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Sustainable nutrient management in Cotton: Impact of nitrogen application through vermicompost on yield, growth attributes, and economic returns

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Abstract

A field investigation titled " Sustainable Nutrient Management in Cotton: Impact of Nitrogen Application through Vermicompost on Yield, Growth Attributes, and Economic Returns " was conducted during the *Kharif* season of 2021-22 at COART (Centre for Organic Agriculture Research and Training), Dr. PDKV, Akola to evaluate the effect of different nitrogen levels applied through vermicompost on the productivity, growth, and economics of rainfed organic cotton (*Gossypium* spp.). The experiment was laid out in a factorial randomized block design (FRBD) with eight treatments, each replicated three times, using vermicompost as the nutrient source. Treatments included the application of 40 or 60 kg N ha⁻¹ via vermicompost to cultivars of *G. hirsutum* and *G. arboreum*. Results revealed significant variation in seed cotton yield, stalk yield, and key growth parameters across treatments. The highest seed cotton yield (1508 kg ha⁻¹) and stalk biomass (3685 kg ha⁻¹) were recorded under 60 kg N ha⁻¹ applied to *G. hirsutum* (T₄), reflecting a 52.3% yield improvement over the lowest-yielding treatment T₁. Enhanced growth attributes, such as plant height, number of sympodia, and boll production, were also observed in T₄. Although differences in harvest index were statistically non-significant, the mean value (28.88%) suggested efficient biomass partitioning under organic nutrient regimes. Economic analysis indicated that T₄ yielded the highest gross returns (₹1,13,400 ha⁻¹), net returns (₹59,400 ha⁻¹), and benefit-cost ratio (2.1). The study affirms that vermicompost, when applied at 60 kg N ha⁻¹, can substantially improve cotton yield, profitability, and sustainability under organic farming systems. These findings support the integration of vermicompost into organic nutrient management strategies for improved productivity and soil health. Further studies should assess the long-term soil fertility impacts and adaptability across agro-climatic zones to refine organic cotton cultivation practices.

Keywords: Economic returns, growth attributes, nitrogen management, vermicompost

1. Introduction

Cotton (*Gossypium* spp.), a principal fibre crop of global significance, plays a pivotal role in the agricultural economy of India, contributing substantially to rural livelihoods, industrial raw material supply, and foreign exchange earnings. Cotton is primarily cultivated for its lint, which serves as the raw material for the global textile and garment sectors often referred to as the "King of Fibres". Despite its commercial value, cotton is a nutrient-exhaustive crop with high nitrogen (N) demand, necessitating efficient and sustainable nutrient management strategies to sustain productivity while preserving soil health (Reddy *et al.*, 2022) [24].

The crop holds substantial socio-economic importance, supporting the livelihoods of millions of farmers, labourers, and workers in associated industries. India leads the world in cotton acreage, with approximately 124.69 lakh hectares under cultivation accounting for nearly 39% of the global cotton-growing area. About 67% of this area is rainfed, while the remaining 33% is under irrigation. Despite this extensive area under cultivation, India ranks second in global cotton production after China but stands 33rd in productivity, with an average production of 25 million bales and contributes to 21% of global production.

Conventional cotton production systems in India have largely relied on chemical fertilizers to meet crop nutrient requirements. However, indiscriminate and imbalanced use of inorganic fertilizers has led to adverse consequences, including nutrient imbalances, declining soil fertility,

reduced factor productivity, and increased production costs (Reddy *et al.*, 2024) ^[25]. In this context, integrated nutrient management (INM), especially the incorporation of organic sources such as vermicompost, offers a promising alternative for enhancing soil fertility, improving crop growth, and maintaining ecological balance (Reddy *et al.*, 2025) ^[23]. It promotes practices that maintain ecological integrity and agroecosystem sustainability over the medium to long term.

Vermicompost, a nutrient-rich organic amendment derived from the biological decomposition of organic matter by earthworms, represents a cornerstone of organic and sustainable agriculture. It is known for its ability to enhance soil fertility, structure, and biological activity, while providing readily available forms of essential nutrients such as nitrogen, phosphorus, and potassium. Vermicompost not only improves plant growth and crop yields but also supports environmental stewardship by recycling organic waste into a valuable agricultural input. Its multifunctional benefits make it a vital component of holistic nutrient management strategies in sustainable cotton cultivation (Reddy *et al.*, 2024) ^[26]. In organic farming, nitrogen from sources like vermicompost is released slowly, ensuring continuous availability throughout the crop cycle. This enhances soil microbial activity and long-term fertility, avoiding issues like leaching or volatilization seen in synthetic N sources.

Soils in major cotton-growing regions of India are often deficient in nitrogen, organic carbon, and phosphorus, reflecting the broader issue of nutrient imbalance in Indian agriculture (Rattan *et al.*, 1999) ^[21]. Nitrogen (N) is a fundamental macronutrient essential for plant growth and development. In cotton, nitrogen contributes significantly to vegetative growth, enhances photosynthetic efficiency, and increases boll formation by promoting the development of nodes and fruiting sites. However, excessive nitrogen application can lead to delayed crop maturity, increased pest pressure, and deterioration in fibre quality. Therefore, optimizing nitrogen inputs is critical for balancing growth, yield, and quality. Adequate nitrogen ensures

rapid development of leaves and branches, increasing the photosynthetic area, which directly supports boll formation. Despite growing interest in organic and sustainable nutrient sources, research quantifying the agronomic and economic impacts of nitrogen application through vermicompost in cotton cultivation remains limited, particularly under field conditions. Moreover, the interactive effects of vermicompost-derived nitrogen on growth attributes, yield components, and profitability need systematic evaluation to guide nutrient management recommendations for cotton growers.

Therefore, the present study was undertaken to evaluate the influence of varying levels of nitrogen applied through vermicompost on the growth, yield, and economic returns of cotton. The findings are expected to contribute to the development of sustainable nutrient management strategies aimed at enhancing cotton productivity while ensuring long-term soil health and economic viability.

2. Materials and Methods

2.1 Site, climate and soil characteristics

The study was carried out at the Central Research Farm, College of Agriculture, Dr. Panjab Rao Deshmukh Krishi Vidyapeeth, Akola, lies in a subtropical zone at 22°42' N latitude and 77°02' E longitude, at an altitude of 304.42 meters above mean sea level. The experimental site exhibited a relatively uniform topography and featured Vertisol soil, classified as montmorillonite and hyperthermic, falling under the Typic Haplusterts subgroup. The soil was clay loam in texture and characterized by smectite clay minerals known for their swelling and shrinking behaviour. Annual rainfall averages 1084 mm, primarily received during the southwest monsoon (July-September). During the crop growth period, the recorded maximum daytime temperature peaked at 40.4 °C, while the minimum nighttime temperature varied, reaching as low as 15.8 °C. Baseline soil properties were assessed prior to the commencement of the experiment (Table 1).

Table 1: Physical and chemical properties of experimental soil before start of organic cotton experiment (2020-21)

S. No.	Particulars	Value	Method adopted	Reference
1	Bulk density (Mg m ⁻³)	1.26	Clod coating method	Blacke and Hartage (1986)
2	Water holding capacity (%)	50.3	Keen box method	Gupta and Dakshinamoorthi (1980) ^[7]
3	pH (1:2.5)	7.6	Glass electrode pH meter	Jackson (1973) ^[11]
4	Electrical conductivity (ds m ⁻¹)	0.3	Electrical conductivity bridge	Jackson (1973) ^[11]
5	Organic Carbon (g kg ⁻¹)	4.9	Walkley and Black rapid titration method	Walkley and Black (1934) ^[33]
6	Available Nitrogen (kg ha ⁻¹)	195	Alkaline permanganate method	Subbiah and Asija (1956) ^[31]
7	Available Phosphorus (kg ha ⁻¹)	16.74	Olsen's method	Olsen <i>et al.</i> , 1954 ^[15]
8	Available Potassium (kg ha ⁻¹)	328	Neutral normal ammonium acetate	Hanway, J.J. and Heidel, H (1952) ^[9]

2.2 Experiment details

The field experiment was initiated in 2020 to evaluate the effect of vermicompost application on growth attributes and yield performance of rainfed cotton during the Kharif season. Vermicompost was applied at two nitrogen-equivalent rates—40 kg N ha⁻¹ and 60 kg N ha⁻¹—across multiple cotton cultivars. The experimental layout followed a factorial randomized block design (FRBD) comprising eight treatment combinations with three replications each. Sowing was performed manually across all plots. To ensure uniform plant population, gap filling and thinning were carried out as needed. Each experimental plot measured 5.4 × 6 m². A seed rate of 10-12 kg ha⁻¹ was used, with sowing done by dibbling at a spacing of 90 × 30 cm.

Table 2: Treatment details

Tr.	Treatment details
T ₁	AV1N1- Arboreum cultivar + 40 kg N ha ⁻¹
T ₂	AV1N2- Arboreum cultivar + 60 kg N ha ⁻¹
T ₃	HV1N1- Hirsutum cultivar + 40 kg N ha ⁻¹
T ₄	HV1N2- Hirsutum cultivar + 60 kg N ha ⁻¹
T ₅	AV2N1- Arboreum cultivar + 40 kg N ha ⁻¹
T ₆	AV2N2- Arboreum cultivar + 60 kg N ha ⁻¹
T ₇	HV2N1- Hirsutum cultivar + 40 kg N ha ⁻¹
T ₈	HV2N2- Hirsutum cultivar + 60 kg N ha ⁻¹

- HV1-Chetna J1
- HV2-GHV 8023
- AV1-AVC 14
- AV2-GAV 8011

2.3 Growth parameters

2.3.1 Plant height (cm)

Plant height, a vital indicator of crop vigour and growth, was measured from the base of the plant to the apex of the terminal bud. Measurements were taken from five randomly selected, representative plants per plot at 30, 60, 90, and 120 days after sowing (DAS), as well as at harvest. The mean plant height per plot was calculated for each interval.

2.3.2 Crop stand

The crop stand was assessed by counting the total number of plants within each net plot area.

2.3.3 Number of bolls per plant

The number of fully opened bolls per plant was recorded during each picking from the observation plants. These values were summed over the cropping period to determine the total number of bolls produced per plant. The average per plant was computed and expressed accordingly.

2.3.4 Number of sympodial branches

Cotton plants exhibit two distinct branch types: monopodial (vegetative) and sympodial (fruit-bearing). The count of sympodial branches—each characterized by a flowering node with a subtending leaf and an axillary bud—was recorded from five representative plants in each net plot.

2.3.5 Days to 50% flowering and 50% boll bursting

The number of days from sowing to the point when 50% of the plants within a plot exhibited flowering was recorded to assess the onset of the reproductive stage.

Similarly, the duration from flowering to the stage when 50% of the plants exhibited boll bursting was documented to evaluate boll maturation and opening.

2.4 Seed cotton yield and Stalk yield

Picking of seed cotton was done as soon as the 50 percent boll bursted with the help of manual labour. In both the pickings. After picking of seed cotton, plants were cut from soil surface manually at harvest. At each harvest interval, the weight of seed cotton collected from all plants within the net plot was recorded and expressed in kilograms.

Harvest index= Economic yield/ biological yield *100, expressed in percentages

2.5 Economic evaluation

Gross returns, net returns, and the benefit-cost (B:C) ratio were computed for each treatment based on the yield and input cost data to assess the economic viability of the treatments.

2.6 Statistical analysis

Experiment followed a Factorial randomized block design (FRBD) and the collected data were subjected to statistical analysis using ANOVA as outlined by Gomez and Gomez (1984), using SPSS software (Version 26.0). Standard errors of the mean were calculated and treatment means were separated using Least significant difference (LSD) test at a significance level of $p < 0.05$. The significance of treatment effects was evaluated using the F-test. Where differences were found to be significant, the Critical Difference (CD) at the 5% probability level was calculated to compare treatment means. Summary tables present standard errors [SE(m)±] along with the corresponding CD values, which formed the basis for interpreting treatment effect.

3. Results and Discussion

3.1 Effect of varying levels of nitrogen through vermicompost on seed cotton yield and stalk yield of cotton:

The data pertaining to seed cotton and stalk yields are presented in Table 3. Seed cotton yield exhibited statistically significant differences across the various organic treatments, ranging from 990 to 1508 kg ha⁻¹. Correspondingly, stalk yield varied between 2475 and 3770 kg ha⁻¹. These results underscore the positive impact of nitrogen supplementation through vermicompost on cotton productivity. Among the treatments, T4 recorded the highest seed cotton yield, marking a 52.3% increase over the lowest-yielding treatment, T1, with the order of effectiveness following the trend: T₄ > T₃ > T₈ > T₆ > T₂ > T₇ > T₅ > T₁. The harvest index reflects the proportion of economic yield relative to the total biological yield and serves as an indicator of how efficiently a plant converts its biomass into harvestable output under a specific treatment. In this study, the influence of different organic inputs and green manuring practices on the harvest index was also evaluated. The mean harvest index recorded for rainfed cotton was 28.88%. However, statistical analysis revealed that differences in harvest index among the various organic treatments were not significant. The study clearly indicated that the application of 60 kg N ha⁻¹ through vermicompost to *Gossypium hirsutum* cultivars resulted in significantly enhanced yields when compared to 40 kg N ha⁻¹ applied to *Gossypium arboreum*. This suggests that higher nitrogen levels under organic management not only improve nutrient availability but also support superior vegetative and reproductive growth, leading to increased boll formation and fibre output.

Consistent with these findings, Tinku *et al.* (2024) [27] reported a notable improvement in seed cotton yield (1323 kg ha⁻¹) with combined application of compost and vermicompost. Similarly, Kshirsagar *et al.* (2024) [1] demonstrated that using vermicompost at 2.5 t ha⁻¹ in conjunction with green manure and plant growth stimulants substantially enhanced seed cotton yield, stalk production, and lint yield in *G. hirsutum*. Selvakumar, *et al.* (2025) [28] compared organic and inorganic nutrient management strategies in *G. hirsutum* (cv. Vaidehi), and while inorganic inputs showed immediate yield advantages, vermicompost-based treatments sustained gradual yield improvements over successive growing seasons, emphasizing their long-term benefits for biomass and soil health.

Solunke *et al.* (2011) [30], who noted substantial yield gains through the integration of FYM at 10 t ha⁻¹, vermicompost at 2 t ha⁻¹, and sunhemp green manuring. Studies by Basavanneppa and Biradar (2002) [2], Hanumanthappa and Shivaraj (2003) [8], Praharaj *et al.* (2004) [17], Mahavishnana (2005) [13], and Bhalerao *et al.* (2011) [3] further validate the yield-enhancing effects of organic nutrient sources. Chavda and Rajawat (2015) [6] similarly observed that vermicompost applied at 5 t ha⁻¹ over two consecutive *Kharif* seasons led to higher yields and improved economic returns compared to chemical fertilizers alone. In a related study, Zhang *et al.* (2020) [34] highlighted the synergistic effect of combining organic manure (6%) with biochar (1%) in enhancing cotton yield, attributing the improvement to increased root development and nutrient availability. Nawlakhe *et al.* (2010) [14] also reported significant increases in boll number, seed cotton yield, and stalk biomass following vermicompost application at 2 t ha⁻¹, achieving performance on par with FYM at 5 t ha⁻¹. These findings are corroborated by Pradhan *et al.* (2016) [16], and Prakash *et al.* (2018), who reported increased yields in diverse crops under organic amendments applied at critical growth stages.

Table 3: Influence of different nitrogen levels applied through vermicompost on seed cotton and stalk yields following the harvest of rainfed organic cotton

Treatments	Cotton Yield (kg ha ⁻¹)		Harvest index (%)
	Seed cotton	Stalk yield	
T ₁	990	2475	28.70
T ₂	1270	3180	28.87
T ₃	1386	3395	28.99
T ₄	1508	3685	29.04
T ₅	1060	2650	28.77
T ₆	1297	3190	28.91
T ₇	1177	2943	28.81
T ₈	1317	3234	28.94
SE (m) ±	29.4	36.6	0.93
CD at 5%	89.96	110.53	NS

3.2 Effect of varying levels of nitrogen through vermicompost on growth parameters of cotton

3.2.1 Plant height

The progression of plant height (cm) in cotton across different

growth stages under various treatments is illustrated in Figure 1. The results indicate a consistent increase in average plant height from 23.53 cm at 30 days after sowing (DAS) to 104.73 cm at the time of harvest. Among the treatments, the tallest plants were observed in T₄, which involved the application of 60 kg N/ha through vermicompost to the *Gossypium hirsutum* cultivar 'Chetna J1'. Conversely, the shortest plants were recorded in T₁, where 40 kg N/ha via vermicompost was applied to the *G. arboreum* cultivar 'AVC 14'. A rapid increase in plant height was noted during the early growth stages, while the rate of growth slowed down in later stages. These observations are consistent with the findings of Tamak *et al.* (1998) [32], who reported that vermicompost application at 5 t/ha significantly enhanced plant height, dry matter accumulation, and seed cotton yield over untreated control. Similarly, Shrikrushnarao *et al.* (2020) [29] found that a nutrient regime comprising 75% FYM + vermicompost + 25% neem cake significantly increased plant height (94.20 cm), with results comparable to treatments receiving 100% FYM plus vermicompost.

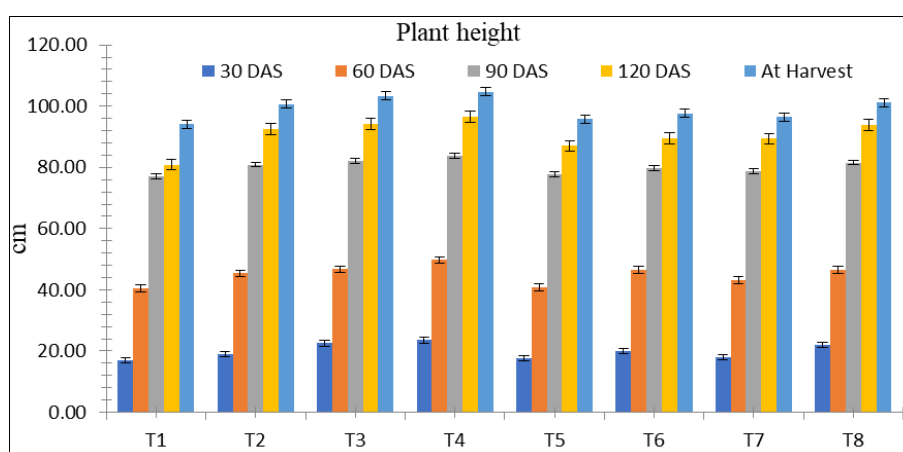


Fig 1: Effect of different levels of nitrogen applied through vermicompost on plant height in rainfed organic cotton Error bars represent standard deviation

3.2.2 Days to 50% flowering and 50% boll bursting:

Flowering plays a critical role in cotton production, as it marks the onset of boll development following successful pollination. The 50% flowering stage where half of the plants in the population initiate flowering serves as an indicator of the crop's reproductive progression and helps assess varietal maturity behaviour. This parameter is particularly useful for identifying early and late maturing genotypes. Similarly, the 50% boll bursting stage signifies the time required for half of the bolls to mature and open, indicating physiological maturity and the crop's readiness for harvest. In the present study, 50% flowering was recorded on September 15, corresponding to 81 days after sowing, while 50% boll bursting occurred after 101 days, in October, reflecting the crop's maturity dynamics under the given treatment conditions.

3.2.3 Crop stand, number of harvested bolls per plant and number of sympodia

A significant variation in crop stand was noted across treatments with the application of vermicompost. The maximum number of plants per plot (114) was recorded under Treatment T₂, which involved the application of 60 kg N ha⁻¹ through vermicompost to the *Gossypium arboreum* cultivar (AVC 14). In contrast, the minimum crop stand (100 plants) was observed in Treatment T₇, where 40 kg N ha⁻¹ was applied via vermicompost to the *Gossypium hirsutum* cultivar (GHV 8023). These observations

are illustrated in Figure 2.

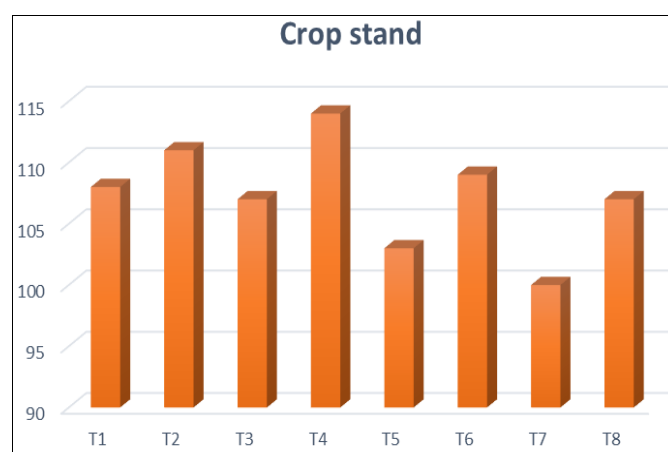


Fig 2: Effect of different levels of nitrogen applied through vermicompost on crop stand in rainfed organic cotton

Table 4 illustrates the number of bolls per plant under varying nitrogen levels applied via vermicompost. The data revealed statistically significant differences among treatments. Notably, the application of organic manures markedly influenced boll production. The maximum number of bolls per plant were recorded in treatment T₄, where 60 kg N ha⁻¹ through

vermicompost was applied to the *Gossypium hirsutum* cultivar (Chetna J1), while the minimum was observed in treatment T₁, which received 40 kg N ha⁻¹ via vermicompost for the *Gossypium arboreum* cultivar (AVC 14). These findings are consistent with Kumari *et al.* (2005), who reported enhanced boll numbers and boll weight with FYM application. A similar trend was observed in the number of sympodial branches, mean boll weight and seed index. The average seed index recorded was 8.34 g.

According to Rannavare *et al.* (2006), application of 2 t ha⁻¹ vermicompost and 5 t ha⁻¹ FYM significantly improved several growth parameters, including plant height, leaf area, number of functional leaves, and sympodia, which ultimately contributed to higher seed cotton and stalk yields. Improvements in the number of harvested bolls, boll weight, and seed index can be linked to enhanced monopodial and sympodial branching and increased dry matter allocation to reproductive structures. This is likely a result of consistent nutrient availability throughout the crop cycle, provided through basal, top-dress, and foliar applications of organics. Nitrogen-driven improvements in photosynthetic efficiency may have contributed to the observed increases in seed index, as suggested by Rajanna *et al.* (2011)^[18]. Supporting evidence comes from Sunil Kumar *et al.* (2017)^[12], who demonstrated enhanced growth and yield attributes in scented rice when 100% of nitrogen was supplied via a 50:50 combination of poultry manure and vermicompost.

Boll traits, particularly the number of bolls per plant, are pivotal yield determinants in cotton. Organic nutrient application significantly influenced these traits. Enhanced boll formation might also be attributed to favourable microclimatic conditions created by organic matter amendments. These results align with the reports of Ramprakash and Mangal Prasad (2000)^[20], and Nawlakhe *et al.* (2010)^[14]. The balanced nutrient supply from organic sources also contributed to improved soil physical properties, further supporting reproductive development. This has been similarly reported in studies by Rajput (1999)^[19], Hulhali and Patil (2005) and Solunke *et al.* (2011)^[30], which confirmed positive outcomes of vermicompost.

Table 4: Influence of different nitrogen levels applied through vermicompost on crop stand, number of harvested bolls plant⁻¹, boll weight, number of sympodia following the harvest of rainfed organic cotton

Treatment	Number of harvested bolls plant ⁻¹	Mean boll weight (g)	Number of sympodia	Seed index
T ₁	7.40	2.10	4.87	8.04
T ₂	10.50	2.55	5.60	8.36
T ₃	11.80	2.61	6.27	8.52
T ₄	12.67	2.65	6.60	8.68
T ₅	7.90	2.20	5.00	8.24
T ₆	9.17	2.45	5.37	8.29
T ₇	8.50	2.39	5.10	8.18
T ₈	11.43	2.55	6.20	8.40
SE (m)±	0.135	0.14	0.063	0.16
CD at 5%	0.414	0.26	0.194	0.31

3.3 Economics

The data on gross monetary returns (GMR), net monetary returns (NMR), and the benefit-cost (B:C) ratio, as presented in Table 5, revealed notable differences among the treatments. The highest economic returns were recorded in treatment T₄, where 60 kg N ha⁻¹ was applied through vermicompost to the *Gossypium hirsutum* cultivar ‘Chetna J1’, resulting in a GMR of ₹1,13,400 ha⁻¹, an NMR of ₹59,400 ha⁻¹, and a B:C ratio of 2.1. In contrast, treatment T₁, which involved the application of 40

kg N ha⁻¹ via vermicompost to the *Gossypium arboreum* cultivar ‘AVC 14’, recorded the lowest GMR (₹73,405 ha⁻¹), NMR (₹22,073 ha⁻¹), and B:C ratio (1.43). These variations can be attributed primarily to higher seed cotton yield and relatively lower cultivation costs in the more productive treatment combinations.

These findings are consistent with those reported by Channagouda *et al.* (2015)^[5], who observed enhanced economic returns with organic nutrient inputs. Similarly, Tinku *et al.* (2024)^[27] evaluated integrated organic nutrient management approaches for *G. hirsutum* and noted that combining compost and vermicompost (equivalent to 50% of the recommended nitrogen dose), along with top-dressing using vermicompost, significantly increased seed cotton yield (approximately 1323 kg ha⁻¹). This increase was accompanied by improvements in NMR and B:C ratio compared to compost-only treatments. Selvakumar *et al.* (2025)^[28] also reported that organic management practices specifically the integration of vermicompost with green manures and biofertilizers resulted in steady improvements in yield attributes and economic performance in cotton. Although initial yields were higher under inorganic fertilizer regimes, the organic treatments exhibited consistent gains over time, underscoring the long-term economic sustainability of vermicompost-based nutrient strategies.

Table 5: Influence of different nitrogen levels applied through vermicompost on GMR, NMR and B:C ratio following the harvest of rainfed organic cotton

Treatments	Gross monetary returns (Rs. ha ⁻¹)	Net monetary returns (Rs. ha ⁻¹)	B:C ratio
T ₁	73,405	22,073	1.43
T ₂	96,120	42,120	1.78
T ₃	97,531	46,199	1.9
T ₄	1,13,400	59,400	2.1
T ₅	76,998	25,666	1.5
T ₆	97,200	43,200	1.8
T ₇	90,334	39,002	1.76
T ₈	99,360	45,360	1.84
SE (m)±	2862	2862	0.39
CD at 5%	7243	7243	0.11

4. Conclusion

Based on these results, the application of 60 kg N ha⁻¹ via vermicompost to *G. hirsutum* cultivars is recommended for optimal yield under organic cultivation practices. Thus, vermicompost-based nitrogen management emerges as a viable alternative to conventional fertilization in organic cotton production systems. Adoption of such strategies can enhance yield sustainability, improve farmer profitability, and reduce environmental externalities associated with chemical inputs. Further research should explore the residual effects of vermicompost on subsequent crops, microbial activity dynamics, and the scalability of these practices across diverse agro-ecological regions to develop robust recommendations for integrated organic nutrient management in cotton.

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