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Research Paper

Eco-friendly nutrient management approaches for sustainable organic fodder production in cowpea-maize cropping sequence

B.G. SHEKARA[1], N.M. CHIKKARUGI[2], MANJANAGOUDA S SANNAGOUDAR[3], N. RANI[4], ALIZA PRADHAN[5], MOHD. ARIF[6], SURABHI[7], VISHAL TYAGI[8] AND GAURENDRA GUPTA[9]

AICRP on Forage Crops and Utilization, V.C. Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka 560065

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ABSTRACT

Conventional farming relies on synthetic fertilizers for immediate nutrient release and availability, but their long-term use can degrade soil quality and reduce microbial activity. Organic amendments, such as farmyard manure (FYM), vermicompost, and bio-compost, offer a viable alternative by improving soil health, enhancing microbial diversity, and ensuring sustained nutrient release. This study evaluated eco-friendly nutrient management approaches for sustainable organic fodder production in cowpea-maize cropping sequence. The results revealed that the highest green fodder yield in maize (425.9 t/ha) and cowpea (25.99 t/ha) was observed under 100% Recommended Rate of Nitrogen (RRN) through inorganic fertilizers, though the combined application of 50% RRN through FYM and 50% through bio-compost also demonstrated noteworthy yield performance. Crude protein content was highest under inorganic fertilizers (8.7% in maize), but organic treatments exhibited similar results, particularly in cowpea (19.0%). Soil health parameters, including microbial biomass and enzymatic activity, were significantly improved under organic amendments. Economically, 100% RRN through inorganic fertilizers recorded the highest net returns (₹85,797/ha) and B:C ratio (2.93), however, the organic treatment (50% RRN through FYM + 50% bio-compost) emerged as a sustainable and profitable alternative. These findings suggest that integrating organic sources can sustain high productivity while enhancing soil fertility and long-term economic viability.

Key words: Green fodder yield, Dry matter, Crude protein, Organic, Soil health, Economics

Livestock serves as a key component of the rural economy, which also serves as a foundation for raising farmers' standard of living. Since agriculture is the main driver of the Indian economy, cattle play an even greater role. Approximately 20.3 million people rely on farm animals for their livelihood, which contributes an average of 15.5% to the incomes of small farm households and 13.8% to the rural population (Roy *et al*., 2019). Additionally, it employs 8.8% of the population and supports the livelihoods of two-thirds of rural communities, contributing 4.11% to the GDP and 25.4% to the total agricultural GDP (IGFRI, 2023). The health and productivity of livestock in any nation depend on the availability of high-quality forages. However, in many developing nations, livestock frequently experience malnutrition due to an insufficient fodder supply, both in quality and quantity. Additionally, the reduction in pastureland, driven by the increasing demand for food crops, has led to lower production potential compared to developed nations. Modern agricultural systems face significant challenges due to unsustainable food and fodder production practices (Baradwal *et al.,* 2022). The overuse of chemical pesticides and fertilizers has led to soil degradation, groundwater pollution, and nutrient loss due to erosion, which in turn diminishes soil fertility and lowers farm income (Patidar *et al.,* 2023). As a result, there is a growing global awareness of the need for alternative, holistic approaches in agriculture. While inorganic fertilizers play a crucial role in supplying essential nutrients for crop growth and development, their indiscriminate use has led to severe nutrient depletion and leaching, posing a major threat to sustainable and environmentally friendly

[1]**Corresponding author's Email:** mssagron@gmail.com
[1,2,4]Principal Scientist, AICRP on Forage Crops and Utilization, V.C. Farm, Mandya 571 405, Karnataka; [3]Scientist, ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh 284 003, [9]Scientist, ICAR-National Institute of Seed Science & Technology, Regional Station, Bengaluru, Karnataka 560 065; [5]Scientist, ICAR-National Institute of Abiotic Stress Management, Baramati- 413 115. [6]Scientist, ICAR-Indian Institute of Farming Systems Research, Modipuram- 250 110. [7]Research Scholar, University of Agricultural Sciences, Bangalore, Karnataka 560 065; [8]Scientist, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

farming practices (Das *et al.,* 2020).

As a result of growing concerns over the negative impacts of chemical fertilizers, there is a gradual shift towards using organic manures as an alternative nutrient source, promoting sustainable agricultural production (Gupta *et al.,* 2022). The indiscriminate application of inorganic fertilizers has been shown to degrade soil properties, ultimately leading to poor crop growth and reduced productivity (Sannagoudar and Murthy, 2018). To address this issue, farmers must adopt healthier and more sustainable crop production practices by utilizing locally available organic nutrient sources, which help maintain and rejuvenate soil and plant health. In India, approximately 350 million tonnes of agricultural waste are generated annually, posing a significant challenge for disposal. However, Sharma et al. (2024) estimated that these wastes alone could supply over 20 million tonnes of essential plant nutrients. The improper disposal of organic waste is becoming an escalating environmental concern, making composting a crucial, eco-friendly, and economically viable solution. Through biological treatment, agricultural waste can be converted into nutrient-rich organic matter, which serves as a fundamental input for organic farming (Das *et al.,* 2020). These organic nutrients, being carbon-based compounds, enhance soil fertility and promote vigorous plant growth, making them an essential component of sustainable agricultural systems. Organic farming significantly reduces reliance on chemical fertilizers, pesticides, and livestock feed additives. Instead, it primarily depends on practices such as crop rotation, the use of crop residues, animal manure, legumes, green manure, off-farm organic waste, mineral-rich rocks, and biofertilizers. These methods help maintain soil health, enhance productivity and tilth, supply essential plant nutrients, and naturally control pests, weeds, and diseases. Additionally, organically grown products not only support environmental sustainability but also fetch higher market value compared to conventionally grown crops. Consequently, organic agriculture is becoming increasingly important in modern food and fodder production systems. In light of these considerations, the present study was conducted to assess the effects of various organic nutrient sources on fodder yield, quality, and soil health in a fodder cowpea-maize cropping sequence.

MATERIALS AND METHODS

Study location: A field experiment was conducted over four consecutive years (2020–2023) to evaluate the effect of organic nutrient sources and inorganic fertilizers on forage yield, quality, and soil health in a fodder cowpea-maize cropping sequence. The study was carried out in an organically converted plot at the Zonal Agricultural Research Station (ZARS), VC Farm, Mandya, Karnataka. The experimental site is located between 12°45' and 13°57' North latitude and 76°45' and 78°24' East longitude, at an altitude of 695 meters above mean sea level. This location falls under Karnataka's Southern Dry Zone (ACZ-VI) and is classified as a semi-arid region of India.

Weather and soil characteristics: The meteorological data from 2020 to 2023 indicate significant seasonal variations in rainfall, temperature, relative humidity, and sunshine hours at the experimental site (Fig. 1). The highest rainfall was recorded in October (227.80 mm), followed by May (186.77 mm) and August (185.30 mm), suggesting that these months experienced peak monsoonal activity. The driest months were January (4.53 mm) and March (9.00 mm), indicating limited moisture availability during this period. Relative humidity remained above 70% for most of the year, peaking in July (85.56%), which coincided with the lowest maximum (19.01°C) and minimum (12.13°C) temperatures. Conversely, April recorded the highest maximum temperature (34.97°C), while December had the lowest minimum temperature (17.05°C). Sunshine hours were highest in March (8.27 hours/day) and lowest in July (0.77 hours/day), reflecting the influence of cloud cover during the monsoon season. These climatic variations highlight the region's semi-arid nature, with distinct wet and dry periods influencing crop growth and productivity. The soil of the experimental site is red sandy loam in texture, neutral in soil reaction (pH 7.1), medium in organic carbon content (0.65%), available nitrogen (285.26 kg ha^{-1}), P_2O_5 (49.55 kg ha^{-1}) and K_2O (218.36 kg ha^{-1}).

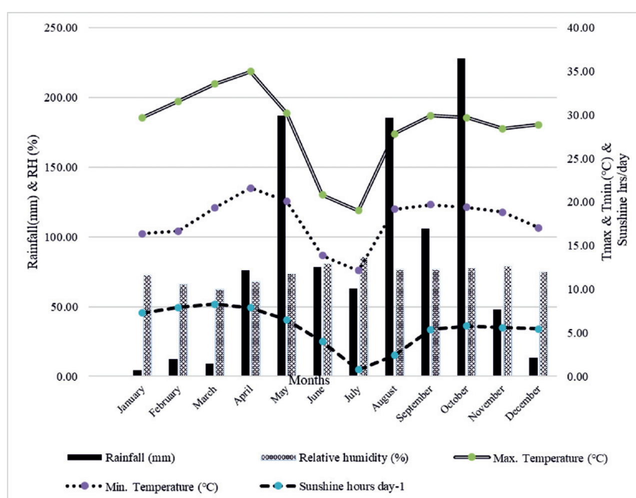


Fig. 1. Meteorological data of the experimental site for the year 2020 to 2023

Treatment details and crop management: The experiment was conducted on a permanent plot basis in an organically converted plot. The experiment consisted of seven treatments viz., T_1-100% RRN through inorganic fertilizers, T_2-100% RRN through FYM, T_3-75% RRN through FYM+ 25% RRN through vermicompost, T_4-75% RRN through FYM + 25% RRN through bio-compost, T_5-50% RRN through FYM + 50% RRN through vermicompost, T_6-50% RRN through FYM + 50% RRN through bio-compost, and T_7-50% RRN through FYM+ 25% RRN through vermicompost + 25% RRN through bio-compost. The trial was laid out in Randomized block design with three replications. The recommended nitrogen dose was provided through various organic manure sources, calculated based on nitrogen equivalence, along with available phosphorus and potassium. No additional phosphorus or potassium was supplied from external chemical sources. The establishment of fodder cowpea and fodder maize followed the locally recommended package of practices. The details of the agronomic practices followed, and the inputs applied during the study are presented in Table 1.

Growth and yield attributes: At the time of harvest, plant height was recorded by measuring from the base to the tip of the main flag leaf, with an average calculated from five plants and expressed in centimeters. The leaf-stem ratio was determined by dividing the total leaf weight by the stem weight. Fresh fodder yield was measured immediately after harvesting each plot and reported in quintals per hectare. For dry weight estimation, five plants were randomly selected from each plot, dried at 80 ± 5 °C for 24 hours until a constant weight was attained, and then recorded. From this value, dry matter yield in t/ha was calculated.

Fodder quality attributes: The crude protein (%) was arrived by finding the nitrogen content of the whole plant through modified micro kjeldhal method (Banerjee, 1978) and then multiplying the nitrogen percentage with factor 6.25 (Doubetz and Wells, 1968). The crude protein yield was calculated by multiplying crude protein percentage with dry matter yield and expressed in t/ha.

Plant nutrients content and uptake: Before sowing, composite soil samples were randomly collected from the experimental field from the 0-15 cm soil depth for physico-chemical analysis. Likewise, post-harvest soil samples were collected from the 0-15 cm depth for each treatment, air-dried in the shade, ground, and sieved through a 2 mm mesh for primary nutrient assessment.

Microbial count, microbial biomass carbon, urease and dehydrogenase activity

The total bacteria, fungi, and actinomycetes in the free rhizosphere were enumerated after the crop harvest using the serial dilution and agar plate method. Soil microbial biomass carbon was assessed using the fumigation-extraction method. Moist soil sub-samples were fumigated with CHCl (Chloroform) and subsequently extracted with KSO (Potassium Sulphate). The biomass carbon content was determined by calculating the difference in carbon levels between fumigated and non-fumigated samples (Cater, 1991). Urease activity was assessed using a colorimetric technique outlined by Kandeler, 1996. Dehydrogenase activity was evaluated using a colorimetric method described by Ohlinger *et al.,* 1996.

Economics: The adoption of any technology largely depends on its economic advantage over existing methods, particularly in terms of higher net returns and a favorable benefit-cost (B:C) ratio. The B:C ratio was determined using the standard formula.

$$\text{BC ratio} = \frac{\text{Gross returns (₹/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

The economic efficiency was calculated by dividing gross returns with crop duration for different treatments in both cowpea and maize as shown below.

$$\text{Economic efficiency (₹/ha/day)} = \frac{\text{Gross returns (₹/ha)}}{\text{Crop duration in days}}$$

Statistical analysis: The data recorded on various growth, yield and quality parameters were subjected to analysis of variance as detailed by Gomez and Gomez (1984). Results have been interpreted for the mean data for four years.

Table 1. Agronomic practices followed and inputs applied during 2020 to 2023 in Cowpea and Maize

Agronomic practice	Fodder Cowpea	Fodder Maize
Variety/hybrid	MFC 09-1	African Tall
Sowing time	Second fortnight of August	First fortnight of February
Seed rate (kg/ha)	37.5	100
Plot size	4.0 m × 5.0 m	4.0 m × 5.0 m
Spacing	30 cm × 10 cm	30 cm × 10 cm
Fertilizers (kg/ha)	25:50:25 NPK	150:75:40 NPK
Harvesting time	Harvested when the crop attained 10% flowering (60 DAS)	Harvested at the dough stage for green fodder (70 DAS)

RESULTS AND DISCUSSION

Growth attributes

The current study revealed that maize achieved the greatest plant height with the application of 100% Recommended Rate of Nitrogen (RRN) through inorganic fertilizers (216.2 cm). However, this treatment was statistically similar to three organic nutrient management treatments: 50% RRN through Farmyard Manure (FYM) + 50% vermicompost (202.3 cm), 50% RRN through FYM + 50% bio-compost (205.7 cm), and 50% RRN through FYM + 25% vermicompost + 25% bio-compost (204.1 cm) (Table 1). These results suggest that organic nutrient sources can effectively meet the nutrient demands of fodder maize, comparable to inorganic fertilizers. For cowpea, the tallest plants were recorded under the 100% RRN through inorganic fertilizers treatment (85.9 cm), followed by the 50% RRN through FYM + 50% bio-compost treatment (78.2 cm). This indicates that organic amendments play a significant role in promoting plant growth, though to a slightly lesser extent than inorganic fertilizers. No statistically significant differences were found among the treatments in terms of the leaf-to-stem ratio in maize. However, the highest ratio was recorded in the 100% RRN through inorganic fertilizers treatment (0.46). In cowpea, the highest leaf-to-stem ratio (0.60) was found in the 100% RRN through inorganic fertilizers treatment, which was significantly superior to all other treatments. The enhanced plant height and leaf-to-stem ratios observed in the inorganic fertilizer treatment (T1) can be attributed to immediate nutrient availability, promoting rapid vegetative growth. Conversely, the organic treatment T6 (50% RRN through FYM + 50% bio-compost) also demonstrated commendable growth performance, likely due to the gradual nutrient release from organic amendments, which supports sustained plant development. These findings are consistent with those of Boateng and Ayisi, 2015, who reported that applying poultry and cattle manures in a maize-cowpea intercropping system resulted in plant heights comparable to those achieved with chemical fertilizers. Additionally, Kumar *et al.* (2020) found that integrating organic sources such as FYM and bio-compost significantly improved growth parameters in a fodder cowpea-maize cropping system.

Green fodder and dry matter yield

The highest green forage yield in maize was obtained with the application of 100% Recommended Rate of Nitrogen (RRN) through inorganic fertilizers (42.59 t/ha), followed by the treatment with 50% RRN through Farmyard Manure (FYM) and 50% bio-compost (37.34 t/ha) (Table 2). Similarly, in cowpea, the highest green forage yield was recorded under 100% RRN through inorganic fertilizers (25.99 t/ha), which was statistically comparable to the treatments where 50% RRN was supplied through FYM and the remaining 50% through either vermicompost (23.56 t/ha) or bio-compost (24.27 t/ha). The total system green forage yield exhibited a similar trend, with 100% RRN through inorganic fertilizers producing the maximum yield (68.58 t/ha), followed by the 50% RRN through FYM + 50% bio-compost treatment (61.61 t/ha). A comparable pattern was observed for dry matter yield, where 100% RRN through inorganic fertilizers resulted in the highest dry matter yield for maize (10.07 t/ha), cowpea (5.17 t/ha), and the total system (15.24 t/ha). The second

Table 1. Plant height and leaf to stem ratio as influenced by organic source of nutrients in fodder cowpea – maize cropping sequence

Treatments	Plant height (cm)		Leaf: Stem ratio	
	Maize	Cowpea	Maize	Cowpea
T_1, 100% RRN through inorganic fertilizers	216.2[a]	85.9[a]	0.46[a]	0.60[a]
T_2, 100% RRN through FYM	187.0[d]	68.9[d]	0.36[a]	0.52[a]
T_3, 75% RRN through FYM+ 25% RRN through vermicompost	198.2[c]	75.8[b]	0.30[a]	0.53[a]
T_4, 75% RRN through FYM+ 25% RRN through Bio-compost	190.5[d]	72.0[c]	0.33[a]	0.53[a]
T_5, 50% RRN through FYM+ 50% RRN through vermicompost	202.3[b]	76.9[b]	0.36[a]	0.54[a]
T_6, 50% RRN through FYM+ 50% RRN through Bio-compost	205.7[b]	78.2[b]	0.35[a]	0.55[a]
T_7, 50% RRN through FYM+ 25% RRN through vermicompost + 25% RRN through Bio compost.	204.1[b]	76.1[b]	0.30[a]	0.55[a]
SEm±	5.2	1.7	0.13	0.01

*RRN: Recommended rate of nitrogen

*Means followed by the same letter(s) within a column are not significantly differed by Duncan Multiple Range Test ($p < 0.05$)

highest dry matter yield was recorded in the 50% RRN through FYM + 50% bio-compost treatment (8.75 t/ha in maize and 4.70 t/ha in cowpea), which was statistically on par with the inorganic fertilizer treatment. The increased forage yields observed in the inorganic fertilizer treatment (T1) can be attributed to the immediate availability of nutrients, which enhances biomass production. Organic treatments, particularly T6, also demonstrated considerable yield performance, likely due to improved soil structure and enhanced microbial activity, which facilitate nutrient availability. These findings are in agreement with Baradwal *et al.* (2023), who conducted a meta-analysis and concluded that the combined application of chemical and organic fertilizers significantly increased maize yield and soil nutrient content. Similarly, Boateng and Ayisi (2015) reported that the incorporation of organic manures in a maize-cowpea intercropping system resulted in forage yields comparable to those achieved with inorganic fertilizers.

Fodder quality

The highest crude protein percentage in maize was recorded under the 100% Recommended Rate of Nitrogen (RRN) through inorganic fertilizers (8.7%), which was statistically comparable to three organic treatments: 50% RRN through Farmyard Manure (FYM) + 50% vermicompost, 50% RRN through FYM + 50% bio-compost, and 50% RRN through FYM + 25% vermicompost + 25% bio-compost (Table 3). For cowpea, as well as the overall system crude protein percentage, the highest values were observed under 50% RRN through FYM + 50% bio-compost (19.0% for cowpea and 13.6% for the total system), showing increases of 20.25% and 11.48% over conventional practices. This treatment was statistically comparable to 50% RRN through FYM + 25% vermicompost + 25% bio-compost (18.7% for cowpea and 13.6% for the total system). The highest crude protein yield in maize was recorded under 100% RRN through inorganic fertilizers (0.87 t/ha), while for cowpea, the highest yield was achieved with 50% RRN through FYM + 50% bio-compost (0.89 t/ha). This was statistically similar to the yields recorded under 100% RRN through inorganic fertilizers (0.82 t/ha) and 50% RRN through FYM + 25% vermicompost + 25% bio-compost (0.84 t/ha). The total crude protein yield of the system was highest under 100% RRN through inorganic fertilizers (1.69 t/ha), but it was statistically comparable to 50% RRN through FYM + 50% bio-compost (1.61 t/ha) and 50% RRN through FYM + 25% vermicompost + 25% bio-compost (1.59 t/ha). Crude protein content is a critical factor in determining fodder quality, directly influencing its nutritional value and digestibility for livestock. The higher crude protein levels observed in inorganic fertilizer treatment can be attributed to the immediate availability of nitrogen, which plays a crucial role in amino acid synthesis and protein formation in plants. Additionally, nitrogen is essential for chlorophyll production and enzymatic activities, thereby enhancing protein accumulation. Similar results were reported by Kumar *et al.* (2020), who found that the application of inorganic fertilizers significantly increased crude protein content in fodder crops. Conversely, the treatment incorporating 50% RRN through FYM and 50% bio-compost (T6)

Table 2. Green forage and dry matter yield as influenced by organic source of nutrients in fodder cowpea – maize cropping sequence

Treatments	Green forage yield (t/ha)			Dry matter yield (t/ha)		
	Maize	Cowpea	System yield	Maize	Cowpea	System yield
T_1, 100% RRN through inorganic fertilizers	42.59[a]	25.99[a]	68.58[a]	10.07[a]	5.17[a]	15.24[a]
T_2, 100% RRN through FYM	36.20[de]	22.06[d]	58.26[d]	8.09[de]	4.15[c]	12.24[d]
T_3, 75% RRN through FYM+ 25% RRN through vermicompost	35.62[e]	21.91[de]	57.54[d]	7.96[e]	4.21[c]	12.17[d]
T_4, 75% RRN through FYM+ 25% RRN through Bio-compost	36.44[cd]	21.46[e]	57.91[d]	8.26[cd]	4.10[c]	12.35[d]
T_5, 50% RRN through FYM+ 50% RRN through Vermicompost	36.96[bc]	23.58[c]	60.54[c]	8.42[c]	4.58[b]	13.00[c]
T_6, 50% RRN through FYM+ 50% RRN through Bio-compost	37.34[b]	24.27[b]	61.61[b]	8.75[b]	4.70[b]	13.46[b]
T_7, 50% RRN through FYM+ 25% RRN through Vermicompost + 25% RRN through Bio compost.	37.37[b]	23.48[c]	60.85[c]	8.86[b]	4.53[b]	13.39[b]
SEm±	1.13	0.83	0.98	0.22	0.19	0.34

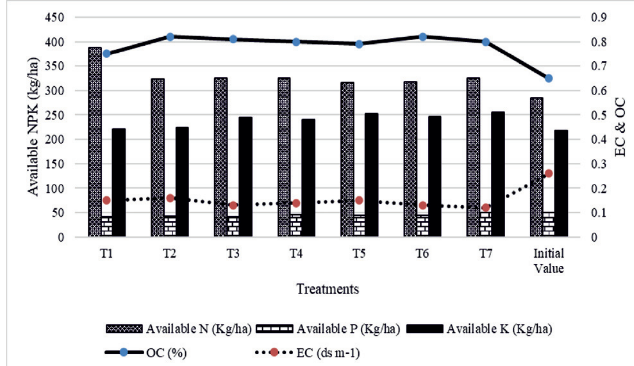
*RRN: Recommended rate of nitrogen

*Means followed by the same letter(s) within a column are not significantly differed by Duncan Multiple Range Test ($p < 0.05$)

also yielded appreciable crude protein levels in both crops. This suggests that organic amendments can serve as an effective nitrogen source, albeit through a slower release mechanism facilitated by microbial decomposition. The gradual nutrient release from organic sources ensures a sustained nitrogen supply, supporting consistent protein synthesis throughout plant growth. A study by Boateng and Ayisi (2015) corroborates these findings, demonstrating that the integration of organic manures enhances crude protein content in fodder crops.

Soil health

Soil organic carbon (OC%) increased in all treatments compared to the initial value (0.65%). The highest organic carbon content (0.82%) was recorded in T6 (50% RRN through FYM + 50% bio-compost) and T2 (100% RRN through FYM), which was significantly higher than the inorganic fertilizer treatment (0.75%) by 9.33% (Table 4). Incorporating organic materials like FYM and bio-compost enhances SOC levels by adding decomposable organic matter to the soil. This increase in SOC improves soil structure, water retention, and cation exchange capacity, which are vital for nutrient availability and overall soil fertility. A study by Li *et al.* (2022) reported that application of organic amendments over a long period led to a significant increase in SOC, thereby enhancing soil quality and productivity. Electrical conductivity (EC) decreased across all treatments compared to the initial value (0.26 dS/m^{-1}). The highest EC was observed in T2 (0.16 dS/m^{-1}), while the lowest was recorded in T7 (0.12 dS/m^{-1}). In this study, a decrease in EC was observed at the end of the cropping sequence, particularly in treatments receiving organic



amendments. This reduction can be attributed to the improved soil structure and increased microbial activity resulting from organic matter addition, which enhance leaching of excess salts and reduce salt accumulation. Ding *et al.* (2020) found that organic amendments decreased soil salinity and EC by promoting salt leaching and improving soil physical properties. Soil available nitrogen (N) increased in all treatments compared to the initial value (285.26 kg/ha), with the highest levels recorded under 100% RRN through inorganic fertilizers (387.98 kg/ha), followed by T4 (325.62 kg/ha) and T7 (325.62 kg/ha). Soil available phosphorus (P) showed a decline in all treatments compared to the initial value (49.55 kg/ha). However, T7 recorded the highest phosphorus content (49.4 kg/ha), which was significantly higher than the 100% inorganic fertilizer treatment (40.7 kg/ha) by 21.98%. Soil available potassium (K) increased across all treatments, with T7 recording the highest potassium content (255.76 kg/ha), significantly higher than the initial value (218.36 kg/ha) and the lowest value observed in the 100% inorganic fertilizer

Table 3. Crude protein (%) and crude protein yield as influenced by organic source of nutrients in fodder cowpea – maize cropping sequence

Treatment	Crude Protein (%)			Crude Protein yield (t/ha)		
	Maize	Cowpea	Total	Maize	Cowpea	Total
T_1, 100% RRN through inorganic fertilizers	8.7^{a}	15.8^{c}	12.2^{c}	0.87^{a}	0.82^{a}	1.69^{a}
T_2, 100% RRN through FYM	7.8^{b}	15.1^{c}	11.5^{d}	0.63^{d}	0.63^{c}	1.26^{c}
T_3, 75% RRN through FYM + 25% RRN through vermicompost	7.9^{ab}	16.7^{b}	12.3^{c}	0.62^{d}	0.70^{bc}	1.32^{c}
T_4, 75% RRN through FYM + 25% RRN through Bio-compost	8.0^{ab}	15.8^{c}	11.9^{cd}	0.66^{cd}	0.65^{c}	1.31^{c}
T_5, 50% RRN through FYM + 50% RRN through vermicompost	8.6^{ab}	17.2^{b}	12.9^{b}	0.72^{bc}	0.79^{ab}	1.51^{b}
T_6, 50% RRN through FYM + 50% RRN through Bio-compost	8.3^{ab}	19.0^{a}	13.6^{a}	0.72^{bc}	0.89^{a}	1.61^{ab}
T_7, 50% RRN through FYM + 25% RRN through vermicompost + 25% RRN through Bio compost.	8.5^{ab}	18.7^{a}	13.6^{a}	0.75^{b}	0.84^{a}	1.59^{ab}
SEm±	0.2	0.2	0.1	0.02	0.03	0.04

*RRN: Recommended rate of nitrogen

*Means followed by the same letter(s) within a column are not significantly differed by Duncan Multiple Range Test ($p < 0.05$)

treatment (221.6 kg/ha). Gao *et al.* (2019) reported that compost application enhanced the availability of P and K by increasing microbial activity and producing organic acids that mobilize these nutrients. This is consistent with findings from a study by Adediran *et al.* (2005), which reported that the application of organic fertilizers led to significant increases in soil organic matter, total N, and available P, thereby enhancing soil fertility and crop yield.

The microbial population was consistently higher in all treatments incorporating organic inputs compared to the 100% inorganic fertilizer treatment, which exhibited the lowest microbial count (Table 4). The highest bacterial (89.76 × 10v cfu/g) and actinomycete (14.96 × 10³ cfu/g) populations were observed in T7 (50% recommended rate of nitrogen through farmyard manure + 25% vermicompost + 25% bio-compost), representing a significant increase of 33.33% and 60%, respectively, over the inorganic fertilizer treatment. Regarding fungal populations, both T5 (50% RRN through FYM + 50% vermicompost) and T7 recorded the highest values (29.92 × 10t cfu/g), demonstrating a 60% increase compared to the 100% inorganic fertilizer treatment (18.70 × 10t cfu/g). These increases can be attributed to the continuous supply of carbon substrates from organic amendments, which serve as energy sources for soil microorganisms. The gradual decomposition of FYM and bio-compost facilitates the slow release of nutrients, creating a favorable environment for microbial proliferation and activity. This aligns with findings from a meta-analysis by Zhou *et al.* (2022), which reported that organic amendments significantly enhance microbial biomass and enzyme activity by improving soil carbon and nutrient availability. Similarly, Ghosh *et al.* (2020) demonstrated that the application of organic fertilizers increased soil microbial biomass carbon and dehydrogenase activity, contributing to improved soil health and fertility. In contrast, soils receiving only inorganic fertilizers generally exhibit lower microbial activity due to the absence of organic substrates essential for microbial growth. While inorganic fertilizers provide readily available nutrients, they do not contribute to the organic carbon pool, which is crucial for sustaining soil microbial communities.

The soil microbial biomass carbon (MBC), dehydrogenase activity (DHA), and urease activity after harvest were consistently higher in all organic input treatments compared to the 100% inorganic fertilizer treatment (Table 5), which recorded the lowest values (190.46 mg/kg soil for MBC, 69.31 µg/TPF/g/24 hrs for DHA, and 96.15 µg/NHz/g/2 hrs for urease activity). Notably, T4 (75% RRN through FYM + 25% bio-compost) and T7 (50% RRN through FYM + 25% vermicompost + 25% bio-compost) consistently exhibited the highest and identical values for all three parameters, recording 224.68 mg/kg soil for MBC, 82.06 µg/TPF/g/24 hrs for DHA, and 117.22 µg/NHz/g/2 hrs for urease activity, being 17.97%, 18.40%, 21.91% greater than the values observed in 100% inorganic fertilizers treatment. This highlights the positive impact of organic amendments on enhancing microbial activity and soil enzymatic functions, which are crucial for maintaining soil fertility and biological health. The increase in MBC observed in organic amendment treatments can be attributed to the provision of readily available carbon sources from the decomposing organic materials, which stimulate microbial growth and proliferation. This finding aligns with the results of Heidari *et al.* (2016), who reported that the appli-

Table 4. Soil microbial count as influenced by organic source of nutrients in fodder Cowpea – Maize cropping sequence

Treatments	Bacterial population Cfu/g × 10^6	Fungal population Cfu/g × 10^4	Actinomycetes population Cfu/g × 10^3
T_1, 100% RRN through inorganic fertilizers	67.32^f	18.70^d	9.35^c
T_2, 100% RRN through FYM	72.93^e	24.31^c	11.22^{bc}
T_3, 75% RRN through FYM+ 25% RRN through vermicompost	76.67^{de}	26.18^{bc}	13.09^{ab}
T_4, 75% RRN through FYM+ 25% RRN through Bio-compost	78.54^{cd}	26.18^{bc}	9.35^c
T_5, 50% RRN through FYM+ 50% RRN through vermicompost	82.28^{bc}	29.92^a	11.22^{bc}
T_6, 50% RRN through FYM+ 50% RRN through Bio-compost	84.15^b	28.05^{ab}	13.09^{ab}
T_7, 50% RRN through FYM+ 25% RRN through vermicompost + 25% RRN through Bio compost.	89.76^a	29.92^a	14.96^a
SEm±	7.51	3.39	2.57

*RRN: Recommended rate of nitrogen

*Means followed by the same letter(s) within a column are not significantly differed by Duncan Multiple Range Test ($p < 0.05$)

Table 5. Soil microbial biomass carbon (MBC), dehydrogenase (DHA), and urease activity after harvest as influenced by organic source of nutrients in fodder Cowpea – Maize cropping sequence

Treatment	MBC (mg/kg Soil)	DHA (µg/TPF/g 24 hrs)	Urease (µg/NH4+/g 2 hrs)
T_1, 100% RRN through inorganic fertilizers	190.46[b]	69.31[b]	96.15[b]
T_2, 100% RRN through FYM	222.92[a]	81.41[a]	116.31[a]
T_3, 75% RRN through FYM+ 25% RRN through vermicompost	223.93[a]	81.78[a]	116.83[a]
T_4, 75% RRN through FYM+ 25% RRN through Bio-compost	224.68[a]	82.06[a]	117.22[a]
T_5, 50% RRN through FYM+ 50% RRN through vermicompost	218.09[a]	79.65[a]	113.79[a]
T_6, 50% RRN through FYM+ 50% RRN through Bio-compost	219.47[a]	80.15[a]	114.51[a]
T_7, 50% RRN through FYM+ 25% RRN through vermicompost + 25% RRN through Bio compost.	224.68[a]	82.06[a]	117.22[a]
SEm±	15.21	9.86	11.78

*RRN: Recommended rate of nitrogen
*Means followed by the same letter(s) within a column are not significantly differed by Duncan Multiple Range Test ($p < 0.05$)

cation of organic manures increased soil microbial biomass in soybean production systems. The elevated DHA in organically amended soils suggests enhanced microbial respiration and metabolic functioning. This enhancement is likely due to the improved availability of organic substrates and nutrients, which promote microbial activity. Dehydrogenase activity is a key indicator of microbial oxidative processes, representing the metabolic capability of soil microorganisms. Similarly, urease activity plays a crucial role in nitrogen cycling by breaking down urea into ammonia, ensuring the availability of nitrogen for plant uptake. Yang *et al.* (2020) observed similar increases in dehydrogenase activity following the application of organic amendments in a study on mine soil remediation.

Economics

The highest gross returns (₹1,28,756/ha) and net returns (₹85,797/ha) were obtained in T1 (100% RRN through inorganic fertilizers). Among organic treatments, T6 (50% RRN through FYM + 50% RRN through bio-compost) recorded the highest gross returns (₹1,16,394/ha) and net returns (₹69,994/ha), followed closely by T7 (₹1,14,982/ha and 65,138/ha, respectively). The lowest net returns (₹57,738/ha) were observed in T3 (75% RRN through FYM + 25% RRN through vermicompost). T1 had the highest B:C ratio (2.93) and economic efficiency (₹1,072.97/ha/day), owing to the immediate availability of nutrients leading to higher yields. Among organic treatments, T6 exhibited a B:C ratio of 2.43 and an economic efficiency of 969.95/ha/day, making it the most profitable organic alternative (Fig. 2). The higher economic returns in T1 can be attributed to the increased yield due to readily available nutrients, which directly enhanced revenue. However, the organic treatment T6 also demonstrated substantial profitability, indicating that bio-compost and FYM together can provide an economically viable alternative to inorganic fertilizers in fodder-based cropping systems. While inorganic fertilizers provide immediate economic returns, continuous reliance on them depletes soil health, necessitating higher input costs over time. On the other hand, organic treatments improve soil structure, nutrient cycling, and microbial activity, leading to long-term sustainability. The results suggest that T6 (FYM + bio-compost) presents a sustainable and economically viable strategy for organic fodder production.

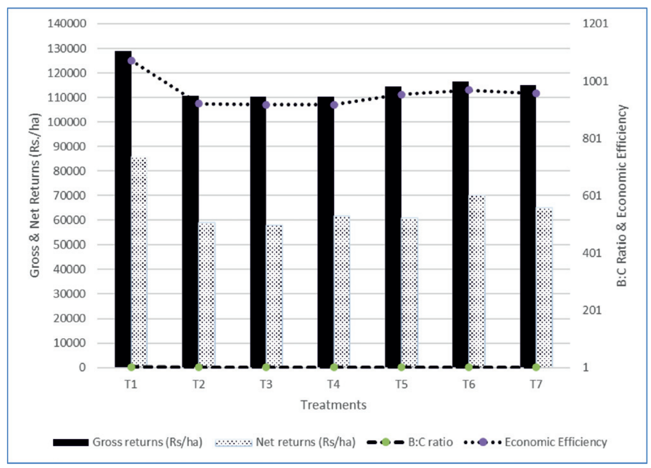


Fig. 2. Economics of cowpea - maize cropping sequence as influenced by organic source of nutrients

Based on four years of experimentation, it can be concluded that the application of 50% nitrogen through FYM and 50% nitrogen through bio compost or 50% nitrogen through FYM, 25% nitrogen through vermicompost, and 25% nitrogen through bio compost are viable and cost-effective organic nutrient management strategies. These treatments resulted in improved crop growth, higher forage yield, enhanced dry matter accumulation, increased crude protein content, and greater economic returns. Additionally, both treatments significantly enhanced soil microbial activity, enzymatic functions, and nutrient availability, contributing to improved soil health. Therefore, integrating FYM with bio compost or a combination of vermicompost and bio compost serves as a sustainable, eco-friendly, and economically viable approach for nutrient management in the fodder cowpea-maize cropping sequence.

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