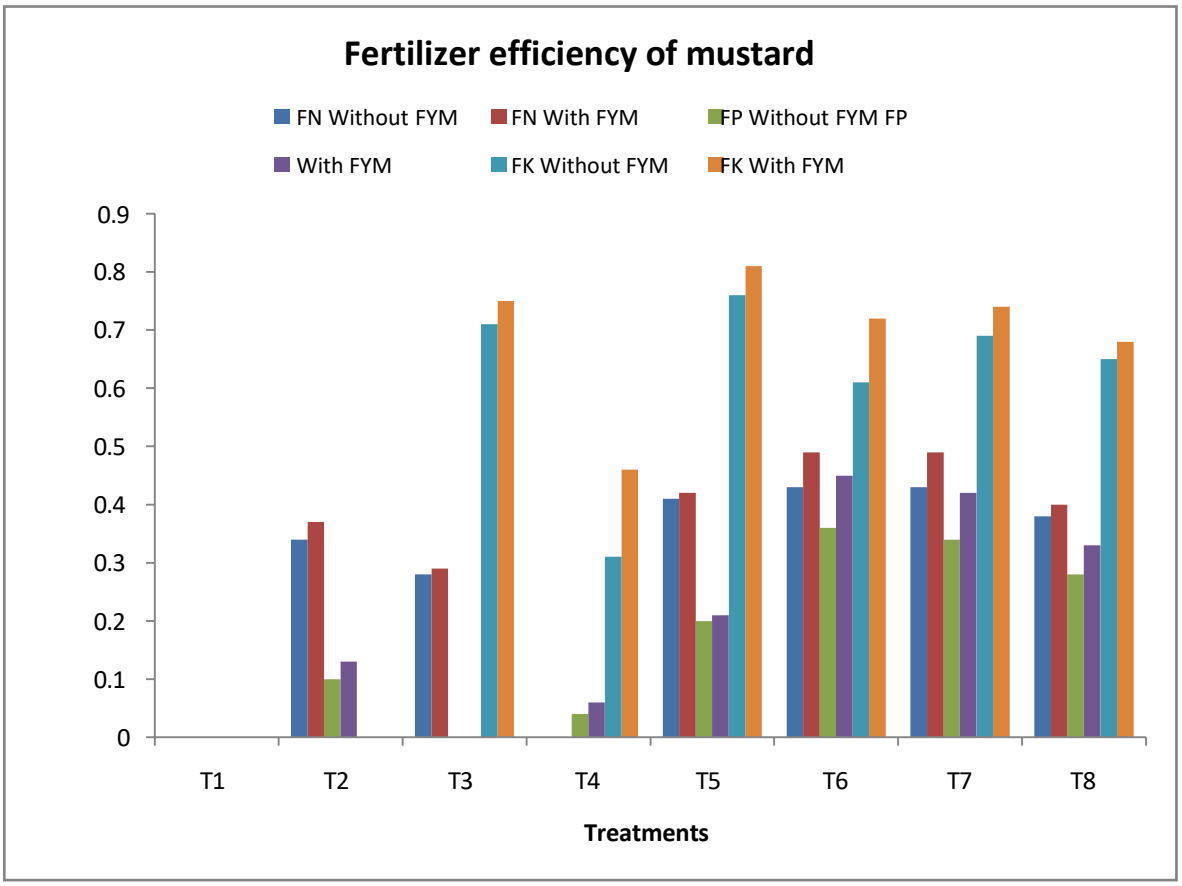


Fig.3 Total cost of cultivation and gross return

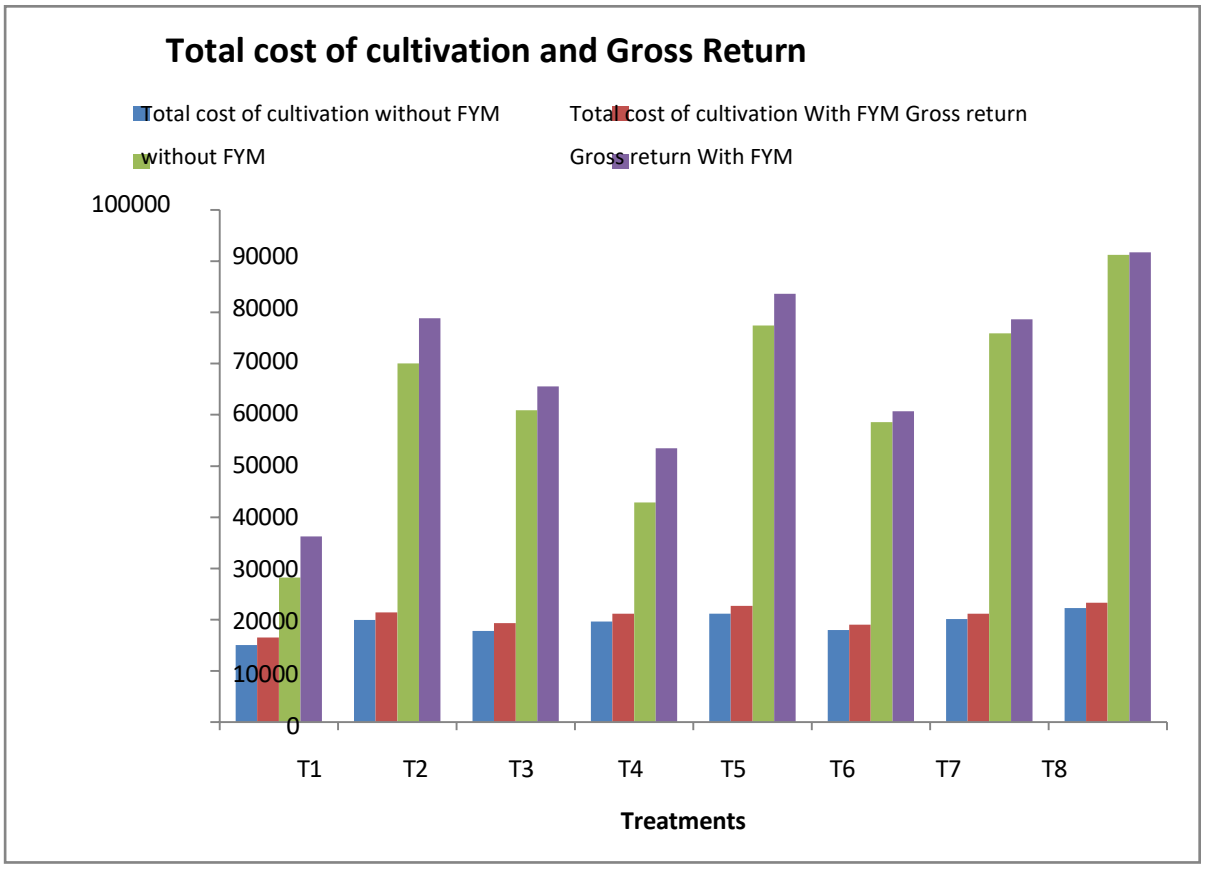


Fig.4 Net Return of Mustard

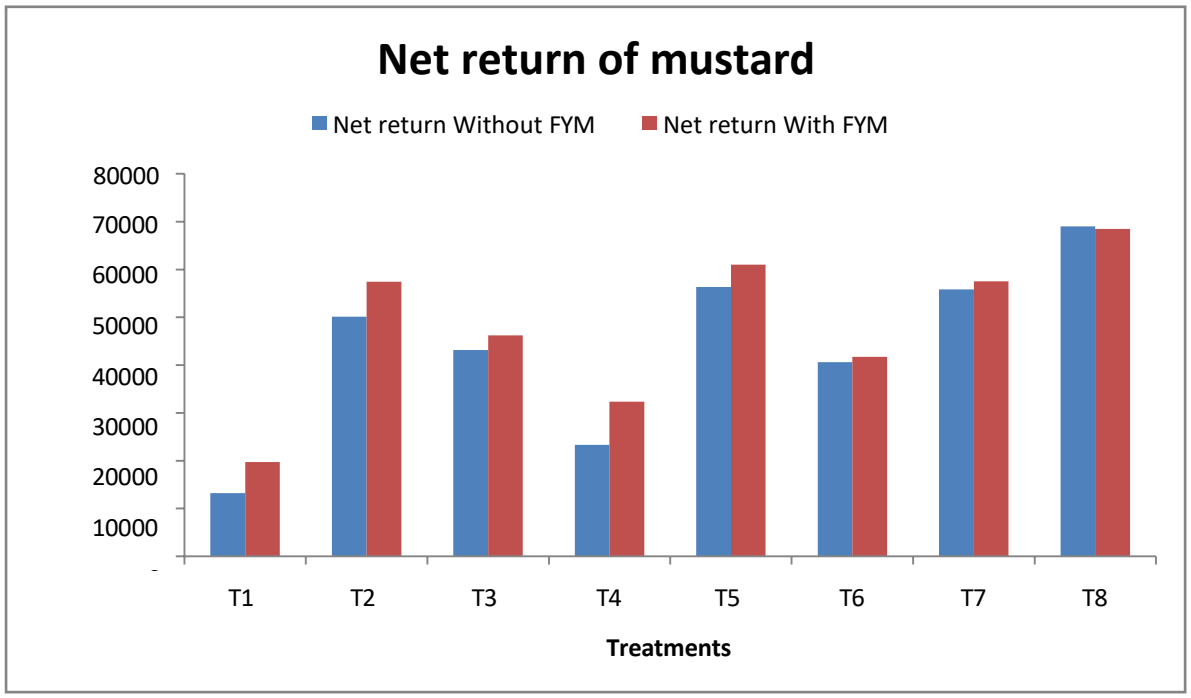
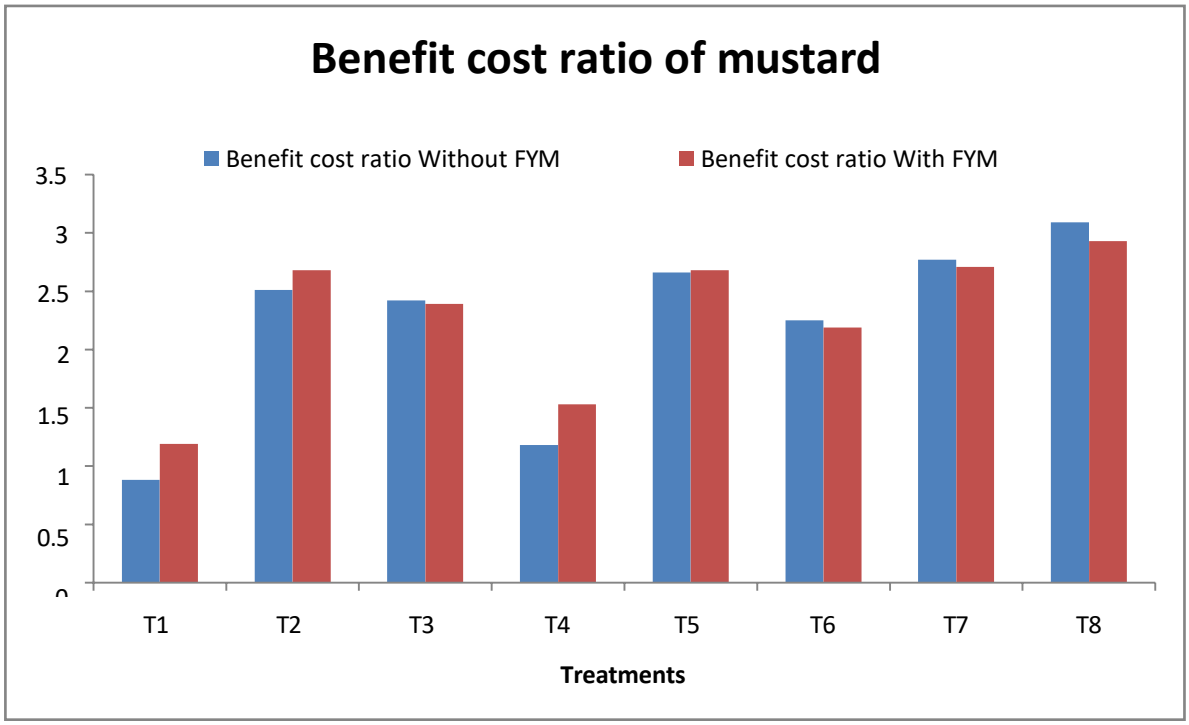


Fig.5 Benefit cost ratio of mustard



Nutrient-use efficiency analysis revealed that STCR-based prescriptions achieved superior NUE, PUE, and KUE compared with blanket fertilizer schedules, with FYM further enhancing nutrient recovery when combined with mineral fertilizers. Nitrogen emerged as a critical driver of both yield and profitability, reaffirming the pivotal role of N management in mustard systems. The results corroborate prior work indicating that yield-targeting nutrient strategies improve both agronomic performance and nutrient-use efficiency, while the benefits of FYM are contingent on dose, timing, and interaction with mineral inputs

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Author Contributions

Onkar Singh: formal analysis, methodology, writing–original draft; Lalit Kumar Srivastava: conceptualization, data curation, formal analysis, methodology, writing – original draft. Anusuiya Panda: formal analysis, data curation, methodology, writing – original draft, Vinay Bachkaiya: formal analysis, writing – original draft;

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Conflict of Interest

The authors declare no competing interests.

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