



RESEARCH ARTICLE

Exploring the synergistic impact of straight fertiliser, nano-fertiliser and biostimulants on growth, yield and quality of cabbage

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Abstract

Integrating nano-fertilisers with conventional chemical inputs and biostimulants offers a pathway to sustainable intensification in heavy-feeding horticultural crops. A field experiment was conducted at the Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal, during the 2021–22 Rabi season to evaluate the synergistic impact of straight fertilisers, nano-fertilisers and biostimulants on the growth, yield and quality of cabbage. The experiment was designed in randomized block design (RBD) with 3 replications 9 treatments, including combinations of straight and nano- fertilisers, were tested to achieve optimal yield targets. Among the 9 treatments, T9 comprising the soil test crop response (STCR) dose for 550 q ha⁻¹ yield target (134.5 kg nitrogen (N) ha⁻¹ from urea + 2920 ppm N from nano-urea + 155 kg phosphorus ha⁻¹ from single superphosphate [SSP] + 278 kg K ha⁻¹ from muriate of potash [MOP] + 400 ppm Sagarika [seaweed extract 28 % w/w]) recorded the maximum plant height (25.86 cm), leaf length (26.63 cm), leaf width (25.20 cm), number of non-wrapper leaves (14.33), polar length (16.87 cm), equatorial diameter (17.82 cm), fresh weight of plant (2.09 kg), head weight (1.39 kg), marketable yield (627.67 q ha⁻¹), total sugar (4.92 %), reducing sugar (2.97 %), non-reducing sugar (1.95 %) and ascorbic acid (17.57 mg / 100 g) while achieved the lowest moisture content (84.50 %). From an economic perspective, T9 generated the highest profitability with gross return (₹ 313835 ha⁻¹), net income (₹ 202639.9 ha⁻¹) and benefit-cost ratio (B:C Ratio) (1.82). However, maximum total soluble solids (TSS) of 6.761 °Brix were observed in T6 (STCR dose for 550 q ha⁻¹ through straight fertilisers), while the highest moisture content (90.55 %) was recorded in the control (T1). These findings suggest that integrating nano-fertilisers with conventional fertilisers and biostimulants enhances cabbage growth, quality and profitability presenting a promising approach for sustainable crop production.

Keywords: Cabbage; growth; nano-fertiliser; soil test crop response; quality

Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most important cole crops worldwide in terms of area, production and year-round availability. It is recognised by consumers to be highly nutritive, being a rich source of micronutrients and phytochemicals, abundant in fibres, vitamins, polyphenols (including flavonoids and especially anthocyanin) and glucosinolates that are secondary plant metabolites with positive effects on human health and it has anti-cancer properties due to the presence of sulforaphane compound (1, 2). There is a great demand for cabbage throughout the year. However, during early winter, the price remains very high, which attracts farmers to cultivate cabbage during the winter season as well as in the off-season to maximise profits. Cabbage growth and productivity are significantly influenced by nutrient management practices. Being a heavy feeder, cabbage has traditionally relied on straight fertilisers. However, the injudicious use of chemical fertilisers has led to environmental concerns such as deteriorating soil quality,

eutrophication, groundwater pollution, and air pollution (3-7). Furthermore, this practice diminishes the soil's macro and micronutrient-supplying capacity (8, 9), with a significant portion of fertilisers remaining unused, causing leaching and inefficient nutrient utilisation. To meet the growing food demand, there has been a disproportionate reliance on chemical fertilisers, especially nitrogen (10, 11). These challenges highlight the need for advanced, sustainable agricultural practices (12, 13). Recently, nano-fertilisers have emerged as a promising alternative, built on nano-scale (1–100 nm) substrates. They can enhance crop yields and food quality by improving nutrient delivery and reducing environmental impact (8, 14, 15). Adopting nano-fertilisers can reduce fertiliser doses, runoff, leaching and atmospheric emissions, thereby contributing to sustainable agriculture in India and around the world through curtailing of fertiliser dosages (7, 11, 16–19). Several studies have demonstrated that spraying crops with nano-urea significantly enhances yield under field conditions in many crops (11, 20–24).

Nevertheless, most research on nanoparticles remains confined to laboratory or pot experiments. Despite their potential, nanoparticles can also be toxic, causing structural and cellular abnormalities in plants (24, 25). Therefore, the development of non-toxic nano-fertilisers is crucial for enhancing grain nutrient content and crop yields and effective utilisation of nitrogen and other nutrients through nano formulations is urgently needed (26). Nano-fertilisers are gaining recognition as valuable agricultural inputs owing to their small size, unique shapes, and promising physicochemical properties, with the potential to enhance crop yields while minimising environmental harm compared with conventional fertilisers (27–30). However, comprehensive field-scale research evaluating the integration of nano-fertilisers with traditional fertilisers and biostimulants remains limited (14, 31, 32). Addressing this knowledge gap, the present study was designed to investigate the synergistic impact of straight fertilisers, nano-fertilisers, and biostimulants on the growth, yield, quality and economics of cabbage under field conditions.

Materials and Methods

The field investigation was carried out at the Central Research Farm, Regional Research Station, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Gayeshpur, Nadia (West Bengal) during the Rabi season 2021–22. The experiment was laid out in a randomized block design (RBD) with 3 replications. The experimental soil was sandy clay loam in texture with good drainage and pH 6.87. The initial soil organic carbon was 0.73 % and available nitrogen (N), phosphorus (P) and potassium (K) contents were 168.10, 46.00 and 141.5 kg ha⁻¹ respectively. Cultivar Kaneko Cross Rare Ball cabbage F1 hybrid was used in the experiment and healthy seedlings of 30 days old were transplanted at 50 cm × 40 cm spacing in a 4 × 4 m² gross plot area. The treatment details were as follows; T1: control, T2: 150 kg ha⁻¹ + 60 kg ha⁻¹ + 90 kg ha⁻¹ NPK ha⁻¹, T3: 75 kg ha⁻¹ of N from urea + 1630 ppm of N from nano urea + 60 kg ha⁻¹ of P + 90 kg ha⁻¹ of K, T4: soil test crop response (STCR) dose for a target yield of 500 q ha⁻¹ via straight and nano-fertilisers [225 kg ha⁻¹ of N from urea + 135 kg ha⁻¹ of P from single superphosphate (SSP), + 224 kg ha⁻¹ of K from muriate of potash (MOP)], T5: STCR dose for a target yield of 500 q ha⁻¹ via straight and nano-fertilisers (112.5 kg ha⁻¹ of N from urea, + 2450 ppm of N from nano urea, + 135 kg ha⁻¹ of P from SSP + 224 kg ha⁻¹ of K from MOP). T6: STCR dose for a target yield of 550 q ha⁻¹ via straight fertilisers (269 kg ha⁻¹ of N from urea 155 kg ha⁻¹ of P from SSP + 278 kg ha⁻¹ of K from MOP), T7: The STCR dose for a target yield of 550 q ha⁻¹ via straight fertilisers (34.5 kg/ha of N from urea + 2920 ppm of N from nano urea + 155 kg ha⁻¹ of P from SSP + 278 kg ha⁻¹ of K from MOP), T8: STCR dose for a target yield of 500 q ha⁻¹ via straight fertilisers (112.5 kg ha⁻¹ of N from urea + 2450 ppm of N from nano urea + 135 kg ha⁻¹ of P from SSP + 224 kg ha⁻¹ of K from MOP + 350 ppm of Sagarika). T9: The STCR dose for a target yield of 550 q ha⁻¹ via straight fertilisers (34.5 kg ha⁻¹ of N from urea, 2920 ppm of N from nano urea, 155 kg ha⁻¹ of P from SSP, 278 kg ha⁻¹ of K from MPO and 400 ppm of Sagarika). According to the treatments, N, P and K were applied in the form of urea, nano urea, SSP, MOP and Sagarika. Before transplanting the seedling, the full dose of P and K and half of the total nitrogen was applied as per the treatment in the plot. The remaining N was applied in 2 equal splits doses at 25 and 45 days after transplanting. The crop was raised by adopting standard cultural practices. The observations recorded were for plant height (cm), leaf length (cm), leaf width (cm), non-wrapper leaves, polar

length (cm), equatorial diameter (cm), fresh weight of plant (kg), head weight (kg), marketable yield (q ha⁻¹), TSS (°brix), total sugar (%), reducing sugar (%), non-reducing sugar (%), ascorbic acid (mg / 100 g) and moisture (%). The vitamin C content was determined using the 2, 6-dichlorophenol indophenol titrimetric method (33). The obtained experimental data were statistically analysed (34).

Results and Discussions

Plant growth promotion

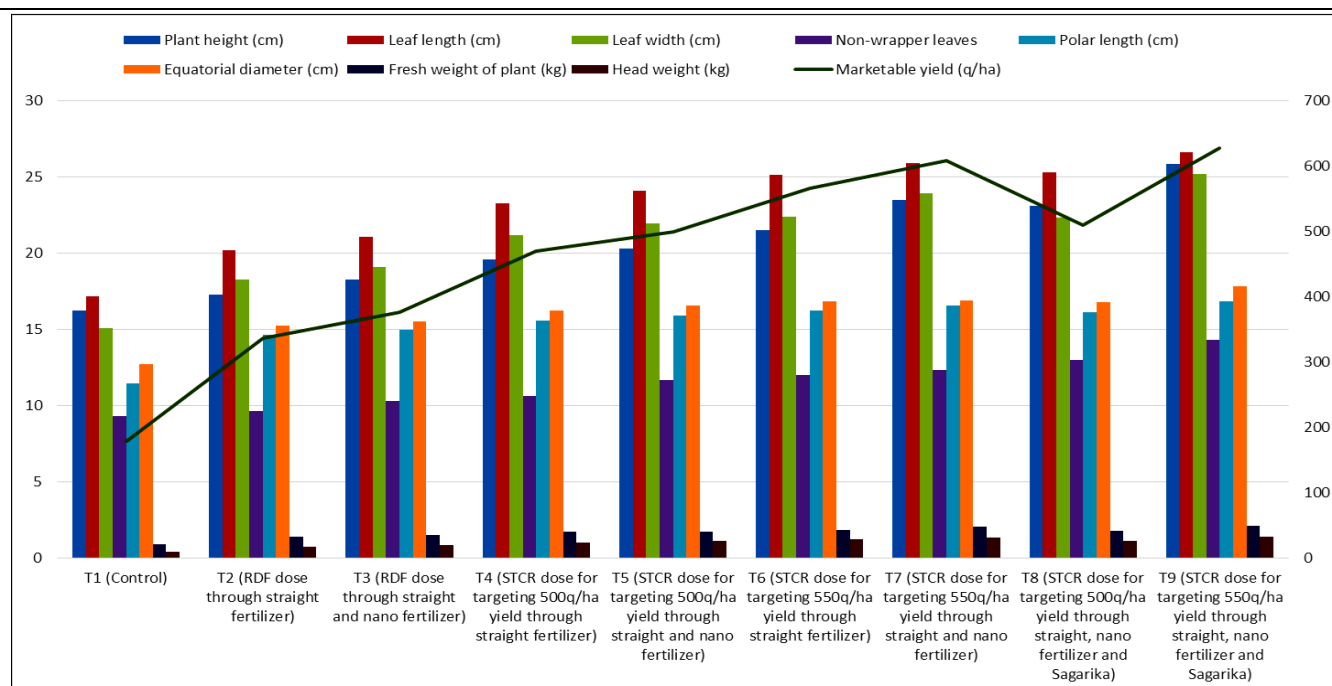
The vegetative growth parameters of cabbage were significantly influenced by the combined application of straight fertilisers, nano-fertilisers, and biostimulants (Table 1, Fig. 1). The growth of cabbage was markedly superior when conventional and nano-fertilisers were supplemented with the biostimulant Sagarika compared to applications of straight or nano-fertilisers alone. The maximum plant height (25.86 cm), maximum leaf length (26.63 cm), maximum leaf width (25.20 cm) and maximum non-wrapper leaves (14.33) of the cabbage was found in T9 (134.5 kg ha⁻¹ of N from urea, 2920 ppm of N from nano urea, 155 kg ha⁻¹ of P from SSP, 278 kg ha⁻¹ of K from MOP and 400 ppm of Sagarika), followed by T7 (23.50 cm) and T8 (23.10 cm). The minimum values for all the above characters were recorded in control (T1). This may be attributed to the fact that the combined use of conventional fertilisers, nano fertilisers and biostimulants enhances nutrient availability and uptake, leading to improved plant growth and development. Straight fertilisers provide essential macronutrients in larger quantities, while nano fertilisers offer more efficient and targeted nutrient delivery due to their smaller particle size and higher surface area. The bio-stimulant (Sagarika) likely promotes physiological processes and enhances the plant's ability to absorb and utilize these nutrients effectively. Together, these inputs create a synergistic effect that results in better plant height, leaf size and leaf number compared to using each component separately. Similar findings with the combined use of nano, conventional and nano fertilisers significantly enhance crop yields in maize, wheat and pearl millet were reported (35, 36). The combination of both conventional (straight) and nano fertilisers with a bio-stimulant (Sagarika) resulted in significantly better growth metrics for cabbage compared to application of straight or nano fertilisers alone. Specifically, treatment T9, which used a specific combination of urea, nano urea, SSP, MOP and the bio-stimulant Sagarika, led to the higher values of plant height, leaf length, leaf width and number of non-wrapper leaves. This suggests that an integrated approach of fertiliser use, including bio-stimulants, can enhance the growth performance of cabbage more effectively than using traditional or nano fertilisers by themselves. These findings are in close conformity (37).

Yield enhancement

The yield and yield contributing parameters were significantly affected by different treatments (Table 1, Fig. 1). The maximum polar length (16.87 cm), maximum equatorial diameter (17.82 cm), maximum fresh weight of plant (2.09 kg), maximum head weight (1.39 kg), maximum marketable yield (627.67 q ha⁻¹) was observed in T9 (134.5 kg ha⁻¹ of N from urea, 2920 ppm of N from nano urea, 155 kg ha⁻¹ of P from SSP, 278 kg ha⁻¹ of K from MOP and 400 ppm of Sagarika). However, minimum polar length (11.45 cm), equatorial diameter (12.73 cm), fresh weight of plant (0.89 kg), head weight (0.39 kg) and marketable yield (178.75 q ha⁻¹) were recorded in control (T1). In the present experiment, the increase in yield is due to

Table 1. Effect of straight and nano fertiliser on growth and yield attribute

Treatment	Growth parameters						Yield parameter		
	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Non-wrapper leaves	Polar length (cm)	Equatorial diameter (cm)	Fresh weight of plant (kg)	Head weight (kg)	Marketable yield (q ha ⁻¹)
T ₁ (Control)	16.23	17.20	15.10	9.33	11.45	12.73	0.89	0.39	178.75
T ₂ (RDF dose through straight fertiliser)	17.30	20.20	18.30	9.66	14.64	15.27	1.40	0.74	336.67
T ₃ (RDF dose through straight and nano fertiliser)	18.26	21.10	19.10	10.33	14.96	15.55	1.53	0.84	376.67
T ₄ (STCR dose for targeting 500 q ha ⁻¹ yield through straight fertiliser)	19.60	23.30	21.20	10.66	15.59	16.23	1.71	1.04	470.00
T ₅ (STCR dose for targeting 500 q ha ⁻¹ yield through straight and nano fertiliser)	20.30	24.10	21.96	11.66	15.91	16.55	1.75	1.11	500.00
T ₆ (STCR dose for targeting 550 q ha ⁻¹ yield through straight fertiliser)	21.50	25.13	22.40	12.00	16.23	16.87	1.85	1.25	565.62
T ₇ (STCR dose for targeting 550 q ha ⁻¹ yield through straight and nano fertiliser)	23.50	25.90	23.96	12.33	16.55	16.90	2.04	1.35	608.07
T ₈ (STCR dose for targeting 500 q ha ⁻¹ yield through straight, nano fertiliser and Sagarika)	23.10	25.33	22.33	13.00	16.13	16.78	1.80	1.13	510.00
T ₉ (STCR dose for targeting 550 q ha ⁻¹ yield through straight, nano fertiliser and Sagarika)	25.86	26.63	25.20	14.33	16.87	17.82	2.09	1.39	627.67
Sem (±)	0.120	0.138	0.198	0.364	0.028	0.024	0.007	0.009	5.21
CD at 5 %	0.362	0.417	0.599	1.102	0.083	0.073	0.022	0.028	15.756

**Fig 1.** Effect of straight and nano fertiliser on growth and yield attribute.

increased morphological traits and chlorophyll content (35, 36). These results agreed with who found that nano liquid fertilisers application increased the yield of onion as compared to control (37). The high concentration of nano fertiliser led to increased yield of corn has been reported (38). Similarly, 2 ml L⁻¹ spray of nano N (optimus plus 30 % amino acid, 5 % N and 3 % organic N) produces significantly the highest yield and yield contributing characters in khol rabi was reported (39).

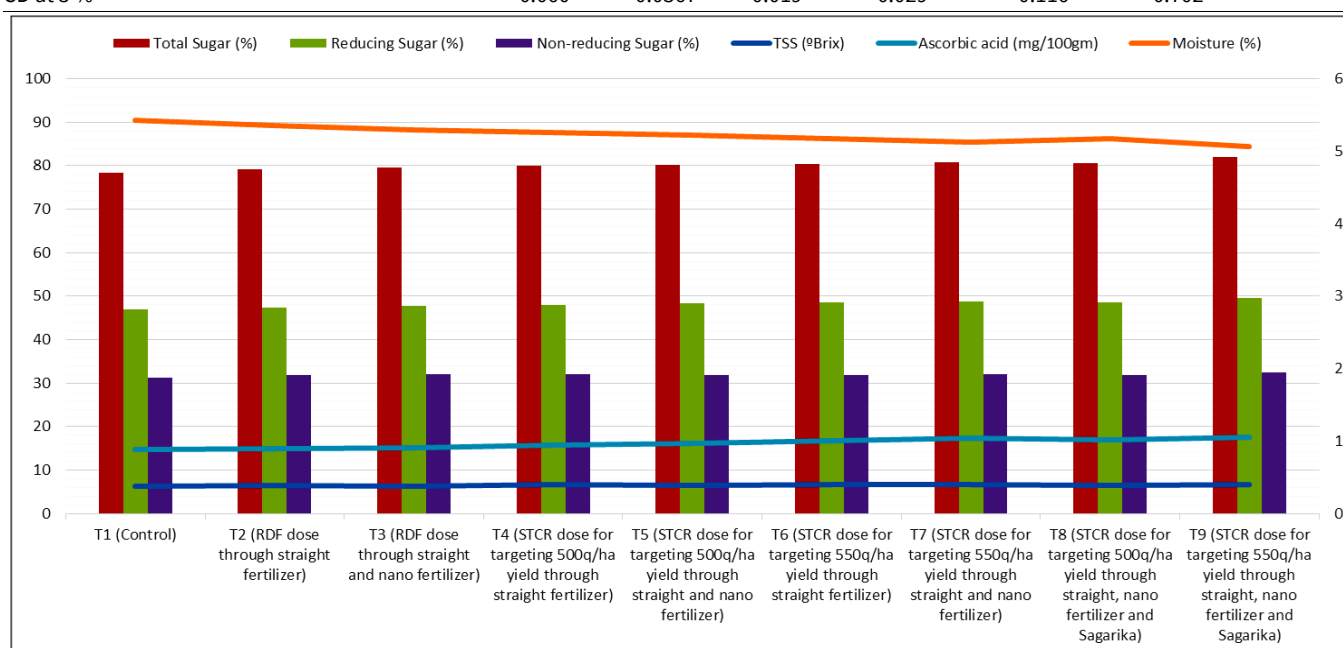
Quality parameters

Quality profiles exhibited significant differences under varying treatment combinations (Table 2, Fig. 2). The result shows that using nano urea combined with conventional fertilisers and bio enhancers (T9) significantly improved plant nutrient uptake, leading to higher

sugar content, ascorbic acid and higher TSS (37). This treatment supports efficient water use, enhancing nutrient density while reducing moisture content. In contrast, the control (T1) had lower nutrient synthesis and higher moisture indicating less effective nutrient utilisation. The highest total sugar content (4.92 %), reducing sugar (2.97 %), non-reducing sugar (1.95 %) and highest ascorbic acid content (17.57 mg / 100 g) were recorded under treatment T9 (134.5 kg ha⁻¹ of N from urea, 2920 ppm of N from nano urea, 155 kg ha⁻¹ of P from SSP, 278 kg ha⁻¹ of K from MOP and 400 ppm of Sagarika), however the maximum TSS 6.761 °Brix) was recorded under T6 (269 kg ha⁻¹ of N from urea 155 kg ha⁻¹ of P from SSP + 278 kg ha⁻¹ of K from MOP) and maximum moisture (90.55 %) was recorded under T1 (control). Minimum total sugar (4.70 %), reducing sugar (2.82 %), non-reducing sugar (1.88 %) and maximum

Table 2. Effect of straight and nano fertiliser on quality attribute

Treatment	Total soluble solids (°Brix)	Total sugar (%)	Reducing sugar (%)	Non-reducing Sugar (%)	Ascorbic acid (mg / 100 g)	Moisture (%)	Cost benefit ratio
T ₁ (Control)	6.242	4.70	2.82	1.88	14.70	90.55	-0.08
T ₂ (RDF dose through straight fertiliser)	6.436	4.75	2.84	1.91	14.95	89.30	0.64
T ₃ (RDF dose through straight and nano fertiliser)	6.311	4.78	2.86	1.92	15.15	88.17	0.83
T ₄ (STCR dose for targeting 500 q ha ⁻¹ yield through straight fertiliser)	6.646	4.80	2.88	1.92	15.85	87.60	1.16
T ₅ (STCR dose for targeting 500 q ha ⁻¹ yield through straight and nano fertiliser)	6.521	4.81	2.90	1.91	16.07	86.97	1.30
T ₆ (STCR dose for targeting 550 q ha ⁻¹ yield through straight fertiliser)	6.761	4.82	2.91	1.91	16.68	86.23	1.54
T ₇ (STCR dose for targeting 550 q ha ⁻¹ yield through straight and nano fertiliser)	6.596	4.85	2.93	1.92	17.30	85.37	1.74
T ₈ (STCR dose for targeting 500 q ha ⁻¹ yield through straight, nano fertiliser and Sagarika)	6.461	4.83	2.92	1.91	16.98	86.16	1.34
T ₉ (STCR dose for targeting 550 q ha ⁻¹ yield through straight, nano fertiliser and Sagarika)	6.758	4.92	2.97	1.95	17.57	84.50	1.82
Sem (±)	0.017	0.010	0.009	0.010	0.038	0.232	
CD at 5 %	0.060	0.0367	0.019	0.029	0.116	0.702	

**Fig. 2.** Effect of straight and nano fertiliser on quality.

ascorbic acid (14.70 mg / 100 g) in the treatment T₁ (control) however minimum moisture percent (84.50 %) was found in T₉. The findings highlight that a balanced nutrient supply with nano formulations is essential for improved fruit quality through enhanced sugar synthesis and metabolic activity. Nitrogen is essential for the synthesis of vitamins and enzymes (10). Nano fertilisers enhanced the N supply in treatments T₉, increasing ascorbic acid levels and present experiment findings supported by the earlier findings in cabbage and potatoes (40, 41).

Economics

The economic analysis of crop production revealed that the combination of treatments had a significant impact on profitability. The data showed that the maximum gross income (₹ 313835 ha⁻¹) and maximum net return (₹ 202639.9 ha⁻¹) were achieved under treatment T₉ (Table 3). This treatment also recorded the highest B: C ratio of 1.82, indicating superior cost-effectiveness. In contrast, the lowest gross income (₹ 89375 ha⁻¹) and minimum net return (₹ 85000/ha) were observed in the control treatment T₁, which also had the lowest B: C ratio (-0.08), highlighting poor economic returns. Although T₆ incurred the highest cost (₹ 111211.4 ha⁻¹), it did not

yield the highest profits. The strong financial performance of T₉ suggests that the advanced nutrient management strategy enhances both productivity and profitability.

Conclusion

The study demonstrated that combining straight and nano fertilisers with bio-stimulant Sagarika significantly enhanced cabbage growth, yield and quality parameters. The treatment T₉, using a specific mix for a target yield of 550 q ha⁻¹, yielded the best results across multiple metrics of growth, yield and quality parameters. This combination also proved economically advantageous, achieving the highest B: C ratio (1.82), indicating that the increased yield outweighs the costs associated with this treatment. The results highlight the potential of integrating nano-fertilisers in nutrient management, particularly in meeting the nutrient demands of high-yielding crops like cabbage. Nano fertilisers, due to their efficient nutrient delivery and reduced environmental impact, present a sustainable alternative to conventional fertilisers. Additionally, bio-stimulants appear to enhance nutrient absorption and utilization further. This integrated nutrient management approach of combining straight fertilisers,

Table 3. Effect of straight and nano fertiliser on cost-benefit ratio of cabbage

Treatment	Yield (q ha ⁻¹)	Gross return (₹ ha ⁻¹)	Fixed cost (₹ ha ⁻¹)	Variable cost (₹ ha ⁻¹)	Total cost (₹ ha ⁻¹)	Net Income (₹ ha ⁻¹)	Cost-benefit ratio
T1	178.75	89375	97590	0.00	97590.00	-8215.00	-0.08
T2	336.67	168335	97590	5366.04	102956.00	65378.96	0.64
T3	376.67	188335	97590	5106.84	102696.80	85638.16	0.83
T4	470.00	235000	97590	11175.02	108765.00	126235.00	1.16
T5	500.00	250000	97590	10788.62	108378.60	141621.40	1.30
T6	565.62	282815	97590	13621.4	111211.40	171603.60	1.54
T7	608.07	304035	97590	13155.06	110745.10	193289.90	1.74
T8	510.00	255000	97590	11226.62	108816.60	146183.40	1.34
T9	627.67	313835	97590	13605.06	111195.10	202639.90	1.82

* Market rate Rs. 500 q⁻¹.

nano-fertilisers, and biostimulants can promote sustainable agriculture by maximising yield and quality while potentially minimising adverse environmental effects, thereby offering a viable strategy for optimising cabbage cultivation and profitability.

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Authors' contributions

AK carried out the research work and drafted the initial manuscript. RR and RS contributed to refining the manuscript. SPK, RK, PK, and YK contributed to reviewing, editing, and providing critical corrections to the manuscript. SJ assisted in data analysis and manuscript improvement. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical issues: None

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