International Journal of Plant & Soil Science

Volume 37, Issue 9, Page 435-445, 2025; Article no.IJPSS.142936
ISSN: 2320-7035

Synergistic Effect of Nitrogen Substitution through Vermicompost on Productivity and Quality of Cauliflower in Low Hills of Himachal Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SJ designed the study, conducted the field experiment, collected and analyzed the data and prepared the first draft of the manuscript. Author AK served as the major advisor, supervised the entire research work, guided the experimental design and critically reviewed and refined the manuscript. Author SS assisted in statistical interpretation and contributed to the review and improvement of the manuscript. Author EJK provided general technical guidance and helped in improving the clarity and structure of the manuscript. Author KJ assisted in literature review, pest-related observations and manuscript editing. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i95721

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/142936

Original Research Article

Received: 21/06/2025
Published: 08/09/2025

ABSTRACT

Aims: To evaluate impact of substituting inorganic nitrogen source with vermicompost, alone and in association with *Azotobacter*, on the growth, yield and quality of cauliflower (*Brassica oleracea* var. botrytis L.).

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Cite as: *Samriti Jaswal, Anil Kumar, Swapana Sepehya, Eby Joseph Kochithara, and Kartik Jaswal. 2025. "Synergistic Effect of Nitrogen Substitution through Vermicompost on Productivity and Quality of Cauliflower in Low Hills of Himachal Pradesh, India". International Journal of Plant & Soil Science 37 (9):435–445. https://doi.org/10.9734/ijpss/2025/v37i95721.*

Study Design: Randomized Block Design (RBD).
Place and Duration of Study: Experimental farm of Department of Soil Science and Water Management, College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh during the *Rabi* season.
Methodology: The layout of the experiment was Randomized Block Design (RBD) comprising 11 treatments replicated thrice.
Results: The experimental data were statistically analyzed using the Analysis of Variance (ANOVA) technique at a 5% level of significance. The treatment involving 100% replacement of the recommended dose of nitrogen (RDN) through vermicompost combined with *Azotobacter* recorded the highest plant height (51.36 cm), leaf count (23.68), curd diameter (15.13 cm), curd weight (906.23 g) and curd yield (268.37 q ha^{-1}). This subsitutional approach significantly improved curd quality with higher crude protein (24.17%), TSS (7.21°B) and enhanced total macro and micronutrient content. Vermicompost enriched soil properties and nutrient availability, while *Azotobacter* enhanced nitrogen fixation and nutrient uptake.
Conclusion: It was concluded that the complete substitution of RDN with vermicompost in addition to *Azotobacter* sustains yield and quality and promotes soil health, offering a viable alternative to chemical fertilizers in cauliflower cultivation.

Keywords: Cauliflower; vermicompost; Azotobacter; nitrogen substitution; curd quality and soil health.

1. INTRODUCTION

Cauliflower (*Brassica oleracea* var. botrytis L.), an eminent member of the family Brassicaceae, is one of the well-liked cole crops among temperate vegetables. It is grown worldwide throughout the year because of its wide adaptability under different ecological conditions and high nutritive and economic value. Cauliflower's edible part curd constitutes about one-fourth of the total above-ground biomass (Batabyal et al*.,* 2016).

West Bengal, Madhya Pradesh, Bihar, Gujarat, Haryana, Orissa, Assam, Uttar Pradesh and Maharashtra are highly contributing states of cauliflower, making India the second largest producer in the world with the production of 9661.72 thousand MT over an area of 500.83 thousand hectares (Government of India, 2024). In Himachal Pradesh, it is cultivated over an area of about 5.55 thousand ha yielding a total production of 123.07 thousand MT (Government of India, 2024).

It serves as a commercial crop that brings profitable returns to marginalized and small-scale hill farmers of Himachal Pradesh, but due to its exhaustive nature, it removes large quantities of nutrients from the soil, resulting in quick nutrition depletion therefore, for the optimum growth and good market yield of the crop a constant supply of nutrients through organic or inorganic sources are required (Subedi et al*.,* 2019). Ongoing nutrient depletion through continuous biomass removal without sufficient nutrient restoration, coupled with unbalanced fertilization practices, poses a substantial threat to sustainable crop production and soil health. The use of inorganic fertilizers for crop production serves as the fastest way of replenishing the depletion of the nutrients, but escalating fertilizer prices, limited input availability and detrimental effects on soil health deter the farmers from using these to the required level. Hence, the use of organic manures such as vermicompost, which contributes as a good source of nutrients, can be a better alternative to synthetic fertilizers for sustaining productivity and quality of the crop. Information related to the replacement of inorganic fertilizers through vermicompost with respect to cauliflower is insufficient. Therefore, the present investigation was planned.

2. MATERIALS AND METHODS

A field trial was executed at the Experimental Farm of the College of Horticulture and Forestry, Neri, Hamirpur (31°41′47.6″ N, 76°28′06.3″ E, 650 m elevation). The studied area falls under the Sub-Montane and low hills Sub-Tropical Zone (Zone I) of Himachal Pradesh. Annually, this region records 1220 mm of precipitation, out of which 82.00 per cent is experienced from June to September. Soil samples from the experimental site were collected prior to transplanting to determine initial soil properties. The soil was sandy loam in texture with a neutral pH of 6.77. Available nitrogen was low (185.20 kg ha^{-1}), while organic carbon (4.30 g kg^{-1}), available phosphorus (14.34 kg ha^{-1}) and available potassium (167.53 kg ha^{-1}) were at moderate levels.

Table 1. Details of experimental treatments involving different combinations of inorganic fertilizer, vermicompost and *Azotobacter*

Treatments		Treatments Combination
T1	:	Absolute Control
T2	:	100 % RDF
T3	:	75 % RDF + 25 % RDN (Vermicompost)
T4	:	50 % RDF + 50 % RDN (Vermicompost)
T5	:	25 % RDF + 75 % RDN (Vermicompost)
T6	:	100 % RDN (Vermicompost)
T7	:	100 % RDF + *Azotobacter*
T8	:	75 % RDF + 25 % RDN (Vermicompost) + *Azotobacter*
T9	:	50 % RDF + 50 % RDN (Vermicompost) + *Azotobacter*
T10	:	25 % RDF + 75 % RDN (Vermicompost) + *Azotobacter*
T11	:	100 % RDN (Vermicompost) + *Azotobacter*

The experiment comprised 11 treatments with different combinations of inorganic fertilizer, vermicompost, and Azotobacter (Table 2). A total of 33 plots (1.8 × 1.8 m each) were laid out, with 12 plants per plot, totaling 396 plants. The late-maturing cauliflower cultivar 'Pusa Snowball K-1' was transplanted one month after sowing at a spacing of 60 × 45 cm. During field preparation, urea was applied in split doses, while SSP and MOP were applied in full. Vermicompost application was adjusted according to its nitrogen content and dry weight. Root dipping with *Azotobacter* was performed as per the treatments prior to transplanting. Control plots, used for comparison, received no fertilizer or manure.

Crop growth and productivity traits, including plant height, leaf count per plant, curd diameter and curd weight were recorded. Yield was recorded plot-wise by summating the weight of curds from all the harvestings and converting it to q ha^{-1}.

The curd samples from each plot were collected, dried and ground for further analysis in the laboratory. The N content of curd samples was determined by the Micro Kjeldahl method as outlined in AOAC, 1970, P content by vanadomolybdate phosphoric acid yellow colour method and K content by flame photometry method as suggested by Jackson, 1973. The turbidimetric method outlined by Chesnin and Yien, 1950, was used to determine Sulphur content and flame photometer assessed the Calcium content of the sample. Mg and micronutrients were evaluated by means of atomic absorption spectrophotometer using the procedure given by Jackson, 1973. The ascorbic acid content of cauliflower curds was determined by 2, 6-dichlorophenolindo-phenol visual titration method. Total soluble solids were estimated with the help of a hand refractometer and their observations were recorded in ^{0}Brix by the method given by Ranganna, 2014. Crude protein was calculated by multiplying the total nitrogen content in the curd sample by a factor of 6.25, as suggested by Jones, 1941 and was expressed in percent (%).

The experimental data were statistically analyzed using the Analysis of Variance (ANOVA) technique and treatment effects were evaluated at a 5% level of significance (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

3.1.1 Plant height

Complete substitution of the recommended nitrogen dose with vermicompost in addition to *Azotobacter* recorded maximum plant height (51.36 cm). In contrast, minimum plant height (30.45 cm) was reported in absolute control where no inorganic fertilizer, manure or bio-fertilizer was applied (Table 2.). Application of recommended doses of chemical fertilizers alone (T_2) or in conjunction with *Azotobacter* (T_7) showed significant increase in the plant height of cauliflower over control (T_1).

Among the treatments where nitrogen was applied through vermicompost and no *Azotobacter* was used (T_3 to T_6), application of 100 per cent of RDN through vermicompost (T_6) reported maximum plant height (42.74 cm) followed by 25 per cent RDF + 75 per cent RDN

through vermicompost (T_5) and 50 per cent RDF + 50 per cent RDN through vermicompost (T_4). Whereas, minimum plant height (41.83 cm) was observed with the application of 75 per cent RDF + 25 per cent RDN through vermicompost (T_3). By increasing the recommended nitrogen dose *via* vermicompost, the height of the crop was significantly increased. However, all these treatments (T_3 to T_6) were statistically at par. *Azotobacter* addition further increases plant height when used with either inorganic fertilizer or vermicompost or both.

Amid the treatments where *Azotobacter* was used (T_7 to T_{11}), the application of 100 per cent RDN through vermicompost + *Azotobacter* (T_{11}) reported maximum plant height (51.36 cm) followed by application of 25 per cent RDF + 75 per cent RDN through vermicompost + *Azotobacter* (T_{10}), 50 per cent RDF + 50 per cent RDN through vermicompost + *Azotobacter* (T_9) and 75 per cent RDF + 25 per cent RDN through vermicompost + *Azotobacter* (T_8). Among these treatments minimum plant height (47.33 cm) was found in T_7 where no vermicompost was used. Application of *Azotobacter* with recommended dose of nitrogen (T_7, T_8, T_9, T_{10} and T_{11}) exhibited significantly more plant height over respective treatments where it was used without *Azotobacter* (T_2, T_3, T_4, T_5 and T_6).

The increase in the plant height of the cauliflower is attributable to the influence of vermicompost, which might have improved the nutrient pool in the soil. Additional application of *Azotobacter* helped to increase the biological nitrogen fixation and P availability which is required for the completion of vegetative cycle of the crop (Islam et al*.,* 2021, Rabindra et al*.,* 2021 and Sharma et al., 2022).

3.1.2 Leaf count per plant

A notable rise in the number of leaves per plant was observed when organic amendment was combined with the application of bio-fertilizer. Replacing the entire recommended nitrogen dose with vermicompost, in the absence of *Azotobacter*, enhanced the leaf number per plant by 12.74% compared to full RDF. The highest leaf count (23.68) was observed when 100% RDN through vermicompost was united with *Azotobacter,* while the lowest (14.64) was in the control (Table 2). The sole use of inorganic fertilizers (T_2) significantly increased the number of leaves per plant over control (T_1). However, conjoint application of 100 per cent RDF + *Azotobacter* (T_7) registered better results than application of inorganic fertilizers alone (T_2). Treatments T_7 to T_{11} performed better than T_2 to T_6, however, were statistically at par with each other.

The observed increase in leaf count per plant with the substitution of RDN by vermicompost may be attributed to its ability to solubilize soil nutrients, chelate metal ions and thereby improve overall nutrient availability. Bio-fertilizers by producing plant growth substances that activate enzymes and stimulate cell division further promote vegetative growth whereas; less leaf count might be due to insufficient nutritional support (Neupane et al*.,* 2020, Islam et al., 2021 and Sharma et al*.,* 2022).

3.2 Yield Attributes

3.2.1 Curd diameter

Incorporation of full recommended nitrogen dose *via* vermicompost in association with *Azotobacter*, gave largest curd diameter (15.13 cm) outperforming all other treatments. Lowest curd diameter (8.67 cm) was found in control plot receiving no nutrient sources (Table 2.). Treatments using *Azotobacter* with RDN (T_7–T_{11}) continuously showed superior results over their counterparts without *Azotobacter* (T_2–T_6) with both groups remaining statistically at par with each other.

No addition of nutrients in the control plots resulted in the lowest curd diameter, whereas application of inorganic fertilizers, manures or bio-fertilizers increased the availability of NPK, due to which growth might have been boosted as they increase in photosynthetic activity and chlorophyll content of plant, which leads to better nourishment of curd (Kaur et al., 2020, Komma et al., 2020, Neupane et al*.,* 2020, Rabindra et al., 2021 and Sharma et al*.,* 2022).

Table 2. Effect of nitrogen substitution through vermicompost on growth and yield attributes of cauliflower

Treatments		Plant height (cm)	No. of leaves	Curd diameter (cm)	Curd depth (cm)	Head weight (g)
T_1	Control	30.45	14.64	8.94	8.67	387.20
T_2	100%RDF	41.52	17.50	11.68	10.91	644.73
T_3	75%RDF+25%RDN (Vermicompost)	41.83	17.86	11.97	11.56	663.20
T_4	50%RDF+50%RDN (Vermicompost)	42.27	18.73	12.03	11.98	688.47
T_5	25%RDF+75%RDN (Vermicompost)	42.66	19.06	12.31	12.10	704.13
T_6	100%RDN (Vermicompost)	42.74	19.73	12.98	12.33	722.27
T_7	100 %RDF+ *Azotobacter*	47.33	20.73	13.16	12.67	745.30
T_8	75%RDF +25%RDN (Vermicompost) + *Azotobacter*	48.92	21.66	13.70	13.17	801.40
T_9	50%RDF +50%RDN (Vermicompost) + *Azotobacter*	49.12	22.48	14.04	13.92	834.61
T_{10}	25%RDF +75%RDN (Vermicompost) +*Azotobacter*	50.24	23.02	14.97	14.32	872.30
T_{11}	100%RDN (Vermicompost) + *Azotobacter*	51.36	23.68	15.13	14.87	906.23
CD(P=0.05)		5.05	2.31	1.98	2.23	34.92

Table 3. Effect of nitrogen substitution through vermicompost on quality parameters of cauliflower

	Treatment	TSS (˚Brix)	Ascorbic acid (mg 100 g^{-1})
T_1	Control	6.10	53.80
T_2	100% RDF	6.37	56.71
T_3	75% RDF+25% RDN (Vermicompost)	6.40	57.23
T_4	50% RDF+50% RDN (Vermicompost)	6.51	57.56
T_5	25% RDF+75% RDN (Vermicompost)	6.67	57.59
T_6	100% RDN (Vermicompost)	6.78	57.82
T_7	100 % RDF+ *Azotobacter*	6.84	58.07
T_8	75% RDF +25% RDN (Vermicompost)+*Azotobacter*	6.91	58.14
T_9	50% RDF +50% RDN (Vermicompost)+*Azotobacter*	7.02	58.25
T_{10}	25% RDF +75% RDN (Vermicompost)+*Azotobacter*	7.14	58.35
T_{11}	100%RDN (Vermicompost) + *Azotobacter*	7.21	58.67
	CD (P=0.05)	0.30	0.84

3.2.2 Curd depth

The maximum curd depth (14.87 cm) was obtained with 100% RDN applied through vermicompost combined with *Azotobacter*, while the minimum (8.67 cm) was observed in the control (Table 2). Use of 100 per cent RDF (T_2) increased the curd depth over control (T_1) by 25.83 per cent. Conjoint use of chemical fertilizer and *Azotobacter* (T_7) showed an increase of 16.13 per cent in curd depth over sole use of chemical fertilizers (T_2). Substitution of recommended dose of nitrogen by vermicompost registered superior values compared to use of chemical fertilizers alone (T_2). Application of *Azotobacter* showed positive influence on curd depth of cauliflower and among the treatments where RDN was substituted by vermicompost and *Azotobacter* was applied additionally (T_8 to T_{11}) with maximum curd depth (14.87 cm) was observed under treatment T_{11}, followed by treatment T_{10} and T_9 however, the difference was found to be at par with each other. A similar trend was observed in treatments T_3 to T_6, where *Azotobacter* was not applied, and the values remained statistically at par with each other.

The increase in curd depth with vermicompost application can be attributed to its improvement of increasing soil properties, enhancing nutrient absorption and curd development. Bio-fertilizers further helped in nutrient mobilization and root development (Kaur et al*.,* 2020, Neupane et al*.,* 2020, Devkota et al*.,* 2021 and Sharma et al*.,* 2022).

3.2.3 Curd weight

The highest curd weight (906.23 g) was attained with 100% RDN applied through vermicompost with *Azotobacter*, whereas the control recorded the lowest value (387.20 g) (Table 2). Curd weight was increased by 86.53% and 134.04% with 100% RDN through vermicompost alone or combined with *Azotobacter,* respectively, over the control. Using 100% RDF alone enhanced curd weight by 257.53 g over control and further increased it by 358.10 g when combined with *Azotobacter*. Synergistic effect of *Azotobacter* was highlighted when combined with vermicompost or inorganic fertilizers in different doses.

While, comparing the treatments where *Azotobacter* was used along with chemical and bio-fertilizers (T_7 to T_{11}), it was found at 100 per cent RDN through vermicompost + *Azotobacter* (T_{11}) reported maximum head weight (906.23 g) followed by 25 per cent RDF through inorganic fertilizer + 75 per cent RDN through vermicompost + *Azotobacter* (T_{10}), 50 per cent RDF through inorganic fertilizer + 50 per cent RDN through vermicompost + *Azotobacter* (T_9) and 75 per cent RDF + 25 per cent RDN through vermicompost + *Azotobacter* (T_8). Whereas, lowest head weight (745.30 g) was reported in treatment (T_7). The treatment T_{11} was found to be at par with treatment T_{10} and significantly superior over T_7, T_8 and T_9. *Azotobacter* was found to be superior for increasing head weight in all the treatments when used with vermicompost or inorganic fertilizer or both (T_7, T_8, T_9, T_{10} and T_{11}) over the respective

treatments where it was not used (T_2, T_3, T_4, T_5 and T_6).

The lowest curd weight in the control was due to the absence of fertilizers, manures or bio-fertilizers, resulting in poor soil nutrition. The increase in curd weight with *Azotobacter* application can be attributed to improved uptake of both nutrients and water. Collaboration of organic manure with inorganic fertilizers enhanced NPK availability, soil fertility and productivity, boosting yield attributes (Komma et al*.,* 2020, Neupane et al*.,* 2020, Singh et al*.,* 2020, Rabindra et al*.,* 2021 and Sharma et al*.,* 2022).

3.3 Curd Yield

The curd yield varied from a minimum of 112.47 q ha^{-1} in control to a maximum of 268.37 q ha^{-1} in plots receiving 100 per cent RDN through vermicompost + *Azotobacter* (T_{11}) (Fig. 1.). Application of recommended doses of fertilizers alone (T_2) or in conjunction with *Azotobacter* (T_7) enhanced the curd yield of cauliflower by 89.86 and 125.80 q ha^{-1} respectively, over control (T_1). The curd yield of cauliflower increased when vermicompost was used as a replacement for recommended dose of nitrogen. It is cleared from the data that with the increase in the replacement of recommended dose of nitrogen with vermicompost there was increase in curd yield of cauliflower. Among the treatments where nitrogen is applied through vermicompost and *Azotobacter* was not used (T_3 to T_6), application of 100 per cent of RDN through vermicompost (T_6) reported maximum curd yield (235.00 q ha^{-1}) followed by 25 per cent RDF through inorganic fertilizers + 75 per cent RDN through vermicompost (T_5) and 50 per cent RDF through inorganic fertilizers + 50 per cent RDN through vermicompost (T_4) and minimum curd yield (208.17 q ha^{-1}) was reported with the application of 75 per cent RDF through inorganic fertilizers + 25 per cent RDN through vermicompost (T_3). Application of *Azotobacter* also showed positive influences on curd yield of cauliflower and similar trend was observed among the treatments where RDN was replaced by vermicompost and *Azotobacter* was not applied. The application of 100 per cent RDF through vermicompost + *Azotobacter* (T_{11}) reported maximum curd yield (268.37 q ha^{-1}) followed by application of 25 per cent RDF through inorganic fertilizers + 75 per cent RDN through vermicompost + *Azotobacter* (T_{10}) and 50 per cent RDF through inorganic fertilizers + 50 per cent RDN through vermicompost + *Azotobacter* (T_9). Whereas, amid these treatments minimum (238.27 q ha^{-1}) curd yield was reported with the application of 100 per cent RDF through inorganic fertilizers + *Azotobacter* (T_7).

Lowest curd yield in control treatment is attributed to poor nutritional status of these plots where no fertilizers or manure or bio-fertilizers was added. Use of vermicompost promotes soil aggregation and stabilizes soil structure. This improves air-water relationship of soil, thus increasing the water retention capacity and encourages extensive development of root system of plants. The increase in yield also may be due to the solubilization effect of the nutrients as well as the chelating effect of vermicompost, thereby, the availability of essential nutrients gets increased. Use of bio-fertilizers in combination with chemical fertilizers was efficient in yield increase over the exclusive application of chemical fertilizers and can be attributed to increase in uptake of nutrients resulting in faster synthesis and translocation of photosynthates from leaves to curd (Devkota et al., 2021, Islam et al*.,* 2021, Rabindra et al*.,* 2021 and Sharma et al., 2022).

3.4 Quality Parameters

3.4.1 Crude protein content

Application of 100% RDN *via* vermicompost along with *Azotobacter* yielded in the highest crude protein content (24.17%), while the control exhibited the lowest content (19.58%) (Table 3.). Application of recommended fertilizers alone or with *Azotobacter* increased crude protein by 1.07% and 19.15%, respectively, over control. Among the treatments substituting RDN with vermicompost (T_3 to T_6), 100% RDN through vermicompost (T_6) recorded the highest TSS (6.78 ˚B), followed by T_5 and T_4, while the lowest (6.40 ˚B) was noted in T_3. Treatment T_6 was statistically at par with T_4 and T_5, but significantly superior to T_3. Substitution of RDN with vermicompost led to a progressive increase in protein content, attributed to the slow and sustained release of nutrients. With the addition of *Azotobacter* (T_8 to T_{11}), a similar trend was observed as in T_3 to T_6, with the highest TSS (7.21 ˚B) under 100% RDN through vermicompost + *Azotobacter* (T_{11}), followed by T_{10} and T_9, while the lowest (6.91 ˚B) was recorded in T_8.

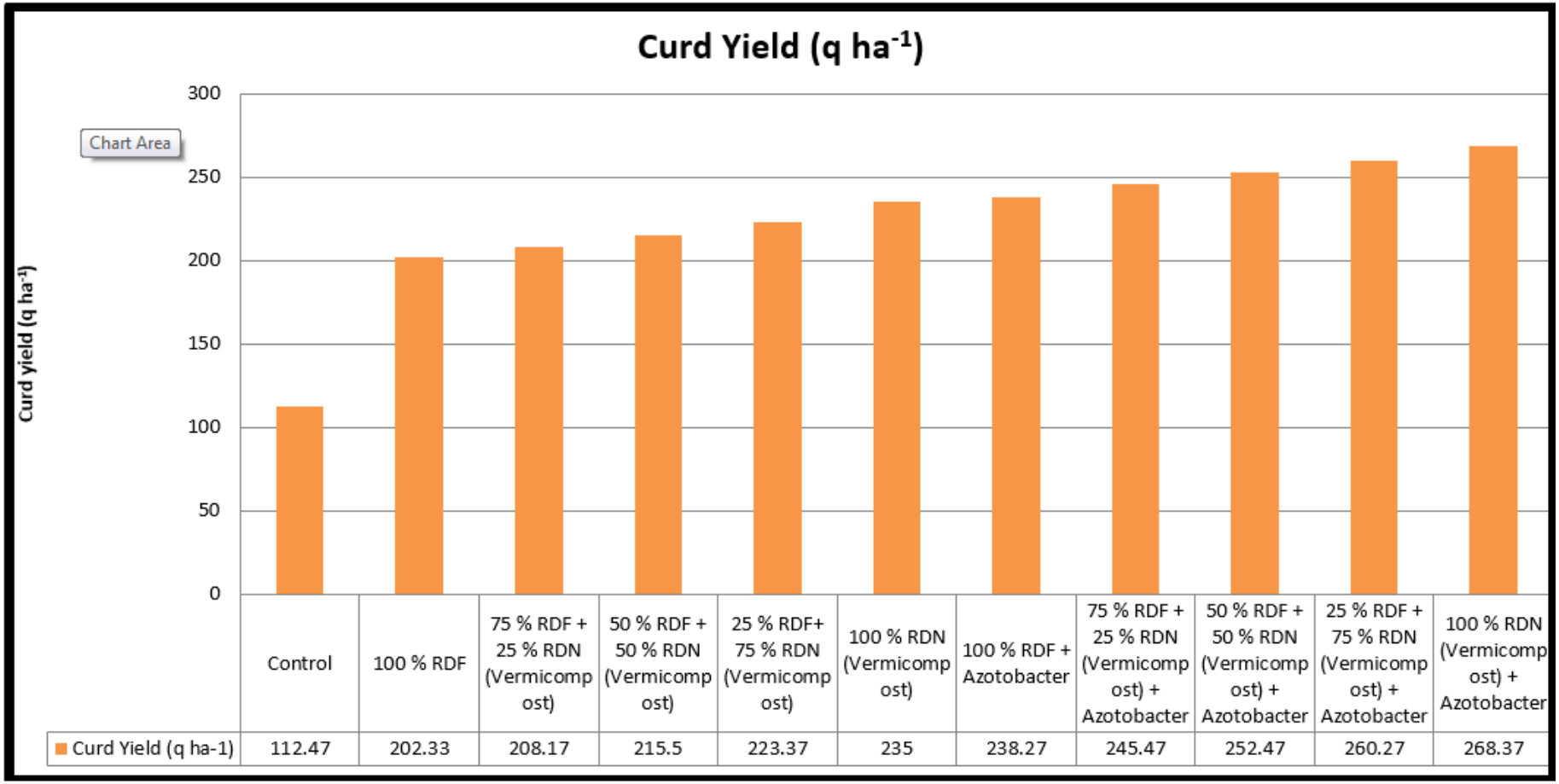

Fig. 1. Effect of nitrogen substitution through vermicompost on curd yield (q ha^{-1})

The additional use of *Azotobacter* further enhanced crude protein levels by improving nitrogen availability and uptake (Wani et al*.,* 2011 and Batabyal et al*.*, 2016).

3.4.2 Total Soluble Solids (TSS) content

The TSS varied from 7.21˚B to 6.10˚B with 100% RDN through vermicompost with *Azotobacter* and control respectively. Progressive substitution of RDN with vermicompost increased TSS, with 100% RDN through vermicompost achieving the highest (6.78˚B) among such treatments (Table 3). In comparision to T_3 to T_6, the lowest TSS (6.40 ˚B) was observed under 75% RDF + 25% RDN through vermicompost (T_3), which increased progressively with higher substitution levels. Maximum TSS (6.78 ˚B) was obtained with 100% RDN through vermicompost (T_6), which remained statistically at par with T_5 and T_4, but significantly superior to T_3.

A similar trend was observed when *Azotobacter* was incorporated, with complete replacement of RDN through vermicompost, showing the highest TSS (7.21 ˚B). The control had the lowest TSS due to the absence of fertilizers. The increase in TSS with vermicompost may be attributed to the secretion of growth-promoting substances that enhance carbohydrate synthesis, while *Azotobacter* enhances chlorophyll function and metabolic enzyme activity (Singh et al*.,* 2018 and Kaur et al*.,* 2020).

3.4.3 Nutrient content

The nutrient content in cauliflower curd was highest when RDN was entirely substituted with vermicompost and *Azotobacter*. The macronutrient composition was recorded as nitrogen (0.27%), phosphorus (0.03%), potassium (0.16%), calcium (0.24%), magnesium (0.28%) and sulfur (0.02%). Additionally, the micronutrient concentrations were zinc (34.4 ppm), copper (25.8 ppm), iron (149.5 ppm) and manganese (44.7 ppm). *Azotobacter* inoculation's benefits can be ascribed to the synergistic interaction between organic and microbial strategies, which enhance soil health and plant nutrition. Vermicompost enriches the soil with essential nutrients, steadily improving their availability to plants. Additionally, it enhances soil structure, microbial biomass and enzymatic activity, creating a favorable rhizosphere for nutrient uptake. *Azotobacter*, being a free-living nitrogen-fixing bacterium, further augments the nitrogen supply by biologically fixing atmospheric nitrogen, thereby meeting the plant's nitrogen demands sustainably. Moreover, *Azotobacter* secretes growth-promoting substances like indole acetic acid (IAA), stimulating root growth and increasing nutrient absorption efficiency. The combined use of vermicompost and *Azotobacter* improves not only the availability of major nutrients like nitrogen, phosphorus and potassium but also enhances the uptake of secondary and micronutrients such as calcium, magnesium, sulfur, zinc, copper, iron and manganese (Rabindra et al*.,* 2021 and Sharma et al*.,* 2022).

4. CONCLUSION

The findings suggest that fully replacing the recommended dose of nitrogen (RDN) with vermicompost, along with *Azotobacter* application, effectively maintains yield and quality while enhancing soil health, presenting a sustainable alternative to chemical fertilizers in cauliflower cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The Author(s) hereby declare that **NO generative AI technologies** such as Large Language Models (ChatGPT, Copilot, etc.) or text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

I sincerely express my heartfelt gratitude to the Department of Soil Science and Water Management, College of Horticulture and Forestry, Neri, Hamirpur (HP) for providing the necessary facilities and support to carry out this research work. I am deeply thankful to my guide, advisory committee and faculty members for their valuable guidance, encouragement and constructive suggestions throughout the course of the study. I also extend my appreciation to the technical staff and field workers who assisted me during the experimentation. Above all, I am grateful to my family and friends for their constant motivation and support during this research journey.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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