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Optimizing soil fertility and profitability in mustard cultivation through integrated nutrient management

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Abstract
In order to determine how integrated nutrient management (INM) affected soil characteristics and the financial performance of Indian mustard (*Brassica juncea* L.), a field experiment was carried out at Jigyasa University in Dehradun during the Rabi season of 2023-2024. Nine treatments with varying ratios of chemical fertilizers (RDF), vermicompost, and biofertilizers (Azotobacter + PSB) were used in the experiment. They were set up in a randomized block design with three replications. The findings showed that the incorporation of both organic and inorganic nutrient sources had a major impact on the physico-chemical characteristics of the soil, such as pH, electrical conductivity (EC), organic carbon, and the availability of phosphorus and nitrogen. The highest levels of organic carbon (0.57%), available nitrogen (154.05 kg ha^{-1}), and phosphorus (13.50 kg ha^{-1}) were recorded by treatment T_4 (80% RDF + vermicompost @ 9 kg + biofertilizer @ 500 ml/kg seed), suggesting increased microbial activity and nutrient cycling as a result of the synergistic effects of integrated inputs. The pH and EC of the soil stayed within ideal values, promoting soil health. In terms of economics, T_4 was more profitable than both chemical-only and organic-only treatments, yielding the highest gross return (₹1, 28, 255 ha^{-1}), net return (₹84, 269 ha^{-1}), and benefit-cost (B:C) ratio (1.92). While solitary vermicompost (T_8) enhanced soil health but had low economic efficiency because of high input costs, sole application of 100% RDF (T_1) demonstrated a reasonable yield but reduced soil carbon and greater EC. According to the study's findings, integrated nutrient management-specifically, combining 80% RDF with vermicompost and biofertilizers-offers the best possible balance between increasing soil fertility and farm profitability, and as such, is advised for the Dehradun region's sustainable mustard farming.

Keywords: Integrated nutrient management (INM), Indian mustard (*Brassica juncea* L.), soil characteristics

1. Introduction
In India, Indian mustard (*Brassica juncea* L.) is extremely important to agriculture, supporting the livelihoods of millions of farmers and accounting for roughly 28.6% of the country's oilseed production. Sustainable farming methods are crucial in Dehradun and other mustard-growing areas to support long-term soil health and farm profitability in addition to meeting the demand for edible oil. Concerns regarding nutrient imbalances, falling factor productivity, and soil degradation have been highlighted by the extensive use of chemical fertilizers in oilseed-based systems (Prasad *et al.*, 2017) [15]. Therefore, increasing soil fertility through integrated methods is essential to guaranteeing environmental sustainability as well as crop productivity.
A comprehensive strategy is provided by Integrated Nutrient Management (INM), which blends organic sources including FYM, vermicompost, and biofertilizers with inorganic fertilizers. These inputs enhance soil organic carbon, microbial activity, and nutrient cycling in addition to providing macro- and micronutrients (Kakraliya *et al.*, 2017) [7]. In particular, vermicompost improves soil aeration, water-holding capacity, and microbial diversity, and FYM offers a source of nutrients that release gradually. The use of organic manures aids in restoring soil health and lessens the adverse impacts of ongoing chemical fertilizer application.
The economic feasibility of growing mustard is influenced by nitrogen management techniques in addition to soil condition. Farmers frequently have to choose between cutting input costs and increasing yields.

By decreasing reliance on pricey chemical fertilizers and increasing nutrient-use efficiency, integrated techniques can increase cost-effectiveness and enhance the benefit-cost ratio. Assessing the financial benefits of various nutrient management techniques in addition to their effects on soil fertility yields important information for suggesting sustainable farming methods to farmers.

In this context, the present study aims to assess the effect of integrated organic and inorganic fertilizer application on soil properties and economics of mustard production under Dehradun conditions, thereby addressing both sustainability and profitability aspects of mustard cultivation.

2. Review of literature

2.1. Effect of Inorganic and Organic Fertilizer on Soil Properties under Mustard Crop

Maintaining mustard productivity depends heavily on soil fertility and nutrient dynamics, and numerous studies have demonstrated the beneficial effects of integrated nutrient management (INM) on soil characteristics. Applying 100% RDN using Panchgavya greatly increased soil nutrient content and uptake, as shown by Sharma *et al*. (2023) [16]. Higher NPK content (2.48, 0.63, and 0.99%, respectively) and uptake (46, 84, 11.86, and 18.72 kg ha^{-1}) were the results. Comparable to higher RDF-based treatments, Venkatesh *et al*. (2023) [21] found that the combined application of 75% STB NPK with FYM and a biofertilizer consortium improved the availability of nitrogen, phosphorus, potassium, and sulfur throughout the crop cycle.

The importance of organic sources in preserving soil fertility is further demonstrated by several investigations. 50% RDF in combination with FYM, vermicompost, biofertilizers, and $ZnSO_4$ increased grain and straw nutrient absorption, according to Dubey *et al*. (2019) [4]. Similarly, Ajnar and Namdeo (2021) [1] found that when 75% RDF was combined with sulphur, vermicompost, Azotobacter, and PSB, the highest levels of N, P, K, and S were found in the seed and stover. Vermicompost treatment increased N (1.52%), P (0.56%), and S (0.23%) in radish roots, according to Meena *et al*. (2023) [10], suggesting that it has the capacity to enrich soil outside of mustard systems.

Improvement of soil health is another focus of long-term INM studies. While Mujumder *et al*. (2017) [11] observed improved organic carbon and sulphur availability under FYM, sulphur, and zinc treatments, Tomar *et al*. (2018) [20] found that combining NPK with FYM and biofertilizers considerably boosted accessible soil N and P. In addition, Chesti *et al*. (2015) [3] verified that, in comparison to fertilizer alone, FYM plus NPK enhanced soil organic carbon and nutrient availability.

All things considered, these results imply that the combined application of chemical fertilizers, organic manures, and biofertilizers improves soil organic matter, nutrient uptake, and total soil fertility, guaranteeing the long-term viability of mustard farming.

2.2. Economics of Mustard Crop under Integrated Nutrient Management

The economic viability of growing mustard is significantly impacted by fertilizer management techniques. Numerous studies have shown that INM increases profitability in addition to yield. According to Sharma *et al*. (2023) [16], in Dehradun conditions, the highest gross return (₹1, 94, 636.6 ha^{-1}), net return (₹1, 61, 649.8 ha^{-1}), and B:C ratio (4.9) were obtained by applying FYM (5 t ha^{-1}) and vermiwash (5%) together. Similarly, 100% RDF yielded the highest net return (₹56, 582 ha^{-1}) and a B:C ratio of 2.66, according to Gora *et al*. (2022) [5].

Research also shows that using organics and inorganics together yields higher financial returns than using just chemical fertilizers. According to Singh *et al*. (2018) [18], the best net yield (₹29, 856 ha^{-1}) and B:C ratio (2.29), when combined with vermicompost, FYM, Azotobacter, and PSB, was obtained with 75% RDF. 100% NPK with FYM, PSB, and sulfur produced the highest gross return (₹67, 003 ha^{-1}) and the highest net return (₹33, 204 ha^{-1}), according to Maurya *et al*. (2019) [9]. Similarly, Singh and Singh (2014) reported that FYM, PSM, and Azospirillum treatments resulted in the highest gross return (₹39, 067 ha^{-1}) and net return (₹25, 547 ha^{-1}).

Studies that focus on particular nutrients also show noteworthy trends in profitability. According to Agnihotri *et al*. (2021) [2], hybrid 5222 with 120 kg N ha^{-1} generated the highest B:C ratio (3.11), net return (₹50, 345 ha^{-1}), and gross return (₹74, 162 ha^{-1}), but lower nitrogen levels led to smaller economic returns. Earlier research by Kumar *et al*. (2016) [8] demonstrated that combining NPK with vermicompost, sulfur, zinc, and boron greatly increased production, economic returns, and nutrient uptake.

Overall, these studies highlight that INM practices not only sustain yields but also maximize profitability by reducing input costs and enhancing benefit-cost ratios, making them a viable strategy for mustard farmers.

3. Material and methods

The field experiment entitled "Impact of Inorganic and Organic Fertilizer on Growth and Yield of Indian Mustard (*Brassica juncea* L.) under Dehradun conditions" was conducted during the Rabi season of 2023-24 at the Research Farm of Agronomy Block, Agriculture Department, Jigyasa University (Formerly Himgiri Zee University), Dehradun, Uttarakhand. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments i.e., T_1: 100% RDF @N:83.58g, P:75.12g, K:47.4g, T_2:80% RDF @ N: 69.65g, P: 62.60g, K:32g + Vermicompost @9kg, T_3:80% RDF @ N: 69.65g, P: 62.60g, K:32g + Biofertilizer (Azotobacter+ PSB@500 ml Kg-1 Seed), T_4: 80% RDF @ N: 69.65g, P: 62.60g, K: 32g + Vermicompost @9kg + Biofertilizer (Azotobacter+ PSB@500 ml Kg^{-1} Seed), T_5: 60% RDF@N:52.24g, P: 46.95, K:24g + Vermicompost@10.8 kg, T_6: 60% RDF @ N: 52.24g, P: 46.95, K: 24g + Biofertilizer (Azotobacter+ PSB@ 500 ml Kg^{-1} Seed), T_7: 60% RDF @N: 52.24g, P: 46.95, K: 24g + Vermicompost@10.8 kg + Biofertilizer (Azotobacter + PSB@ 500 ml Kg^{-1} Seed), T_8 100% Vermicompost @20 Kg and T_9:100% Biofertilizer (Azotobacter+ PSB@500 ml Kg-1 Seed) and three replications. The mustard variety HY-805 was sown on 20th October 2023 at a spacing of 45 cm × 10 cm, with a plot size of 3 m × 2 m. The recommended dose of fertilizer (RDF) was 80:60:40 kg ha^{-1} N:P:K, supplemented with vermicompost and biofertilizers (Azotobacter + PSB) as per treatment combinations. Standard agronomic practices were followed throughout the cropping period.

Before planting and after harvest, representative soil samples from each plot were taken, ranging in depth from 0 to 15 cm. pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), available phosphorus (P), and available potassium (K) were measured using standard techniques after the samples were air-dried and sieved (2 mm) (Jackson, 1973; Subbiah & Asija, 1956; Olsen *et al*., 1954) [6, 19, 12]. The purpose of these investigations was to examine how integrated nutrient management techniques affected soil fertility.

The following parameters were estimated for economic evaluation: Actual field operations, labor, and input expenses are used to calculate the cost of cultivation (₹ ha^{-1}). Based on stover yield at current local market rates and seed yield at Minimum Support Price (MSP), the gross return (₹ ha^{-1}) is calculated. After deducting the cultivation cost from the gross return, the net return (₹ ha^{-1}) is the result. The benefit-cost (B:C) ratio is computed by dividing net return by cultivation costs.

4. Results and Discussion

4.1. Effect of Organic and Inorganic Fertilizers on Soil Properties (Table 1)

The post-harvest physico-chemical characteristics of the soil were greatly impacted by the application of various mixes of organic and inorganic fertilizers. pH of the soil The pH of the soil varied between treatments, ranging from 7.33 to 7.78. T_4 (80% RDF + Vermicompost + Biofertilizer) had the lowest pH (7.33), indicating acidification brought on by microbial activity and the generation of organic acid. However, T_1 (100% RDF) had the highest pH (7.78), which may be because chemical fertilizers are alkaline. Nonetheless, the pH fluctuation stayed within the neutral to slightly alkaline range, suggesting that there were no negative impacts on the health of the soil.

Conductivity of electricity (EC) T_1 had the greatest soil EC and T_4 had the lowest, with a range of 1.13 to 1.61 dS m^{-1}. Lower salt accumulation may be the cause of the decreased EC with integrated and organic treatments, suggesting improved soil structure and a lower likelihood of salinization. Organic carbon (OC) Treatments with organic amendments showed a considerable increase in organic carbon content. T_1 had the lowest OC (0.38%), while T_4 had the highest OC (0.57%), followed by T_8 (0.54%). Vermicompost and biofertilizers, which add organic matter and support microbial activity and long-term soil fertility, are responsible for this improvement.

Phosphorus and Nitrogen Availability The range of accessible phosphorus and nitrogen was 6.63 to 13.50 kg ha^{-1} and 85.33 to 154.05 kg ha^{-1}, respectively (Fig.1.). The synergistic effect of integrated nutrient management (INM) on N and P mineralization and availability was demonstrated by the maximum values for both in T_4. Through processes including N mineralization and native phosphorus solubilization, the increased microbial activity in organic and INM treatments probably improved nutrient availability and cycling. These results are consistent with findings of Panwar (2008) [13] and Patra *et al.* (2011) [14], who reported that the use of organic inputs enhances nutrient release and microbial transformation processes in soil.

4.2. Economic Analysis of Mustard Cultivation

According to the economic analysis, maximizing profitability also benefited from integrated nutrient application (Table 2). The price of cultivation Because organic inputs are expensive, T_8 (100% Vermicompost) had the highest cultivation cost (Rs. 54, 603 ha^{-1}). T_9 (100% Biofertilizer) had the lowest (Rs. 32, 022 ha^{-1}), which is indicative of its inexpensive input cost. Net and Gross Returns Following T_1 and T_3, T_4 had the highest net return (Rs. 84, 269 ha^{-1}) and gross return (Rs. 1, 28, 255 ha^{-1}). Despite its high cost, T_8 had the lowest net return, demonstrating that applying vermicompost alone was not very cost-effective.

Cost: Benefit (B:C) The ratio T_4 had the highest B:C ratio (1.92), while T_8 had the lowest (0.62). This proves unequivocally that integrated nutrient management is more cost-effective than using only chemical or organic fertilizers. These results support those of Singh and Sinsinwar (2006) [17] and Kumar *et al.* (2011), who found that increased yield and input efficiency under integrated nutrient management led to increased profitability. The study unequivocally shows that applying 80% RDF along with vermicompost and biofertilizers (T_4) increases soil fertility, nutrient availability, and yields the highest possible economic returns while growing mustard. Although it produced good results, the application of chemical fertilizers alone (T_1) was not as effective as integrated techniques. Vermicompost (T_8) and other solely organic inputs enhanced soil health but were not economical. For sustainable mustard production, integrated nutrient management is advised in order to maximize soil health and financial gain.

Table 1: Influence of organic and inorganic fertilizer on the soil parameters under INM in Mustard.

Treatment		Soil pH	EC (dS m-1)	OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})
T_1	100% RDF @N:83.58g, P:75.12g, K:47.4g	7.78	1.61	0.38	85.33	6.63
T_2	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Vermicompost @9kg	7.69	1.43	0.52	148.53	11.44
T_3	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Biofertilizer (*Azotobacter*+ PSB@500 ml Kg^{-1} Seed)	7.7	1.47	0.5	140.59	10.22
T_4	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Vermicompost @9kg + Biofertilizer (*Azotobacter*+ PSB@500 ml Kg^{-1} Seed)	7.33	1.13	0.57	154.05	13.5
T_5	60% RDF@N:52.24g, P: 46.95, K:24g + Vermicompost@10.8 kg	7.74	1.43	0.47	131.48	9.15
T_6	60% RDF @ N:52.24g, P: 46.95, K:24g + Biofertilizer (*Azotobacter*+ PSB@ 500 ml Kg^{-1} Seed)	7.57	1.47	0.48	134.07	9.28
T_7	60% RDF @N:52.24g, P: 46.95, K:24g + Vermicompost@10.8 kg + Biofertilizer (Azotobacter + PSB@ 500 ml Kg-1 Seed)	7.65	1.53	0.51	142.95	10.83
T_8	100% Vermicompost @20 Kg	7.7	1.3	0.54	148.95	11.71
T_9	100% Biofertilizer (Azotobacter+ PSB@500 ml Kg-1 Seed)	7.73	1.4	0.45	126.07	9.11
C.D.		N/A	N/A	0.02	4.71	0.79
SE(m)		0.19	0.11	0.01	1.56	0.26
SE(d)		0.26	0.15	0.01	2.21	0.37
C.V.		4.22	12.83	2.73	2.01	4.44

Table 2: Impact of organic and inorganic fertilizer on the economics studies of Mustard.

	Treatment	Cost of cultivation (Rs.ha^{-1})	Gross return (Rs.ha^{-1})	Net return (Rs.ha^{-1})	B:C ratio
T_1	100% RDF @N:83.58g, P:75.12g, K:47.4g	33716.00	98189.47	64473.47	1.91
T_2	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Vermicompost @9kg	43736.00	110890.67	67154.67	1.54
T_3	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Biofertilizer (*Azotobacter*+ PSB@500 ml Kg^{-1} Seed).	33486.00	96803.33	63317.33	1.89
T_4	80% RDF @ N: 69.65g, P: 62.60g, K:32g + Vermicompost @9kg + Biofertilizer (*Azotobacter*+ PSB@500 ml Kg^{-1} Seed).	43986.00	128255.00	84269.00	1.92
T_5	60% RDF@N:52.24g, P: 46.95, K:24g + Vermicompost@10.8 kg	45350.00	101797.84	56447.84	1.24
T_6	60% RDF @ N:52.24g, P: 46.95, K:24g + Biofertilizer (*Azotobacter*+ PSB@ 500 ml Kg^{-1} Seed).	33000.00	89026.15	56026.15	1.70
T_7	60% RDF @N:52.24g, P: 46.95, K:24g + Vermicompost@10.8 kg + Biofertilizer (*Azotobacter* + PSB@ 500 ml Kg^{-1} Seed).	45600.00	111210.83	65610.83	1.44
T_8	100% Vermicompost @20 Kg	54603.00	88234.59	33631.59	0.62
T_9	100% Biofertilizer (*Azotobacter*+ PSB@500 ml Kg^{-1} Seed).	32022.00	86845.17	54823.17	1.71

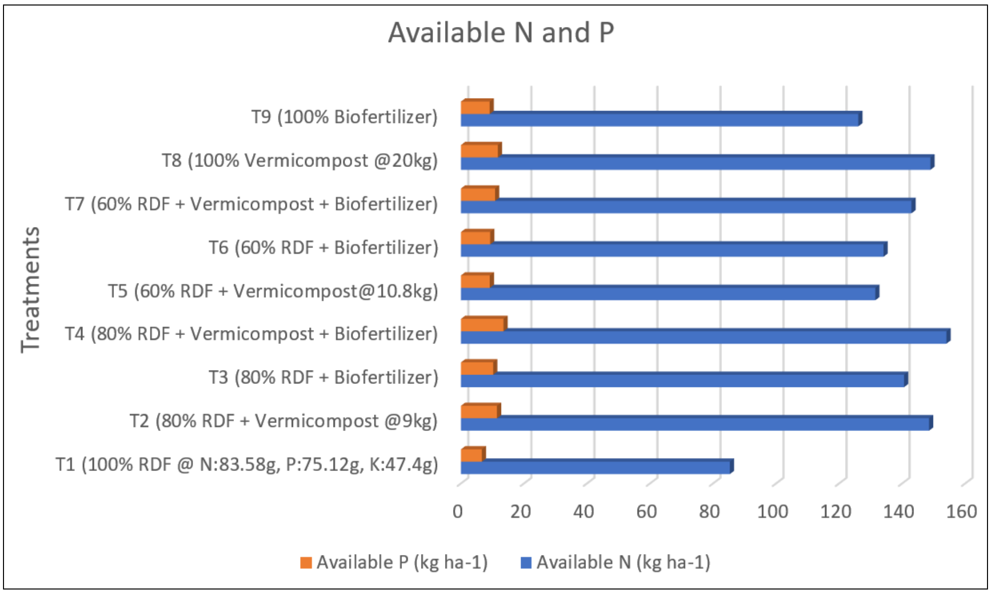

Fig 1: Available N and P content in soil under the influence of organic and inorganic fertilizer

5. Summary

The purpose of this study was to evaluate the effects of combined organic and inorganic fertilizer treatments on soil health and the profitability of growing mustard (*Brassica juncea* L.) in the agroclimatic conditions of Dehradun. Nine different nutrient management treatments were used in the study, including solitary applications of organic or bio inputs, combinations with vermicompost and biofertilizers (Azotobacter + PSB), and complete RDF (Recommended Dose of Fertilizer). Economic metrics like gross return, net return, and benefit-cost ratio were computed, and soil characteristics including pH, EC, organic carbon, and accessible NPK were measured both before and after harvest.

The results showed that treatment T_4 (80% RDF + vermicompost + biofertilizer) consistently performed better than the others, exhibiting the highest levels of nutrient availability and soil organic carbon (0.57%), as well as the highest economic returns. Although 100% RDF (T_1) was successful in preserving yields, it resulted in decreased organic carbon and increased soil EC. Although sole vermicompost (T_8) enhanced soil qualities, its high input costs made it unfeasible. Although it produced somewhat lower returns, the biofertilizer-only treatment (T_9) was the most cost-effective in terms of inputs. According to the study's findings, integrated nutrient management-specifically, using 80% RDF in conjunction with organic amendments-is a practical way to produce mustard that is both economically profitable and sustainable for the soil.

6. Conclusion

The current study unequivocally shows that integrated nutrient management techniques, which combine vermicompost and biofertilizers (T_4) with 80% of the prescribed fertilizer dose, greatly increase soil fertility, improve nutrient availability, and optimize financial returns in mustard farming. Chemical fertilizers by themselves can maintain yields, but over time, their usage alone may deteriorate soil health. On the other hand, whereas organic inputs alone enhance soil qualities, their high prices and reduced yields may make them unfeasible. As a result, integrated techniques provide mustard farmers in the Dehradun region with a viable and profitable strategy that promotes soil conservation and boosts profitability. In order to achieve long-term agricultural sustainability, it is imperative that such balanced nutrient management practices be adopted.

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