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Synergistic impact of integrated nutrient and pest management on cabbage productivity: A multivariate and principal component approach

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Abstract

A field experiment was conducted to evaluate the synergistic impact of integrated nutrient and pest management on cabbage (*Brassica oleracea* var. capitata) productivity: A multivariate and principal component approach. The study comprised three treatments: farmer practices (control), improved cultivar with integrated nutrient management (INM), integrated pest management (IPM) and biological consortia and the same combination with lime application. The results revealed that integrated management practices significantly improved growth parameters and yield compared to the control. The highest yield (8060.47 kg acre⁻¹) and head weight (1417.61 g) were recorded under the treatment involving improved cultivar + IPM + INM + biological consortia. Statistical analysis showed a highly significant effect of treatments on yield ($p < 0.001$), while the treatment $\times$ year interaction was non-significant, indicating consistent performance across seasons. Post-hoc analysis confirmed that integrated treatments significantly outperformed conventional practices. Multivariate analysis (MANOVA) further confirmed significant treatment effects on combined growth and yield traits, while principal component analysis (PCA) identified head weight, and plant vigor as key contributors to productivity. The study concludes that integrated crop management practices offer a sustainable and efficient approach to enhance cabbage yield and can be recommended for improved productivity and soil health.

Keywords: Cabbage (*Brassica oleracea* var. capitata), integrated nutrient management (INM)

1. Introduction

Cabbage (*Brassica oleracea* var. capitata) is an important cool-season vegetable crop belonging to the family *Brassicaceae* and is widely cultivated across the globe for its economic and nutritional value. It is a rich source of vitamins (A, C, and K), minerals, antioxidants and dietary fiber, making it an essential component of a balanced human diet. In India, cabbage occupies a significant area among vegetable crops and contributes substantially to the income of small and marginal farmers due to its high market demand and relatively short duration (Patel *et al.*, 2021)^[10]. Despite its importance, the productivity of cabbage in many regions is still below its potential, primarily due to suboptimal agronomic practices, nutrient imbalances, pest and disease pressure and declining soil fertility (Saba, *et al.*, 2025)^[12].

The increasing demand for higher productivity has led to the excessive and often indiscriminate use of chemical fertilizers and pesticides under conventional farming systems (Hossain *et al.*, 2022)^[6]. While these inputs may provide short-term yield gains, their continuous and imbalanced use has resulted in several adverse consequences, including deterioration of soil health, reduction in beneficial soil microbial populations, environmental pollution, and development of pest resistance. These challenges necessitate the adoption of sustainable and eco-friendly production practices that can maintain productivity while conserving natural resources (Udodiugwu *et al.*, 2025)^[15].

Integrated Crop Management (ICM) has emerged as a holistic approach that combines various compatible technologies to optimize crop productivity and sustainability. It involves the use of

improved cultivars along with Integrated Nutrient Management (INM), Integrated Pest Management (IPM) and biological inputs. INM focuses on the judicious use of chemical fertilizers in combination with organic manures and biofertilizers to ensure balanced nutrient supply, improve nutrient use efficiency and enhance soil physical, chemical and biological properties. IPM, on the other hand, emphasizes the use of environmentally safe and economically viable pest control methods, including biological control agents, cultural practices, and need-based application of pesticides, thereby minimizing ecological risks (Singh *et al.*, 2023)^[14].

The incorporation of biological consortia, consisting of beneficial microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing microbes and plant growth-promoting rhizobacteria, further enhances nutrient availability and plant growth (Devi *et al.*, 2022, Khopade *et al.*, 2025)^[2, 9]. These microbial inoculants play a crucial role in improving soil fertility, stimulating root development, and increasing plant resilience against biotic and abiotic stresses. In addition, soil amendments like lime are particularly important in acidic soils, as they help in correcting soil pH, improving nutrient availability, and reducing toxicity of elements such as aluminum and iron, thereby creating a favorable environment for crop growth.

Although individual components of integrated management have been widely studied, their combined effects on cabbage growth, yield and yield-attributing traits under field conditions require systematic evaluation (Hasi, 2021). Furthermore, understanding the interrelationships among different growth and yield parameters is essential for identifying key determinants of productivity. Advanced statistical tools such as analysis of variance (ANOVA) provide insights into treatment effects on individual parameters, while multivariate techniques like multivariate analysis of variance (MANOVA) and principal component analysis (PCA) help in assessing the overall plant response and identifying major contributing traits (Fuzy *et al.*, 2021). In this context, the present study was undertaken to evaluate the impact of integrated management practices involving improved cultivars, integrated nutrient and pest management, biological consortia and liming on the growth and yield of cabbage. The study also aims to analyze the relationships among growth and yield parameters and to identify the key factors contributing to enhanced productivity. The findings are expected to provide valuable insights for developing sustainable cabbage production strategies and promoting the adoption of integrated approaches among farmers for improved yield and soil health.

2. Materials and Methods

2.1 Experimental Site and Design

The field experiment was conducted during the rabi season at a representative farmers' fields during 2023-24 and 2024-25. The soil of the experimental field was well-drained and suitable for vegetable production, with moderate fertility status. Climatic conditions during the experiment were conducive for cabbage growth. The experiment consisted of three treatments with three replications under field conditions. Treatments were randomly assigned within each block to ensure unbiased comparison and reduce experimental error.

2.2 Treatments Details

The study consisted of three treatments combining crop management practices and planting materials. The treatments included: 1) farmers' variety (i.e. Local) with farmers' practice

(FV + FP), 2) improved cultivar (Harekrishna) with integrated nutrient management, integrated pest management and biological consortia (IC + INM + IPM + BC) and 3) integrated nutrient management, integrated pest management and biological consortia along with soil amendment (IC + INM + IPM + BC + Lime). These treatments were designed to evaluate the effectiveness of improved technologies compared to conventional farming practices.

2.3 Crop Establishment and Management

Healthy seedlings of both improved cultivars and farmers' varieties were raised in nursery beds under optimal conditions. Proper irrigation and plant protection measures were followed to ensure uniform germination. Seedlings aged 25–30 days were transplanted into the main field at recommended spacing during evening hours to reduce transplanting stress and improve establishment.

2.4 Land Preparation

The field was prepared through ploughing and harrowing to achieve a fine tilth suitable for transplanting. Well-decomposed farmyard manure was incorporated during final land preparation to enhance soil fertility. The field was levelled, and plots were laid out according to the experimental design with proper bunds and irrigation channels.

2.5 Nutrient Management (INM Component)

Integrated nutrient management practices were followed by combining organic and inorganic nutrient sources. Soil test based nutrient application i.e. 180 kg urea+ 160 kg DAP+ 130 kg MOP+ 10 kg ZnSO₄ + 5 kg Borax + biologicals (*Azotobacter* + PSB) / acre was done under Treatment 2 and 3 and additionally Lime @ 150 kg/ acre were under Treatment 3.

2.6 Pest and Disease Management (IPM Component)

Integrated pest management practices were implemented to control pests and diseases in an environmentally sustainable manner. Regular monitoring was conducted, and biological and cultural methods were prioritized. Chemical pesticides were used only when necessary, based on economic threshold levels.

2.7 Application of Biological Consortia (BC)

Biological consortia containing *Azotobacter* + PSB was applied to enhance soil health and nutrient availability. Seedlings were treated through root dipping before transplanting, and additional soil drenching was done near the root zone after establishment.

2.8 Intercultural Operations

Standard intercultural practices were uniformly followed across all treatments. Irrigation was applied at regular intervals based on crop requirements. Manual weeding was carried out to maintain weed-free conditions. Earthing up was done to support plant growth and improve soil aeration.

2.9 Observations Recorded

Growth, phenological, and yield parameters of cabbage were recorded using standard procedures in two rabi seasons, 2023-24 and 2024-25. Plant height (cm) was measured from the base to the top of the plant at harvest. The number of leaves per plant was counted manually.

Yield attributes such as head weight (g), head diameter (cm) and head length (cm) were measured using appropriate tools. Total yield per plot was recorded and converted into yield per hectare using the following formula:

$$\text{Yield (kg acre}^{-1}\text{)} = \frac{\text{Yield per plot (kg)}}{\text{Plot area (m}^2\text{)}} \times 4000$$

2.10 Statistical Analysis

The collected data was analyzed using standard statistical methods. Descriptive statistics, including mean, standard deviation and standard error were calculated. Analysis of variance (ANOVA) under RBD was used to test treatment effects, and significant differences were further analyzed using Tukey’s HSD test. Additionally, multivariate analysis of variance (MANOVA) was conducted to evaluate the combined effect of treatments on multiple traits. Principal component analysis (PCA) was performed to identify key contributing variables and reduce data dimensionality. All analyses were carried out using appropriate statistical software at standard levels of significance.

3. Results and Discussion

3.1 Effect of Treatments on Growth Parameters

The growth parameters of cabbage were markedly influenced by the different management practices adopted in the study. Treatment 2 (Improved Cultivar + IPM + INM + Biological Consortia) recorded the highest plant height (28.01 cm), number of leaves per plant (33.06), and head length (48.86 cm), indicating superior vegetative growth and overall plant vigor. Treatment 3, which included lime application along with integrated practices, also exhibited enhanced growth compared to the control, with plant height (23.89 cm) and leaves per plant (27.22), but remained slightly inferior to Treatment 2. The control treatment (Farmer Variety + Farmer Practices) recorded the lowest values for all growth parameters, reflecting the inefficiency of conventional practices in meeting the nutritional and physiological requirements of the crop. The improved growth under integrated treatments can be attributed to the synergistic effect of balanced nutrient supply through INM, reduced pest pressure through IPM and enhanced soil microbial activity due to biological consortia. These factors

collectively improve root development, nutrient uptake and photosynthetic efficiency, leading to better vegetative growth and head formation. The improved growth performance may be attributed to balanced nutrient supply, reduced pest incidence and enhanced microbial activity, leading to better nutrient uptake and photosynthetic efficiency. These results are in similar line with the findings of Adesemoye *et al.*, (2017) ^[1].

3.2 Effect of Treatments on Yield Attributes and Yield

Yield and its contributing characters showed significant variation among treatments (Table 1). The highest head weight (1417.61 g) and yield (8060.47 kg acre⁻¹) were recorded in Treatment 2 (IC + IPM + INM +BC), followed by Treatment 3 (IC + IPM + INM +BC + Lime) with head weight of 1207.89 g and yield of 7621.68 kg acre⁻¹. In contrast, the control treatment recorded the lowest head weight (666.22 g) and yield (5473.64 kg acre⁻¹). The significant positive relationship observed between average fruit weight and fruit yield is also supported by previous studies, which indicated that fruit weight is one of the most important yield-determining components in cabbage (Rani *et al.*, 2008) ^[11]. Similarly, Shilpa *et al.*, (2024) ^[13] revealed that the positive association between number of fruits per plant and yield has been widely reported, suggesting that higher fruit set directly contributes to increased yield. The substantial increase in yield under Treatment 2 (approximately 47% higher than the control) clearly demonstrates the effectiveness of integrated crop management practices. The improved yield can be attributed to enhanced nutrient availability, better pest control and increased physiological efficiency of plants, resulting in larger and heavier cabbage heads. Although the addition of lime in Treatment 3 improved yield compared to the control, it did not significantly outperform Treatment 2. This suggests that the soil conditions may not have been strongly acidic, or that the combined effect of INM and biological inputs had already optimized nutrient availability, thereby reducing the marginal benefit of liming.

Table 1: Comparative analysis of basic statistics (Mean, SE Mean, and SD) for growth and yield parameters of cabbage under varied treatment modules.

Treatment	Statistic	Plant height (cm)	Number of leaves plant ⁻¹	Head length (cm)	Head Diameter (cm)	Head Weight (g)	Yield per acre (in Kg)
F V +FP	Mean	20.12	24.17	34.83	20.48	666.22	5473.64
	SD	2.12	5.66	7.51	3.34	179.92	735.86
	SE(Mean)	0.50	1.33	1.77	0.79	42.41	173.44
	CV	0.11	0.23	0.22	0.16	0.27	0.13
IC + IPM + INM +BC	Mean	28.01	33.06	48.86	31.22	1417.61	8060.47
	SD	2.68	3.46	4.87	9.24	130.98	902.54
	SE(Mean)	0.63	0.81	1.15	2.18	30.87	212.73
	CV	0.10	0.10	0.10	0.30	0.09	0.11
IC + IPM + INM +BC + Lime	Mean	23.89	27.22	41.22	26.34	1207.89	7621.68
	SD	2.82	4.47	3.78	7.48	160.46	895.68
	SE(Mean)	0.66	1.05	0.89	1.76	37.82	211.11
	CV	0.12	0.16	0.09	0.28	0.13	0.12
Average	Mean	24.01	28.15	41.63	26.01	1097.24	7051.93
	SD	4.11	5.86	7.99	8.28	355.32	1412.09
	SE(Mean)	0.56	0.80	1.09	1.13	48.35	192.16
	CV	0.17	0.21	0.19	0.32	0.32	0.20

3.3 Post-hoc (Tukey’s) Test

To further examine the differences among treatment means, a post-hoc comparison was performed using Tukey’s Honest Significant Difference (HSD) test at a 5% level of significance (Table 2). This test allows pairwise comparison of treatments to identify which specific treatments differ significantly from each

other after obtaining a significant result in ANOVA. The results of Tukey’s test revealed that Treatment 2 (Improved Cultivar + IPM + INM + Biological Consortia) produced a significantly higher yield compared to Treatment 1 (Farmer Variety + Farmer Practices), with a mean difference of 2586.83 kg acre⁻¹ and a 95% confidence interval ranging from 1904.32 to 3269.34 kg

acre⁻¹. This clearly indicates that the adoption of integrated management practices leads to a substantial and statistically significant improvement in cabbage yield over conventional farmer practices.

Similarly, Treatment 3 (Improved Cultivar + IPM + INM + Biological Consortia + Lime) also showed a significant increase in yield compared to the control (Treatment 1), with a mean difference of 2148.04 kg acre⁻¹. This confirms that the inclusion of integrated nutrient and pest management practices, along with biological inputs and soil amendment, enhances crop productivity significantly over traditional methods.

However, the comparison between Treatment 2 and Treatment 3 revealed no statistically significant difference in yield. This suggests that although lime application contributed to yield improvement compared to the control, its additional effect over the integrated management practices alone was not significant under the prevailing experimental conditions. This could be attributed to the possibility that soil pH and nutrient availability were already optimized through integrated nutrient management and biological consortia, thereby limiting the incremental benefit of lime application.

Overall, the post-hoc analysis confirms that both integrated management treatments (T₂ and T₃) are significantly superior to the conventional farmer practice (T₁), while performing comparably with each other. These findings reinforce the effectiveness of integrated crop management strategies in enhancing cabbage productivity and provide strong evidence for their recommendation in sustainable vegetable production systems.

Table 2: Tukey Test for pairwise comparison of treatment effects on cabbage yield

Yield	Contrast	Std. err.	Tukey [95% conf. interval]	
Treatment				
2 vs 1	2586.831	282.7325	1904.321	3269.342
3 vs 1	2148.039	282.7325	1465.529	2830.55
3 vs 2	-438.7922	282.7325	-1121.303	243.7183

3.5 ANOVA Results

The analysis of variance indicated a highly significant effect of treatments on cabbage yield ($F_{2,46} = 74.85$, $p < 0.001$), confirming that the differences observed among treatments were statistically robust (Table 3). The significant effect of year ($F_{1,46} = 31.51$, $p < 0.001$) suggests that environmental factors such as temperature, rainfall, and seasonal variability also played a crucial role in influencing crop performance.

Table 3: ANOVA of treatment, year and their interaction effects on growth and yields of cabbage

Number of obs = 54 Root MSE = 678.857 R-squared = 0.7994 Adj R-squared = 0.7689					
Source	Partial SS	df	MS	F	Prob>F
Model	84482296	7	12068899	26.19	0.0000
Treatment	68989839	2	34494920	74.85	0.0000
Year	14523013	1	14523013	31.51	0.0000
Treatment#Year	291788.81	2	145894.41	0.32	0.7302
Block	677654.52	2	338827.26	0.74	0.4849
Residual	21198930	46	460846.3		
Total	1.057e+08	53	1993985.4		

However, the non-significant treatment × year interaction ($F_{2,46} = 0.32$, $p = 0.73$) indicates that the relative performance of treatments remained consistent across different years. This

stability highlights the reliability and adaptability of integrated management practices under varying environmental conditions. Additionally, the non-significant block effect suggests that the experimental field was relatively homogeneous, ensuring minimal spatial variability. The high coefficient of determination ($R^2 = 0.799$) indicates that nearly 80% of the variation in yield was explained by the model, demonstrating the effectiveness of the experimental design and treatment structure.

3.6 Multivariate Analysis of Variance (MANOVA) Results

Multivariate analysis of variance (MANOVA) was employed to evaluate the combined effect of treatments on multiple dependent variables simultaneously (Table 4), providing a comprehensive understanding of plant response beyond individual traits. The results indicated a highly significant effect of treatments on the combined set of growth and yield parameters, as evidenced by a Wilks' λ value of 0.0193 ($p < 0.001$).

The low value of Wilks' lambda suggests that a large proportion of variation in the dataset is explained by treatment effects, confirming that integrated management practices significantly influenced overall plant performance. Unlike univariate ANOVA, which analyzes each variable separately, MANOVA considers the interdependence among variables, making it more robust in detecting treatment differences across multiple traits. The effect of year was also found to be significant (Wilks' $\lambda = 0.4189$, $p < 0.001$), indicating that environmental factors such as seasonal variability influenced crop growth and yield. However, despite this variability, the overall model remained highly significant (Wilks' $\lambda = 0.0103$, $p < 0.001$), demonstrating that treatment effects were strong and consistent.

Further interpretation of MANOVA results, supported by subsequent univariate ANOVA, confirmed that yield and associated growth traits were significantly affected by the treatments. The absence of a significant treatment × year interaction in univariate analysis suggests that the integrated management practices performed consistently across different years. The substantial influence of yield-related traits such as average fruit weight and number of fruits per plant further reinforced the multivariate significance. These results are consistent with Hair *et al.* (2010) [4], who highlighted the effectiveness of MANOVA in identifying treatment effects across correlated variables.

Table 4: MANOVA showing the effect of treatments on multiple dependent variables

		W = Wilks' lambda P = Pillai's trace		L = Lawley-Hotelling trace R = Roy's largest root		
Source	Statistic	df	F(df1,	df2) =	F	Prob>F
Model	W 0.0232	3	18.0	127.8	19.74	0.0000 a
	P 1.5529		18.0	141.0	8.41	0.0000 a
	L 19.9978		18.0	131.0	48.51	0.0000 a
	R 18.9907		6.0	47.0	148.76	0.0000 u
Residual	50					
Treatment	W 0.0383	2	12.0	90.0	30.80	0.0000 e
	P 1.2064		12.0	92.0	11.65	0.0000 a
	L 18.6983		12.0	88.0	68.56	0.0000 a
	R 18.3505		6.0	46.0	140.69	0.0000 u
Year	W 0.4349	1	6.0	45.0	9.75	0.0000 e
	P 0.5651		6.0	45.0	9.75	0.0000 e
	L 1.2995		6.0	45.0	9.75	0.0000 e
	R 1.2995		6.0	45.0	9.75	0.0000 e
Residual	50					
Total	53					

e = exact. a = approximate. u = upper bound on F

e = exact, a = approximate, u = upper bound on F

Overall, MANOVA results reinforce the conclusion that integrated approaches influence not just individual parameters but the entire growth-yield system of the crop, thereby validating their effectiveness in improving cabbage productivity.

3.7 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was carried out to reduce the dimensionality of the dataset and to identify the major traits contributing to variability and yield (Figure 1). The analysis revealed that the first two principal components (PC1 and PC2) explained a substantial proportion of the total variation in the data.

The first principal component (PC1) was strongly associated with plant height, head weight, head length, and yield, and can be interpreted as a productivity or vigor axis. Traits with high positive loadings on PC1 indicate that they contribute significantly to overall plant performance and yield. The strong association of yield with PC1 suggests that these traits are the primary drivers of productivity in cabbage.

The second principal component (PC2) was mainly influenced by number of leaves per plant and growth-related characteristics, representing a vegetative growth axis. This component reflects the balance between vegetative growth and reproductive development. Interestingly, head diameter showed a negative association with PC2, indicating a possible trade-off between leaf production and head expansion. The PCA results clearly demonstrate that yield is more closely aligned with PC1 traits, particularly head weight and head length, rather than solely with vegetative traits. This indicates that while vegetative growth is important, efficient partitioning of assimilates towards head development is crucial for achieving higher yields.

Furthermore, PCA provides a simplified representation of complex relationships among variables, making it easier to identify key traits for selection and management. The findings suggest that improving traits associated with PC1 can significantly enhance cabbage productivity, and these traits should be given priority in future research and crop improvement programs. The findings are in line with those reported by Jolliffe (2002)^[7], who highlighted the usefulness of PCA in identifying key variables within multivariate datasets. Similar conclusions were drawn by Yan and Kang (2002)^[16], who demonstrated that PCA-based biplots are effective tools for visualizing treatment performance and relationships among traits in crop studies.

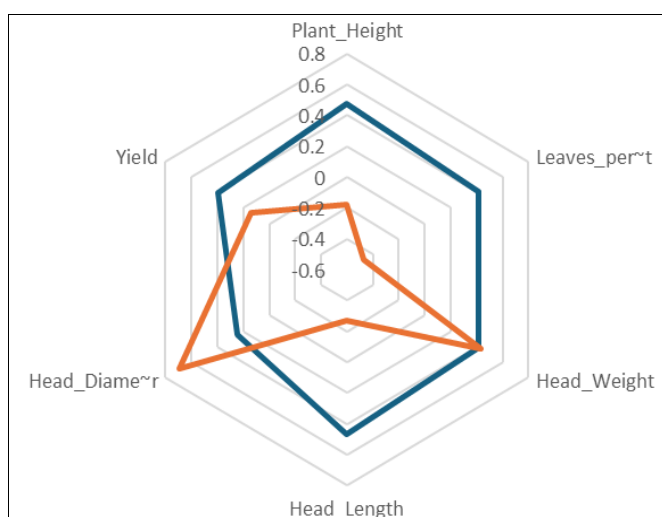


Fig 1: Principal Component Analysis Showing Trait Loadings and Variance in Cabbage

The analysis revealed that the first principal component (PC1) accounted for the major proportion of total variability and was strongly associated with plant height, plant spread area, head length, head weight and yield. This component can be interpreted as the “productivity or vigor axis”, as it represents traits directly contributing to biomass accumulation and economic yield. The strong loading of yield on PC1 indicates that improvements in these traits directly enhance cabbage productivity.

The second principal component (PC2) was mainly influenced by number of leaves per plant and days to flower initiation. This component represents a “growth versus maturity axis”, where higher leaf number and delayed flowering contribute positively, while traits like head development show an inverse relationship. This suggests a physiological balance between vegetative growth and reproductive development.

The PCA clearly indicated that yield is more strongly associated with PC1 traits, particularly head weight, head length and plant spread area. This implies that these parameters are the key determinants of yield and should be the primary focus for improving cabbage productivity. Additionally, PCA helps in visualizing the relationship among traits and treatments, showing that integrated treatments (Treatment 2 and Treatment 3) are closely associated with high PC1 values, reflecting superior performance in terms of growth and yield. The findings are in line with those reported by Jolliffe (2002)^[7], who highlighted the usefulness of PCA in identifying key variables within multivariate datasets. Similar conclusions were drawn by Yan and Kang (2002)^[16], who demonstrated that PCA-based biplots are effective tools for visualizing treatment performance and relationships among traits in crop studies.

4. Conclusion

The present study clearly demonstrates that integrated crop management practices significantly enhance the growth and yield of cabbage compared to conventional farmer practices. The superior performance of the treatment combining improved cultivars with integrated nutrient management (INM), integrated pest management (IPM), and biological consortia highlights the synergistic effects of these components in improving plant growth, head development, and overall productivity. Although the addition of lime showed some improvement over the control, it did not result in a statistically significant advantage over integrated management alone, indicating that its benefits are likely dependent on specific soil conditions, particularly soil acidity.

Statistical analyses, including ANOVA, MANOVA, and principal component analysis, confirmed that treatment effects were highly significant and consistent across years. Strong positive correlations among growth and yield traits especially head weight, head length, and plant vigor underscore the importance of these parameters as key drivers of productivity. The findings further reveal that integrated management practices positively influence the entire plant system rather than isolated traits.

Overall, the results strongly support the adoption of integrated crop management as a sustainable and effective strategy for enhancing cabbage productivity. Such approaches not only improve yield but also contribute to maintaining soil health and environmental sustainability, making them highly suitable for long-term agricultural advancement and farmer adoption.

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