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RESEARCH ARTICLE

Integrated nutrient management strategies for reducing chemical inputs without compromising yield in cauliflower

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Abstract
Integrated Nutrient Management (INM) offers a pathway to reduce synthetic fertilizer use while maintaining or improving crop productivity and soil health. A field experiment conducted during Rabi 2020–21 at the Research Farm, Udai Pratap (Autonomous) College, Varanasi evaluated nine nutrient management treatments combining 50% recommended dose of fertilizer (RDF) with organic inputs (FYM, vermicompost) and the biofertilizer *Azospirillum*. Cauliflower cv. Pusa Snowball K-1 grown on a sandy-loam soil with medium fertility showed that integrated packages substantially improved vegetative growth, accelerated curd initiation and maturity, and increased curd size and weight compared with no-input and inorganic-only controls. The combination T9 (50% RDF + FYM 5 t/ha + vermicompost 1 t/ha + *Azospirillum* 2.5 kg/ha) produced the greatest plant height (63.48 cm), leaf area (1,343 cm^2), largest curd diameter (18.38 cm), highest curd weight (938 g) and maximum yield (341.78 q/ha), and delivered the highest net return and benefit:cost ratio. Treatment T8 (50% RDF + vermicompost 2.5 t/ha + *Azospirillum* 5 kg/ha) best preserved post-harvest soil N, P and K, indicating superior residual fertility. Economic analysis demonstrated that selected INM packages can lower chemical input costs and enhance profitability without yield penalties. These results underscore that well-designed INM strategies, integrating reduced inorganic fertilizers with organic amendments and biofertilizers, can sustainably maintain cauliflower yields, improve soil nutrient status, and increase farm returns, offering a scalable approach for reducing chemical dependence in vegetable production.

Keywords: RDF, FYM, INM, Growth, Yield & economics.

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Introduction
Cauliflower (*Brassica oleracea* L. var. *botrytis*) is one of the most important cool season vegetable crop from family Brassicaceae. Cauliflower originated from Mediterranean region (Cyprus), it was introduced in India in 1822 by Dr. Jemson (Swarup & Chattarjee, 1972). Since, then it is one of the most important vegetables crops grown in India. It is widely cultivated in subtropical states of India like West Bengal, Bihar, Maharashtra, Madhya Pradesh, Odisha, Gujrat, Utter Pradesh and Haryana. It is being grown in 0.51 mha. with production of 9.79 million metric tonnes in 2023-24 (Final estimates-2023-24 of Department of Agriculture & Farmers Welfare, Govt. of India). India is the second largest producer of cauliflower in world with contributing 32.7% in world production. Cauliflower is mainly used as vegetable and pickle. Pre-floral fleshy apical meristem is used fresh for this purpose. Cauliflower is a heavy nutrient feeder crop that requires nutrients in high amount for optimum yield and better quality. Chemical fertilizers are mostly used to provide these nutrients, but excessive and irregular uses of chemical fertilizers degrade the quality of produce and

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also soil fertility. Excessive chemical fertilizer use is well known to have a negative impact on the environment and living organisms as well (Farashiani et al., 2021). The rising cost of chemical fertilisers, as well as their negative impact, had forced farmers to seek alternative sources of nutrients for optimum and quality cauliflower production. Organic manure retains nutrients for a long period of time and improves soil fertility and productivity. Because organic manure contains low amount of nutrients, it cannot offer vital nutrients on its own in sufficient amount (Pahalvi et al., 2021). In the case of cauliflower, Integrated Nutrient Management (INM) is a relatively new method of supplying nutrients to the plants. The primary goal of INM is to increase crop yields while preserving soil fertility (Amanullah et al. 2023). INM is important for sustainable agriculture practises since it focuses on the profitable use of chemicals, bio-fertilizers, and organic manure to boost productivity and maintain soil health (Panta & Parajulee, 2021). An integrated nutrient delivery and management system is urgently needed to promote effective and balanced usage of plant nutrients. While the focus has been on improving the proper and balanced use of inorganic fertilizer, green manure and organic composting should be regarded as a supplement and replacement. (Dash et al., 2017). Integrated application having judicious combination of mineral fertilizer with organic and biological sources of nutrients are not only complimentary but also synergetic as organic inputs have beneficial effects (Roy et al., 1981) The integrated use of inorganic fertilizers with organic and bio-fertilizers can meet nutrient demand without showing any ill effect on the soil health.

Despite broad recognition of INM's potential, specific combinations, proportions and application methods need optimization for particular crops, cultivars and soil types (Selim, 2020). For cauliflower, research is required to identify INM packages that maintain or increase curd size and yield while lowering synthetic fertilizer inputs, and to evaluate residual effects on post-harvest soil N, P and K, crop quality and farm economics. In particular, locally adapted packages combining 50% recommended dose of fertilizer (RDF) with differing rates of farmyard manure (FYM), vermicompost and inoculation with *Azospirillum* merit attention because they may provide a cost-effective pathway to reduce chemical inputs without yield loss. This study evaluates nine INM treatments combining 50% RDF with graded organic amendments and *Azospirillum* to (i) quantify effects on vegetative growth, curd initiation and maturity, curd size and yield, (ii) assess post-harvest soil nutrient status (available N, P and K), and (iii) analyze the economic returns and benefit:cost ratios of INM packages. The findings aim to inform practical nutrient management options that sustain cauliflower productivity, improve soil fertility and reduce dependence on chemical fertilizers.

Materials and Methods

An experimental trial was conducted at the Research Farm, Department of Horticulture, Udai Pratap (Autonomous) College, Varanasi, following a randomized block design with three replications and nine treatments: T1 - no application of manures or fertilizers; T2 - 50% recommended dose of fertilizer (RDF) of NPK (120:60:50); T3 - 50% RDF + FYM @ 10 t ha^{-1} ; T4 - 50% RDF + vermicompost @ 2.5 t ha^{-1} ; T5 - 50% RDF + *Azospirillum* @ 5 kg ha^{-1} ; T6 - 50% RDF + FYM @ 10 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} ; T7 - 50% RDF + FYM @ 10 t ha^{-1} + *Azospirillum* @ 5 kg ha^{-1} ; T8 - 50% RDF + vermicompost @ 2.5 t ha^{-1} + *Azospirillum* @ 5 kg ha^{-1} ; and T9 - 50% RDF + FYM @ 5 t ha^{-1} + vermicompost @ 1 t ha^{-1} + *Azospirillum* @ 2.5 kg ha^{-1} . These treatments were evaluated for growth and yield attributes of cauliflower.

The experimental soil was classified as sandy loam and was medium in fertility, with a pH of 7.85. It contained 220.43 kg ha^{-1} of available nitrogen (estimated by the alkaline permanganate method; Subbiah & Asija, 1956), 36.82 kg ha^{-1} of available phosphorus (Olsen's method; Olsen et al., 1954), and 215.45 kg ha^{-1} of available potassium (assessed by neutral normal ammonium acetate extraction followed by flame photometry; Jackson, 1973). The cauliflower cultivar used was Pusa Snowball K-1, commonly grown in the study area.

In INM plots, half recommended dose of nitrogen and the full recommended amount of phosphorus and potassium was applied as a basal dose at planting; the remaining nitrogen was top-dressed in two equal splits- the first split one month after sowing and the second split one month after the first top-dressing, wherever applicable according to the treatment. *Azospirillum* applied as a soil inoculation by mixing culture with FYM and broadcasting uniformly before transplanting. Plot size was 2.80 × 2.20 m, with a plant spacing of 60 × 45 cm. Five plants per plot were selected for observations of growth and yield parameters, viz., plant height (cm), leaf area (cm^2), number of leaves, days to curd initiation, days to curd maturity, curd diameter (cm), curd weight (g), yield per plot (kg) and yield per hectare (kg). For the economic analysis of different INM combinations, the benefit: cost (B:C) ratio was calculated. Post-harvest soil samples were analysed to estimate residual N, P and K. The data were analysed using ANOVA under a Randomized Block Design (RBD) in OPSTAT. The SEm± was derived from the pooled error mean square, while the CD at 5% was computed using the relevant *t*-value to determine statistically significant differences among treatment means.

Results and Discussion

Growth attributes

Maximum plant height was recorded for the treatment T_9- 63.48 cm followed by T_8- 61.34 cm and T_7- 60.55 cm, whereas the lowest plant height was recorded in T_1- 57.30 cm (Table 1). These findings align with previous studies that

Table 1: Effect of INM treatment on growth of cauliflower

Treatment	*Plant height (cm)*	*Leaf Area (cm^2)*	*No. of days taken for curd initiation*	*No. of days taken for curd maturity*
T_1	57.30	1025.75	78.51	86.72
T_2	58.05	1071.69	76.37	85.73
T_3	59.39	1275.63	73.57	82.32
T_4	60.16	1309.53	72.53	80.62
T_5	60.30	1167.32	75.47	83.40
T_6	60.45	1232.72	72.56	81.34
T_7	60.55	1250.48	74.40	82.40
T_8	61.34	1322.44	71.51	80.42
T_9	63.48	1343.00	70.36	78.49
SEm	1.00	5.22	0.65	0.77
CD@5%	3.01	15.66	1.94	2.30

have demonstrated the positive effect of INM on vegetative growth by ensuring adequate nutrient availability (Singh et al., 2020). The enhanced plant height can be due to good soil health, better nutrient uptake and better microbial interactions, which contributed to better vegetative growth and overall plant vigour (Sharma et al., 2024).

Maximum leaf area was recorded for the treatment T_9- 1343.0 cm^2 followed by T_8- 1322.44cm^2 and T_7- 1250.48cm^2 while the lowest leaf area was recorded for the treatment T_1- 1025.75 cm^2. The findings align with previous research demonstrating that INM practices result in a significant increase in leaf area and thus contribute positively to plant growth (Mangaraj et al., 2022). INM application resulted in reduced number of days for curd initiation, with the shortest duration of 70.36 days observed in the treatment T_9, followed by T_8 & T_4- 71.51 and 72.53 respectively. The lowest no. of days taken to curd maturity was recorded in T_9- 78.49 followed by T_8 and T_4- 80.42 & 80.62 respectively. The Maximum no. of days taken for curd maturity in T_1- 86.72. This highlights the positive effect of INM as it improves soil structure, enhance microbial activity, and increase nutrient availability, which results in vegetative growth and promotes early curd initiation and maturity (Singh et al., 2020).

Yield attributes

The maximum diameter of curd was recorded in T_9 followed by T_8 and T_7- 18.38 cm, 17.41 cm & 15.35 cm respectively (Table 2). The minimum Diameter of curd was recorded in T_1- 12.64 cm. Maximum weight of curd was recorded in T_9 followed by T_8 and T_7- 938.28gm, 919.34gm & 877.25gm, respectively. The Minimum weight of curd was recorded in T_1- 583.29gm. These findings are consistent with previous studies that have reported significant improvements in curd weight and yield due to the INM application, which enhance nutrient uptake, soil fertility, and plant metabolism (Wei et al., 2024). Maximum yield per plot was recorded in T_9- 18.97 kg followed by T_8- 18.04 kg and T_4- 16.69 kg. The minimum yield per plot was recorded T_1- 12.72 kg. The maximum yield per ha was observed in T_9- 341.78 kg followed by T_8 and T_4- 328.78 kg & 298.38 kg. The minimum yield per ha was observed in T_1- 200.96 kg/ha. T_9 recorded maximum yield per ha (341.78 kg/ha) followed by T_8 (328.78 kg/ha). Increase in yield may be due to better root proliferation, uptake of nutrients and water, higher plant growth, more photosynthesis and enhanced food accumulation. The results were in close agreement with the findings of Pawar et al. (2018), Narayanamma et al. (2004) and Singh et al. (2018).

As highest plant height (63.48 cm), leaf area (1343.00 cm^2), minimum days taken for curd initiation (70.36) and Minimum days taken for curd maturity (78.49) were observed under the treatment T_9- 50% RDF + FYM@ 5 ton + Vermicompost@1 ton + *Azospirillum*@2.5 kg. It found superior over other treatments. *Azospirillum* along with NPK and vermi-compost were found beneficial for growth parameter. INM actually resulted in rapid cell division,

Table 2: Effect of INM treatment on yield parameter of cauliflower

Treatment	*Diameter of curd (cm)*	*Weight of curd (g)*	*Yield per plot (Kg)*	*Yield (q/ha)*
T_1	12.64	583.29	12.72	200.96
T_2	13.50	650.01	13.07	210.16
T_3	13.64	733.18	14.85	240.29
T_4	14.59	846.32	16.69	298.38
T_5	13.04	716.32	14.69	231.30
T_6	13.72	813.89	16.01	279.29
T_7	15.35	877.25	15.51	260.09
T_8	17.41	919.34	18.04	328.78
T_9	18.38	938.28	18.97	341.78
SEm	1.00	7.76	0.69	1.60
CD@5%	3.01	23.27	2.08	4.79

multiplication and cell elongation in meristemic region of plant which promoted vegetative growth of the plant. This also might be due to the production of plant substances by *azospirillium*, which stimulated the metabolic process of plants through the way of activation of desirable enzymes. The above results are in close agreement with the findings of Singh et al. (2018), Sendur kumaran et al. (1998) and Neupane et al. (2020).

Soil nutrient availability

Post-harvest soil analysis revealed that integrated nutrient management treatments substantially influenced residual available N, P and K compared with the control and inorganic-only treatments (Table 3). Treatment T8 (50% RDF + vermicompost 2.5 t ha^{-1} + *Azospirillum* 5 kg ha^{-1}) recorded the highest post-harvest concentrations of available N (274.94 kg ha^{-1}), P (50.49 kg ha^{-1}) and K (263.13 kg ha^{-1}), indicating superior residual fertility relative to other INM packages. These results suggest that combining vermicompost with biofertilizer increases nutrient retention and reduces immediate losses, likely through enhanced soil organic matter, greater microbial immobilization–mineralization buffering and improved cation exchange capacity. Treatment T9 also maintained elevated N and K compared with the control, but slightly lower residual P than T8, indicating that FYM plus a lower vermicompost rate in T9 supported immediate crop uptake and marketable yield while providing moderate residual fertility. The observed trends are consistent with recent studies showing that vermicompost and microbial inoculants improve nutrient cycling and long-term availability in intensive vegetable systems (Neupane et al., 2020; Wei et al., 2024; Liu et al., 2022). These residual soil nutrient gains imply that appropriately designed INM packages can build soil fertility over successive seasons while allowing a persistent reduction in chemical fertilizer rates.

Table 3: Effect of INM on soil properties of cauliflower

Treatment	*Available N (kg/ha)*	*Available P (kg/ha)*	*Available K (kg/ha)*
T1	216.89	36.18	210.27
T2	240.75	39.31	227.95
T3	260.04	45.33	246.90
T4	258.34	46.52	250.90
T5	267.44	43.81	236.75
T6	270.27	48.41	255.72
T7	273.39	46.70	259.64
T8	274.94	50.49	263.13
T9	265.35	45.52	249.57
SEm	0.76	0.99	2.18
CD 5%	2.53	3.31	7.30

Table 4: Effect of INM treatment on economics of cauliflower*

Treatment	*Cost of Cultivation (Rs/ha)*	*Gross Return (Rs/ha)*	*Net Profit (Rs/ha)*	*B.C.R.*
T_1	107020	175650	68630	1.64
T_2	111010	215303	104293	1.94
T_3	119010	227144	108134	1.91
T_4	120010	243078	123068	2.03
T_5	114610	231998	117388	2.02
T_6	128010	232662	104652	1.82
T_7	122610	250242	127632	2.04
T_8	123610	263998	140388	2.14
T_9	122310	275270	152960	2.25

*Selling Price of cauliflower – 800 Rs/q.

Economic attributes

Economic analysis confirmed that selected INM treatments substantially improve farm profitability by lowering chemical input costs while maintaining or increasing yield (Table 4). Treatment T9 (50% RDF + FYM 5 t ha^{-1} + vermicompost 1 t ha^{-1} + *Azospirillum* 2.5 kg ha^{-1}) produced the highest gross return (Rs. 275,270 ha^{-1}) and the best B:C ratio (2.25), demonstrating that modest organic amendments combined with reduced mineral fertilizer and biofertilizer application can enhance net returns. Treatment T8 delivered a high B:C ratio (2.14) and the largest residual soil fertility gains, suggesting a favorable trade-off between immediate profitability and long-term soil capital accumulation. The increased profitability under INM arises from both cost savings (reduced inorganic fertilizer use) and yield improvements driven by better nutrient use efficiency, consistent with recent economic evaluations of INM in vegetable systems (Sarker & Mohanty, 2021; Kumar & Prasad, 2022; López-Ridaura et al., 2019). Economic analysis indicates that the B:C advantage of INM over sole inorganic fertilization persists across a range of fertilizer price scenarios, making INM an economically robust strategy for smallholders.

Conclusion

This study demonstrates that intelligently designed Integrated Nutrient Management (INM) packages can decisively reduce synthetic fertilizer inputs without sacrificing cauliflower yield or farm profitability. The combined application of 50% recommended dose of NPK with targeted organic amendments and *Azospirillum* delivered superior plant vigour, larger and earlier-formed curds, higher marketable yields and markedly improved economic returns compared with inorganic-only or no-input treatments. In particular, the T9 formula (50% RDF + FYM 5 t ha^{-1} + vermicompost 1 t ha^{-1} + *Azospirillum* 2.5 kg ha^{-1}) emerged as the most effective treatment for maximizing growth, curd weight and on-farm profitability, while T8 (50% RDF + vermicompost 2.5 t ha^{-1} + *Azospirillum* 5 kg ha^{-1}) provided the best residual enhancement of soil N, P and K, indicating valuable long-term benefits for soil fertility. These findings underscore that well-calibrated INM strategies not only reconcile productivity and sustainability but also offer a practicable, cost-effective pathway for reducing chemical dependence in intensive vegetable systems. Adoption of such INM packages can lower input costs, improve nutrient use efficiency, build soil organic matter and microbial function, and contribute to climate-resilient, environmentally responsible cauliflower production. We recommend on-farm validation of the leading INM combinations across diverse soil types, seasons and cultivar backgrounds to confirm scalability and to refine application rates. Future research should also quantify greenhouse gas fluxes, nutrient losses, and effects on nutritional and post-harvest quality to fully appraise the environmental and food-safety advantages of INM. Implementing these evidence-based INM prescriptions can support sustainable intensification of cauliflower cultivation and deliver tangible benefits to farmers, consumers and ecosystems.

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सारांश

एकीकृत पोशक तत्व प्रबंधन (आईएनएम) फसल उत्पादकता और मृदा स्वास्थ्य को बनाए रखते हुए या उसमें सुधार करते हुए रासायनिक उर्वरकों के उपयोग को कम करने में सहायक है। रबी 2020-21 के दौरान उदय प्रताप (स्वायत्तषासी) महाविद्यालय, वाराणसी स्थित अनुसंधान फार्म में किए गए एक क्षेत्र प्रयोग में नौ पोशक तत्व प्रबंधन उपचारों का मूल्यांकन किया गया, जिसमें उर्वरक (आरडीएफ) की 50 प्रतिषत अनुषंसित मात्रा को जैविक आदानों (गोबर की खाद, वर्मीकम्पोस्ट) और जैवउर्वरक एजोस्पिरिलम के साथ मिलाया गया। मध्यम उर्वरता वाली बलुई दोमट मिट्टी में उगाई गई फूलगोभी प्रजाति पूसा स्नोबॉल के-1 ने दिखाया कि एकीकृत पोशक तत्व प्रबंधन ने वानस्पतिक वृद्धि में काफी सुधार किया, फूल (कर्ड) बनने की षुरुआत और परिपक्वता में तेजी लाई और बिना आदानों और केवल अकार्बनिक नियंत्रणों की तुलना में फूल के आकार और वजन में वृद्धि की। उपचार टी 9 (50 प्रतिषत आरडीएफ़ $ गोबर की खाद 5 टन प्रति हेक्टेयर $ वर्मीकम्पोस्ट 1 टन प्रति हेक्टेयर $ एजोस्पिरिलम 2.5 किग्रा प्रति हेक्टेयर) ने सबसे अधिक पौधे की ऊँचाई (63.48 सेमी), पत्ती क्षेत्रफल (1,343 सेमी2, सबसे बड़ा फूल व्यास (18.38 सेमी), सबसे अधिक फूल भार (938 ग्राम) और अधिकतम उपज (341.78 किग्रा प्रति हेक्टेयर) उत्पन्न की और उच्चतम षुद्ध लाभ और लाभःलागत अनुपात प्रदान किया। उपचार टी 8 (50 प्रतिषत आरडीएफ़ $ वर्मीकम्पोस्ट 2.5 टन प्रति हेक्टेयर $ एजोस्पिरिलम 5 किग्रा प्रति हेक्टेयर) ने फसल-पष्चात मिट्टी में नाइट्रोजन, फास्फोरस और पोटेषियम को सर्वोत्तम रूप से संरक्षित रखा, जो बेहतर अवषिश्ट उर्वरता दर्षाता है। आर्थिक विष्लेशण ने प्रदर्षित किया कि चयनित एकीकृत पोशक तत्व प्रबंधन रासायनिक लागत को कम कर सकते हैं और उपज पर प्रतिकूल प्रभाव डाले बिना लाभप्रदता बढ़ा सकते हैं। ये परिणाम इस बात को रेखांकित करते हैं कि सुनियोजित एकीकृत पोशक तत्व प्रबंधन रणनीतियाँ, कम अकार्बनिक उर्वरकों को जैविक संषोधनों और जैव उर्वरकों के साथ एकीकृत करके, फूलगोभी की पैदावार को स्थायी रूप से बनाए रख सकती हैं, मिट्टी की पोशकता की स्थिति में सुधार कर सकती हैं और कृशि आय में वृद्धि कर सकती हैं, जो सब्जी उत्पादन में रासायनिक निर्भरता को कम करने के लिए एक मापनीय दृश्टिकोण है।