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Agronomic and Biochemical Responses of Sunflower under Integrated Nutrient Management and its Residual Effects on Fodder Cowpea

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ABSTRACT

A two-year field study was carried out during January–April and May–June of 2022 and 2023 at Uttar Chandamari village, Nadia district, West Bengal, India to evaluate the impact of integrated nutrient management (INM) on the agronomical and biochemical characteristics of sunflower (*Helianthus annuus* L.) and its residual effects on a subsequent fodder cowpea (*Vigna unguiculata* L.) crop. The study comprised nine nutrient management treatments combining varying proportions of inorganic fertilizers with organic sources, arranged in a randomized block design with three replications. Application of 100% recommended dose of fertilizer (RDF) through inorganic fertilizers achieved the highest sunflower growth, seed yield and nutrient uptake. However, the integrated treatment receiving 75% RDF through chemical fertilizers and 25% recommended dose of nitrogen (RD_N) through vermicompost performed comparably while enhancing soil nutrient status and seed quality attributes. Sole organic treatments produced lower sunflower yields but significantly enhanced oil content and oleic acid composition. Residual effects were pronounced in fodder cowpea, with the highest fodder yield and nutrient uptake observed under 100% RD_N through vermicompost in previous crop. Economically, the application of 100% RDF through inorganic fertilizers resulted in the maximum net returns and benefit-cost ratio, closely followed by partial substitution of inorganic nitrogen with vermicompost. The findings underscored the agronomic and environmental advantages of integrated nutrient management strategies, recommending the combination of 75% RDF from inorganic source with 25% RD_N through vermicompost as the most balanced approach for enhancing system productivity and soil health in intensive cropping systems of Eastern India.

KEYWORDS: INM, sunflower, fodder cowpea, organic manure, soil fertility

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1. INTRODUCTION

India's rapidly expanding population is generating a significant pressure on the country's food production systems. Simultaneous, the country possesses the world's largest livestock population, estimated at 536.76 million animals (Anonymous, 2019), which substantially escalates the demand for quality fodder alongside food. The concurrence of population growth, climatic variability, shrinking arable land and progressive degradation of soil resources has resulted in declining soil fertility and nutrient imbalances, thereby posing serious challenges to sustainable agricultural production and ecological balance (Si et al., 2025). Oilseed crops have garnered considerable attention due to their rich phytochemical composition and associated health benefits, making them indispensable components of diversified and nutritionally secure farming systems (Laaraj et al., 2025). Among oilseeds, sunflower (*Helianthus annuus* L.) occupies a unique position due to its wide adoptability, thermo- and photo-insensitivity and production of high-quality edible oil with desirable fatty acid composition (Suryavanshi et al., 2015). Its versatility and short duration make sunflower a promising crop for inclusion in intensive and climate-resilient cropping systems (Puttha et al., 2023). With the increasing consumer preference for healthier edible oils, enhancing sunflower productivity has become imperative to bridge the demand–supply gap at both state and national levels. Parallel to food and oilseed shortages, India is grappling with a serious fodder deficit, estimated at 35.6% for green fodder and 10.95% for dry fodder, which directly affects livestock productivity and farm profitability (Kumar et al., 2023). Expansion of cereal and cash crop cultivation has further reduced land availability for fodder production, aggravating the problem (Bhaumik and Rajeev, 2024). In this context, integrating fodder crops within existing cropping sequences emerges as a practical strategy to enhance fodder availability without compromising food production. Integrated Nutrient Management (INM) has been emerged as a promising strategy to restore soil fertility and stabilize agricultural productivity (Sande et al., 2024). Soils, though finite, function as vital reservoir of essential nutrients and their efficient management can substantially enhance plant health, improve soil structure and ensure the long-term sustainability of agricultural ecosystems (Bhat et al., 2024; Lal, 2015). INM, combining the balanced use of organic, biological and chemical nutrients sources enhances nutrient use efficiency, improves soil organic carbon and microbial activity, and reduces environmental degradation in the intensive cropping system (Paramesh et al., 2023; Wu and Ma, 2015). Furthermore, the inclusion of fast-growing forage legumes as catch crops-planted in between two main crop cycles-presents a viable strategy for improving nutrient cycling, boosting soil health and enhancing overall system sustainability (Whittaker et al., 2023). Cultivation of fodder cowpea following sunflower harvest in summer can rationalize land use, enrich soil organic matter, improve nutrient status and particularly alleviate fodder shortages (Kumar et al., 2025). The New Alluvial Zone (NAZ) receives adequate rainfall (average annual rainfall: 1300–1600 mm; Mandal et al., 2022) and has sufficient irrigation facilities, which provides substantial scope for cropping intensification through diversified, remunerative and climate-resilient cropping systems. In Eastern India, where a large number of farmers depend on livestock-based livelihood (Mishra et al., 2024), a sunflower-fodder cowpea cropping sequence offers a viable option for both food and fodder production. However, productivity of this system remains constrained due to inadequate and imbalanced nutrient management practices. This study, therefore, aimed at evaluating the agronomic and biochemical responses of sunflower under different Integrated Nutrient Management (INM) strategies and assessing their residual effects on growth, yield and fodder productivity of succeeding cowpea, with the objective of improving system productivity, soil fertility and profitability of the sunflower-fodder cowpea system.

2. MATERIALS AND METHODS

The field experiment was conducted during January–April and May–June of 2022 and 2023 at the farmer's field of Uttar Chandamari, Nadia district, West Bengal, India, over the two consecutive cropping seasons. The experimental site is situated in a sub-tropical and humid climatic region at an elevation of 9.8 m above mean sea level and is intersected by 22°57'22''N latitude and 88°20'14''E longitude. The textural class of the experimental soil is sandy clay loam with a composition of 56.2% sand, 20.3% silt and 23.5% clay. The soil exhibited a slightly acidic pH of 6.64, electrical conductivity of 0.29 ds m^{-1} and organic carbon content of 0.57% at the surface layer (0–30 cm). Initial soil nutrient levels before the experiment were 203.3 kg ha^{-1} nitrogen, 18.50 kg ha^{-1} phosphorus and 176.33 kg ha^{-1} potassium. The experiment was laid out in Randomized Block Design (RBD) with nine treatments replicated thrice. The treatments were: T_1: 100% Recommended Dose of Fertilizer (RDF) through inorganic sources (IF); T_2: 75% RDF (IF)+25% recommended dose of nitrogen (RD_N) from vermicompost; T_3: 75% RDF (IF)+25%RD_N from farmyard manure (FYM); T_4: 50% RDF (IF)+50% RD_N from vermicompost; T_5: 50% RDF (IF)+50% RD_N from FYM; T_6: 25% RDF (IF)+75% RD_N from vermicompost; T_7: 25% RDF (IF)+75% RD_N from FYM; T_8: 100% RD_N from vermicompost; and T_9: 100% RD_N from FYM. The recommended doses of fertilizer (RDF) for sunflower were 80–40–40 kg N–P–K ha^{-1}. Both organic manures were produced at the household level. Since organic manures were often unregulated agro-inputs, farmers frequently struggle with purchasing substandard products from the open market. The nutrient composition of the organic manures applied in both years indicated that vermicompost contained 1.53% N, 0.58% P_2O_5 and 1.02% K_2O in the first year and 1.57% N, 0.63% P_2O_5 and 0.99% K_2O in the second year. In comparison, farmyard manure contained 0.65% N, 0.26% P_2O_5 and 0.41% K_2O in the first year and 0.63% N, 0.25% P_2O_5 and 0.39% K_2O in the second year. The organic as well as phosphatic and potassic fertilizers were incorporated before final land preparation, while nitrogen was applied in two splits: one at sowing and another during early vegetative stage. Fodder cowpea was grown as a residual crop, relying solely on residual soil fertility from the preceding sunflower crop without any external fertilizer or manure application. Sunflower (*cv.* MSFH-17) was planted manually using dibbling, with spacing of 60×30 cm^2. Fodder cowpea (*cv.* Bundel-2) was sown in rows with a spacing of 30×15 cm^2. The net plot area for measuring crop yields was maintained at 5.0×4.0 m^2. Sunflower was harvested manually at physiological maturity with grain yield. Since cowpea was grown for fodder, the aerial biomass was harvested using a single-cut method and the fresh yield was recorded accordingly. Except for the nutrient management component, all other agronomic management practices were effectively implemented as per the recommended package of practices for the respective crops. Observations on various growth, yield and quality parameters were recorded following standard protocols. Animal unit equivalents for fodder cowpea were calculated considering one mature cow (454 kg) with an average daily forage consumption of 12 kg dry matter day^{-1} (Menendez III et al., 2023). Based on this standard, treatment-wise animal units were determined. System productivity was assessed in terms of sunflower grain equivalent yield (SEY) by converting the green fodder yield of cowpea based on prevailing market prices and expressed in kg ha^{-1} (Dixit et al., 2017).

SEY=(Yield of cowpea×Price of cowpea)/Price of sunflower

The experimental data were subjected to statistical analysis using analysis of variance (ANOVA) under a randomized block design (RBD). Treatment means were compared for statistical significance using the critical difference (CD) at a p=0.05 probability level. The pooled data from two years were statistically analysed using the F-test following the standard procedure.

3. RESULTS AND DISCUSSION

3.1. Growth parameters of sunflower

The growth response of sunflower to varied nutrient management strategies (Table 1) exhibited marked differences across treatments, reflecting the influence of integrated application of organic and inorganic inputs on vegetative and physiological development. The treatment comprising 100% recommended dose of fertilizer though inorganic fertilizer (T_1) significantly outperformed all others, registering the highest plant height (148.82 cm), leaf area index (2.53) and crop growth rate (4.87 g m^{-2} day^{-1}) during 60–90 DAS. Notably, the treatment T_2 (75% RDF+25% RD_N through vermicompost) demonstrated statistically comparable performance, indicating the efficacy of partial substitution of inorganic N by organic one in sustaining growth attributes. Ghosh et al. (2022) and Mallick and Majumder (2023) similarly reported that partial substitution of chemical fertilizers with organic sources resulted in superior growth attributes compared to the sole application of inorganic fertilizers. In contrast, sole organic nutrient applications (T_8 and T_9) exhibited suboptimal performance across all parameters. Mahapatra et al. (2021) and Islam et al. (2024) also reported the lowest growth attributes of sunflower under sole organic condition. Sluggish mineralization resulting in slow availability of nutrients by the plants might be the root cause of such suboptimal performance. These findings underscored the agronomic advantage of integrated nutrient management, particularly substituting 25% RD_N through vermicompost (T_2), which optimized growth potential while enhancing nutrient use efficiency and contributing to sustainable soil fertility management.

3.2. Yield parameters, yield and harvest index of sunflower

The yield parameters presented in Table 1 indicated that 100% RDF though chemical fertilizer (T_1) exhibited the highest performance across all attributes, with the maximum number of filled seeds $capitulum^{-1}$ and the largest capitulum diameter. This treatment showed statistical parity with T_2 (75% RDF+25% RD_N from vermicompost). On the other hand, the plot solely treated FYM had the lowest values for these parameters. However, there was no significant difference on the test weight of sunflower grain. Our findings corroborated the observations of Moitra et al. (2012), who reported improved yield attributes and higher seed yield of summer sunflower with 25% substitution of inorganic fertilizer through vermicompost. Based on pooled analysis, application of 100% RDF though chemical fertilizer consistently resulted the highest seed yield (2.10 t ha^{-1}) and exhibited statistical parity with 75% RDF from inorganic fertilizer+25% RDN through vermicompost (Table 1). Mim et al. (2024) and Sefaoglu et al. (2021) also reported higher sunflower yield under the integration of vermicompost with inorganic fertilizers. Combination of organic manure and inorganic fertilizer showed positive impact on yield of sunflower which have been prominently reflected through the performance of T_2. In contrast,

Table 1: Effect of different organic and inorganic sources of fertilizers on growth, yield parameters and yield of sunflower

Treatment	Growth parameters			Yield parameters			
	Plant height (cm) at 90 DAS	LAI at 90 DAS	CGR (60–90 DAS)	Capitulum diameter (cm)	Filled seed capitulum^{-1}	1000 seed weight (g)	Seed yield (t ha^{-1})
T_1	150.78	2.53	4.87	20.43	751.86	53.94	2.10
T_2	147.38	2.48	4.84	20.00	750.35	53.59	2.07
T_3	139.94	2.44	4.68	18.70	678.80	52.22	1.90
T_4	129.87	2.16	4.09	18.02	674.45	52.61	1.91
T_5	122.99	2.07	3.46	14.77	555.65	53.28	1.72
T_6	120.39	1.98	3.18	15.09	601.10	52.44	1.75
T_7	109.93	1.87	3.08	12.84	446.47	52.06	1.51
T_8	103.91	1.71	2.77	13.14	497.54	51.35	1.56
T_9	97.00	1.58	2.53	11.61	413.06	51.18	1.34
SEm±	1.52	0.02	0.04	0.18	7.34	0.65	0.02
CD (p=0.05)	4.68	0.07	0.14	0.53	22.09	NS	0.06

T_1: 100% RDF through inorganic fertilizer (IF); T_2: 75% RDF (IF)+25% RDN from vermicompost; T_3: 75% RDF (IF)+25% RDN from FYM; T_4: 50% RDF (IF)+50% RDN from vermicompost; T_5: 50% RDF (IF)+50% RDN from FYM; T_6: 25% RDF(IF)+75% RDN from vermicompost; T_7: 25% RDF(IF)+75% RDN from FYM; T_8: 100% RDN from vermicompost and T_9: 100% RDN from FYM; LAI: leaf area index; CGR: Crop growth rate

solely FYM treated plot recorded the lowest seed yield (1.34 t ha^{-1}), indicating the fact that only organic source of nitrogen was not sufficient for maximizing sunflower yield. Significant difference amongst the treatments have not been visualized through the computed data on harvest index. These results emphasized the crucial role of integrated nutrient management in optimizing sunflower yield while reducing dependency on chemical fertilizers.

3.3. Quality parameters of sunflower seed and oil

The figure 1 represented the influence of different nutrient sources on sunflower seed quality, including oil content, protein content and fatty acid composition. During both the years of the investigation, solely vermicompost treated treatment (T_8) was found to be superior in terms of oil content (43.16% and 42.96% in respective years) and this treatment was statistically comparable with the treatment T_9, receiving 100% RD_N through FYM. The treatment T_2 (75% RDF+25% RD_N through vermicompost) recorded the highest protein content 17.79% and 17.58% in respective years, indicating the role of integrated nutrient sources in enhancing protein synthesis in sunflower seeds. Regarding fatty acid composition in sunflower oil, the treatment T_8 (100% RD_N though vermicompost) demonstrated the highest oleic acid content, which was crucial for improving the nutritional quality of sunflower oil. The treatment T_1 (100% RDF from inorganic sources) exhibited the highest linoleic acid content (43.7% in Year I and 42.3% in Year II), contributing to the polyunsaturated fatty acid profile. The palmitic and stearic acid contents remained relatively stable across the treatments as well as years, i.e. showing minimal variation. These results underscored the positive impact of organic sources, particularly vermicompost and FYM, on enhancing sunflower oil quality and protein content, highlighting their potential for improving both yield and nutritional value in sunflower cultivation. Sefaoglu et al. (2021) and Alzamel et al. (2022) also reported positive effect of organic manure on the quality attributes of sunflower.

3.4. Fresh yield and sunflower equivalent yield of residual fodder cowpea along with its corresponding livestock support capacity

The study evaluated the residual effect of different sources of nutrients on the productivity and livestock supported capacity of fodder cowpea over the two consecutive years (Table 2). Among all the treatments, the plot treated exclusively with vermicompost in the previous season produced the highest fresh yield, recording 50% more than the plot previously treated with 100% RDF through chemical fertilizer (T_1). This treatment was statistically similar to T_9 (100% N through FYM), which yielded 21.32 t ha^{-1}. The same trend was observed for sunflower equivalent yield and animal unit (days). Organic manures like FYM and vermicompost, when applied before sunflower sowing, do not provide immediate nitrogen, limiting sunflower yield. This might be due to the fact that the organic manure released plant nutrients slowly but steadily to the

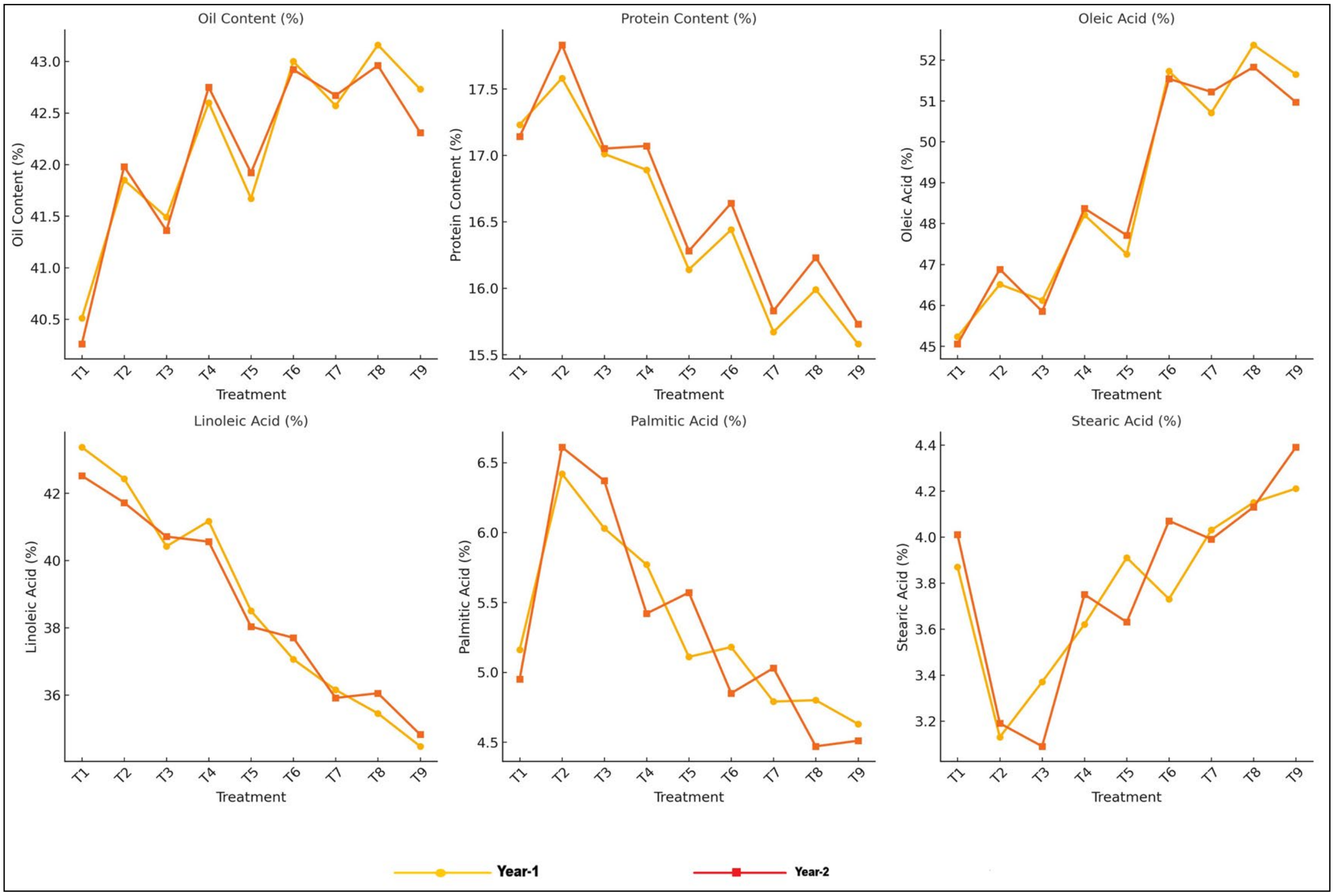

Figure 1: Effect of different organic and inorganic sources of fertilizers on biochemical parameters of sunflower

crops in sequence resulting in its better performance in the succeeding crops in a sequence. The nutrients present in the manures remained in the soil as a reserve and become available to the crop through mineralization thereby leading to higher fodder yield. This result was in authentication with the statements of Singh et al. (2011), Ebbisa et al. (2025) and Niivedidhaa et al. (2021) reflecting significant residual effects of vermicompost on succeeding crops. Their studies further indicated that vermicompost application enhances soil physico-chemical and biological properties beyond a single cropping season.

Table 2: Effect of different organic and inorganic sources of fertilizers on yield of residual fodder cowpea along with corresponding animal unit grown in the sequence

Treatment	Fresh yield (t ha^{-1})	Sunflower eq. yield of cowpea (t ha^{-1})	Animal unit (days)
T_1	14.53	0.45	183.25
T_2	16.41	0.51	251.17
T_3	15.34	0.48	215.46
T_4	18.34	0.57	283.59
T_5	17.78	0.55	246.58
T_6	20.59	0.64	332.63
T_7	19.78	0.62	293.96
T_8	21.85	0.68	362.92
T_9	21.32	0.66	324.21
SEm±	0.25	0.006	3.84
CD (p=0.05)	0.74	0.02	11.65

3.5. Nodule content and quality parameters of residual fodder cowpea grown in the sequence

The results presented in Table 3 demonstrated the positive impact of nutrient management on the nodule content and quality parameters of residual fodder cowpea over two years. The treatment pervious treated with sole vermicompost (T_8) consistently showed superior performance as compared to other treatments, achieving the highest number of nodules plant^{-1} and the maximum nodule biomass (Table 3). Moreover, the maximum protein content as well as ascorbic acid content were also achieved through this treatment. The lowest values for the above cited parameters were observed under the plot treated exclusively with inorganic source in the preceding season (T_1). Absence of any organic manure in this treatment might be the probable reason behind such

Table 3: Effect of different organic and inorganic sources of fertilizers on nodule content and quality parameters in residual fodder cowpea grown in the sequence

Treatment	Nodules plant^{-1} (40 DAS)	Nodule biomass (40 DAS)	Protein content (%)	Ascorbic acid (mg (100 g^{-1} leaf)
T_1	18.55	172.03	12.10	12.18
T_2	23.77	289.23	13.49	13.44
T_3	20.93	248.64	12.82	12.98
T_4	27.81	347.66	14.13	13.58
T_5	25.09	273.94	13.24	13.12
T_6	30.10	425.97	14.79	15.32
T_7	26.96	369.43	14.03	14.73
T_8	33.10	484.98	15.32	15.90
T_9	31.12	425.85	14.34	15.05
SEm±	0.36	5.02	0.18	0.19
CD (p=0.05)	1.08	15.22	0.54	0.56

poor performance. Khatri et al. (2025); Amaya-Gómez et al. (2025) and Panda et al. (2012) reported that growth attributes, nodulation and yield of cowpea increased significantly with the application of organic manure.

3.6. *NPK uptake by both the crops grown in sequence*

The data presented in Table 4 represented considerable variation in the uptake of nitrogen, phosphorus and potassium (kg ha^{-1}) by sunflower and residual fodder cowpea under various nutritional treatments over two years. In sunflower, highest total uptake of N, P, and K was recorded under treatment T_1 (100% RDF through inorganic fertilizers), which was statistically at par with T_2 (75% RDF+25% RDN through vermicompost), thereby establishing their superiority over the remaining treatments. Conversely, the worst nitrogen uptake was obtained under solely FYM treated plot (T_9). The superior performance of T_1 could be ascribed to the immediate solubility and rapid nutrient release characteristics of chemical fertilizers. However, a little bit substitution of chemical fertilizers through organic manure especially vermicompost (T_2) was also proved to be a better choice. This was likely due to its dual role: sustaining soil physico-chemical properties while ensuring a gradual nutrient release, synergistically complemented by the high nutrient availability of the inorganic fraction. This result proved the findings of Mehta et al. (2024) and Mallick and Majumdar (2023), who reported enhanced nutrient uptake in sunflower when organic sources were integrated with 75% of the recommended dose of fertilizers (RDF). For the residual cowpea crop, treatment T_8 (100% RD_N through vermicompost applied in preceding crop) showed the highest total N, P and K uptake (Table 4). Whereas, the poorest assessment on NPK uptake was observed in the plot getting fully inorganic source nutrient in former crop (T_1). These findings suggested that, the organic sources, such as vermicompost, contributed to better long-term soil fertility, enhancing nutrient uptake in the residual cowpea crop.

2.7. *Economics*

The pooled data over two consecutive years of experimental study indicated that (Table 5) the maximum total cost of cultivation of the system was observed under the sole organic

Table 4: Effect of different organic and inorganic sources of fertilizers on total NPK uptake by sunflower and fodder cowpea grown in the sequence

Treatment	Sunflower			Fodder cowpea		
	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Total K uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})	Total K uptake (kg ha^{-1})
T_1	78.75	27.68	65.53	42.67	4.59	16.73
T_2	78.68	26.57	64.08	65.15	7.18	24.54
T_3	70.10	22.57	55.99	53.06	5.76	20.11
T_4	68.35	23.35	56.42	76.98	8.81	29.14
T_5	59.31	19.07	48.62	62.69	7.16	24.41
T_6	61.04	19.73	48.96	94.46	11.00	35.41
T_7	50.26	15.08	41.00	79.23	8.98	29.87
T_8	52.41	16.37	41.37	106.81	12.37	39.12
T_9	44.10	13.15	35.32	89.29	10.73	33.94
SEm±	0.77	0.24	0.62	1.13	0.13	0.41
CD (p=0.05)	2.37	0.74	1.88	3.43	0.39	1.26

treatment through FYM (T_9), whereas, the minimum cost of cultivation was noticed under the treatment receiving the chemical fertilizers only (T_1). The treatment superiority with consideration to net return as well as B-C ratio was identified under the sole chemical treatment (T_1) and it was closely followed by the treatment received 75% RDF along with 25% N from vermicompost.

Table 5: Effect of different organic and inorganic sources of fertilizers on economics of the cropping system

Treatment	Total cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
T_1	82162.85	175868.00	93705.15	2.14
T_2	83133.50	176602.00	93468.50	2.12
T_3	83677.85	163421.00	79743.15	1.95
T_4	84098.64	169906.00	85807.36	2.02
T_5	85187.35	156147.00	70959.65	1.83
T_6	85100.29	163959.00	78858.71	1.93
T_7	86733.35	145779.00	59045.65	1.68
T_8	86065.43	153430.00	67364.57	1.78
T_9	88242.85	135959.00	47716.15	1.54

4. CONCLUSION

Application of 75% RDF along with 25% RD_N through vermicompost emerged as a superior option, ensuring enhanced system yield, economic profitability and nutritional quality, while simultaneously promoting sustainable nutrient management compared with sole reliance on chemical fertilization.

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