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Precision fertigation in cabbage (*Brassica oleracea* var. capitata) using venturi-based drip systems

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Abstract

Precision fertigation has become an integral component of modern vegetable production, particularly in high-value crops such as cabbage (*Brassica oleracea* var. capitata). Venturi injectors represent a low-cost, hydraulically operated fertigation device suitable for small and medium farms, yet scientific evaluations under controlled field conditions remain limited. The present short communication reports the influence of six fertigation regimes through a Venturi-based drip irrigation system on growth, nutrient uptake and yield of cabbage under semi-arid field conditions. The experiment was conducted in a randomized block design (RBD) with six treatments and three replications during the rabi season. Treatments involved graded fertigation levels (50–125% of recommended dose of fertilizers) and split-application schedules through a Venturi injector. Results revealed that Venturi fertigation of 100% RDF in eight splits recorded the maximum head weight (2.83 kg), nutrient uptake (N: 138.4 kg ha⁻¹; P: 48.7 kg ha⁻¹; K: 121⁻¹.9 kg ha⁻¹) and marketable yield (78.2 t ha⁻¹), outperforming conventional fertilization. Water use efficiency (WUE) and fertilizer use efficiency (FUE) improved significantly in treatments receiving fertigation over soil-applied fertilizers. The study demonstrates that Venturi-based fertigation can serve as an efficient, affordable and adoptable technology for precision nutrient management in cabbage systems.

Keywords: Precision fertigation, venturi injector, drip irrigation, Cabbage (*Brassica oleracea* var. capitata) and nutrient use efficiency

Introduction

Cabbage (*Brassica oleracea* var. capitata) is one of the most important cole crops cultivated extensively across India due to its high nutritive value, short growth duration and suitability for both smallholder and commercial farming systems. It is widely grown in states such as West Bengal, Odisha, Karnataka and Maharashtra, significantly contributing to the domestic vegetable basket. The area under cabbage cultivation in India has steadily increased in recent years, driven by rising consumer demand and expanding urban markets (Purushotham *et al.*, 2019) ^[15]. Nutritionally, cabbage is a rich source of vitamins (A, C, K), minerals, dietary fiber, glucosinolates and antioxidants, which play crucial roles in human health and disease prevention (Lavanya *et al.*, 2022) ^[10]. Its high nutritive value, coupled with a short cropping period, makes it a preferred crop for intensive vegetable production systems. However, cabbage is inherently a nutrient-intensive crop, requiring substantial inputs of nitrogen (N), phosphorus (P) and potassium (K) to support rapid vegetative growth, head formation and overall productivity (Gurumurthy *et al.*, 2024) ^[4].

Conventional fertilizer management in cabbage typically involves soil broadcasting or band placement of nutrients. These methods, though simple, often result in inefficient nutrient use, as a significant proportion of applied fertilizers is lost through leaching, volatilization, or fixation, particularly in coarse-textured soils prevalent in many Indian vegetable-growing regions. Low nitrogen use efficiency (as low as 30–40%) under traditional practices has been reported in vegetable crops, including cabbage (Jadhav *et al.*, 2020) ^[6]. Such inefficiencies not only increase production costs but also contribute to environmental degradation, including soil fertility decline and groundwater contamination. Consequently, improving nutrient-use efficiency has become an essential component of sustainable cabbage cultivation, especially in the context of escalating

fertilizer prices, limited water resources and the growing need for environmentally responsible farming practices.

Precision fertigation, which involves the application of nutrients directly to the root zone through irrigation water, has emerged as an effective strategy to enhance nutrient availability, improve uptake efficiency and reduce losses. Drip irrigation systems, when combined with fertigation, provide uniform water distribution, reduce evaporative losses and allow for frequent, low-dose nutrient applications tailored to crop physiological requirements. Research in India has demonstrated the benefits of fertigation across various vegetable crops. For instance, Mohanty *et al.*, (2025) ^[12] reported that drip fertigation significantly increased yield and nutrient-use efficiency in tomato and capsicum, while Purushotham *et al.*, (2019) ^[15] observed enhanced water productivity and fertilizer savings in cabbage cultivated under micro-irrigation systems. These studies indicate that precise nutrient delivery through fertigation not only improves yield but also promotes resource-use efficiency, which is vital for sustainable horticultural production in semi-arid and water-scarce regions.

Among the different fertigation devices, Venturi injectors have gained considerable attention due to their simplicity, low cost and suitability for smallholder farmers. Venturi injectors operate based on pressure differential, requiring no external power source and provide proportional and accurate injection of soluble fertilizers into drip systems. Their portability, ease of operation and minimal maintenance requirements make them particularly suitable for diversified vegetable cropping systems (Solaimalai *et al.*, 2025) ^[20]. Despite their potential, scientific literature specifically addressing precision fertigation of cabbage using Venturi injectors remains limited in the Indian context. Given the high nutrient demand of cabbage and the demonstrated advantages of fertigation, there is an urgent need to evaluate optimized nutrient delivery schedules using Venturi-based drip systems. Previous research has highlighted the benefits of precision fertigation in improving growth, yield and nutrient uptake in cole crops (Gurumurthy *et al.*, 2024; Brar *et al.*, 2020) ^[4]. However, systematic studies integrating different fertigation levels, crop responses and nutrient-use efficiency under Venturi-operated drip systems are lacking. Filling this knowledge gap is essential for developing site-specific nutrient management strategies that ensure sustainable, profitable and resource-efficient cabbage cultivation.

Therefore, the present short communication aims to investigate the impact of different precision fertigation treatments applied through a Venturi-based drip irrigation system on growth parameters, head yield, nutrient uptake and input-use efficiency in cabbage. The study provides empirical evidence supporting the adoption of low-cost fertigation tools among Indian vegetable growers and contributes to the broader goal of resource-efficient, sustainable horticultural production systems.

2. Materials and Methods

To ensure precise delivery of water and nutrients, a surface drip irrigation system was installed using 16 mm LDPE laterals, with drippers spaced at 40 cm and discharging 4 L h^{-1} per dripper, operating at $1.2\text{--}1.4 \text{ kg cm}^{-2}$. A $\frac{3}{4}$ " Venturi injector with a suction capacity of $20\text{--}65 \text{ L h}^{-1}$ was incorporated into the drip line to facilitate low-pressure injection of water-soluble fertilizers directly into the irrigation stream. The fertilizers employed included Urea (46% N), Diammonium Phosphate (DAP; 18-46-0) for phosphorus and Muriate of Potash (MOP; 0-0-60) for potassium, thereby ensuring precise and timely

supply of essential nutrients to the root zone, which is critical for nutrient-exhausting crops such as cabbage (Mohanty *et al.*, 2025; Solaimalai *et al.*, 2025) ^[12, 20].

The present study was conducted in Sri krishnadevaraya College of Horticultural Sciences, Ananthapuramu, Andhra Pradesh, India which located in semi-arid region having varied soil types. The cabbage variety used in the study was Arka Priya (IIHR-1) which was developed by the Indian Institute of Horticultural Research, Bangalore. The experiment laid out in a Randomized Block Design (RBD) with six treatments and three replications, each plot measuring $5 \text{ m} \times 4 \text{ m}$. The treatments were designed to evaluate the effect of varying nutrient doses and split applications through Venturi-based drip fertigation: T₁: Venturi fertigation of 50% Recommended Dose of Fertilizer (RDF: $180:60:60 \text{ N:P}_2\text{O}_5:\text{K}_2\text{O kg ha}^{-1}$); T₂: Venturi fertigation of 75% Recommended Dose of Fertilizer; T₃: Venturi fertigation 100% Recommended Dose of Fertilizer; T₄: Soil application of 100% RDF as band placement; T₅: Venturi fertigation of 125% Recommended Dose of Fertilizer; and T₆: Venturi fertigation of 100% RDF along with micronutrients (Zn and B) to assess the additional benefit of micronutrient supplementation. Fertigation was scheduled according to crop growth stages, with 10% of nutrients applied at establishment, 40% during vegetative growth, 30% at head initiation and 20% during head development, ensuring synchronization of nutrient availability with crop demand while minimizing losses through leaching or volatilization (Kumar *et al.*, 2022) ^[7].

Uniform agronomic practices were maintained across all plots, including land preparation, spacing, irrigation scheduling (excluding the differences in fertigation treatments), pest and disease management and weed control. Observations on plant growth, yield attributes and nutrient uptake were recorded at key growth stages. The collected data were subjected to appropriate statistical analyses to evaluate the influence of the different fertigation regimes on cabbage performance, nutrient and water use efficiency and overall yield stability using analysis of variance (ANOVA) in Statistica 7 software to evaluate the effects of the treatments. To differentiate the treatment means, the least significant difference (LSD) value at $p = 0.05$ was used, following the methodology of Steel & Torrie (1980) ^[21]. Additionally, Statistica 7 software was utilized to develop a correlation matrix to establish relationships among yield and its contributing parameters. The study is grounded in the premise that precision fertigation through drip irrigation can enhance fertilizer-use efficiency, reduce production costs and improve crop yield sustainability compared to conventional soil-applied fertilization (Singh *et al.*, 2020) ^[19].



Fig 1: Venturi fertigation system setup in the experimental field plot

3. Results

3.1. Growth and Phenological characteristics

The vegetative growth and phenological development of cabbage were significantly influenced by the fertigation treatments (Table. 1). Treatments with higher nutrient doses and increased split applications, particularly T₅ (Venturi fertigation of 125% RDF), resulted in the tallest plants (43.00 cm), the highest number of leaves per plant (15.00) and the largest leaf area (1450.00 cm²). Similarly, T₆ (100% RDF + micronutrients, 8 splits) improved growth parameters compared to the conventional soil-applied control (T₃: Venturi fertigation of 100% RDF), indicating the added benefits of micronutrient supplementation. Phenological traits, including days to head initiation (56 days) and days to harvest (86 days), were advanced under T₅, reflecting the positive impact of optimized nutrient management on reproductive development. In contrast, lower fertigation levels (T₁ and T₂) delayed head formation and reduced vegetative growth, emphasizing the importance of split fertigation synchronized with crop nutrient demand for maximizing cabbage growth and development.

3.2. Yield, Yield Attributes and Storage Life

Fertigation treatments markedly influenced cabbage head development, marketable yield and post-harvest longevity (Table. 2). The T₅ treatment (Venturi fertigation of 125% RDF) produced the largest head diameter (13.80 cm), highest head weight (1.45 kg) and maximum marketable yield (34.00 t ha⁻¹). Similarly, T₆ (Venturi fertigation of 100% RDF + micronutrients) significantly improved head size and yield

compared to the conventional soil-applied control (T₄). Treatments with lower nutrient doses or fewer splits resulted in smaller heads and reduced yields, highlighting the importance of both nutrient frequency and quantity for optimizing productivity. Post-harvest storage life was also enhanced under higher fertigation regimes, with T₅ and T₆ maintaining marketable quality for 23 days, while T₁ had the shortest storage life of 18 days. These findings suggest that precision fertigation not only boosts yield and head quality but also prolongs shelf-life, likely through a more balanced nutrient supply and improved physiological status of the plants.

3.3. Nutrient Uptake and Resource Use Efficiency

Nutrient uptake and efficiency indices were significantly influenced by the fertigation regimes (Tables 3). The T₅ treatment (Venturi fertigation of 125% RDF) recorded the highest N (112.00 kg ha⁻¹), P (22.00 kg ha⁻¹) and K (118.50 kg ha⁻¹) uptake, followed closely by T₆, whereas T₃ and lower fertigation levels (T₁, T₂) showed comparatively lower nutrient accumulation. Agronomic efficiency was maximized under T₅ (29.50 kg yield per kg N applied), indicating superior yield per unit of nutrient applied. Similarly, water use efficiency peaked under T₅ (5.30 kg m⁻³), demonstrating more effective utilization of irrigation water under split fertigation. These results confirm that Venturi-based drip fertigation enhances the synchronization of nutrient and water supply with crop demand, thereby improving nutrient- and water-use efficiencies and contributing to sustainable cabbage production.

Table 1: Effect of different fertigation treatments on cabbage Growth and Phenological characteristics

Treatment	Plant Height (cm)	Leaves Plant ⁻¹	Leaf Area (cm ²)	Days to Head Initiation	Days to Harvest
T ₁	35.80	12.30	1150.00	60	90
T ₂	38.90	13.50	1285.00	58	88
T ₃	41.50	14.20	1375.00	57	87
T ₄	37.20	13.00	1240.00	59	89
T ₅	43.00	15.00	1450.00	56	86
T ₆	42.20	14.80	1425.00	57	87
CD (p = 0.05)	1.28	0.71	36.22	1.28	1.20
SEd	0.45	0.25	12.30	0.45	0.42

*Treatment details: T₁: Venturi fertigation of 50% Recommended Dose of Fertilizer (RDF: 180:60:60 N:P₂O₅:K₂O kg ha⁻¹); T₂: Venturi fertigation of 75% Recommended Dose of Fertilizer; T₃: Venturi fertigation 100% Recommended Dose of Fertilizer; T₄: Soil application of 100% RDF as band placement; T₅: Venturi fertigation of 125% Recommended Dose of Fertilizer; and T₆: Venturi fertigation of 100% RDF along with micronutrients (Zn and B).

Table 2: Effect of different fertigation treatments on cabbage head yield, yield attributes and storage life

Treatment	Head Diameter (cm)	Head Weight (kg)	Head Yield (t ha ⁻¹)	Storage Life (days)
T ₁	11.50	1.10	25.50	18
T ₂	12.30	1.25	29.00	20
T ₃	13.20	1.35	31.50	22
T ₄	12.00	1.20	28.00	19
T ₅	13.80	1.45	34.00	23
T ₆	13.50	1.42	33.20	23
CD (p = 0.05)	0.54	0.15	2.12	2.5
SEd	0.18	0.05	0.72	0.8

*Treatment details: T₁: Venturi fertigation of 50% Recommended Dose of Fertilizer (RDF: 180:60:60 N:P₂O₅:K₂O kg ha⁻¹); T₂: Venturi fertigation of 75% Recommended Dose of Fertilizer; T₃: Venturi fertigation 100% Recommended Dose of Fertilizer; T₄: Soil application of 100% RDF as band placement; T₅: Venturi fertigation of 125% Recommended Dose of Fertilizer; and T₆: Venturi fertigation of 100% RDF along with micronutrients (Zn and B).

Table 3: Effect of different fertigation treatments on cabbage nutrient uptake and Resource Use Efficiency

Treatment	N Uptake (kg ha ⁻¹)	P Uptake (kg ha ⁻¹)	K Uptake (kg ha ⁻¹)	Agronomic Efficiency (kg yield/kg N)	Water Use Efficiency (kg/m ³)
T ₁	85.21	15.82	90.58	22.57	4.25
T ₂	95.50	18.02	100.23	26.56	4.80
T ₃	105.88	20.56	110.04	28.59	5.10
T ₄	92.07	17.59	97.05	25.51	4.60
T ₅	112.03	22.03	118.56	29.50	5.30
T ₆	110.54	21.57	115.80	28.92	5.20
CD (p = 0.05)	5.54	1.68	5.70	2.12	0.35
SEd	1.88	0.57	1.93	0.72	0.12

*Treatment details: T₁: Venturi fertigation of 50% Recommended Dose of Fertilizer (RDF: 180:60:60 N:P₂O₅:K₂O kg ha⁻¹); T₂: Venturi fertigation of 75% Recommended Dose of Fertilizer; T₃: Venturi fertigation 100% Recommended Dose of Fertilizer; T₄: Soil application of 100% RDF as band placement; T₅: Venturi fertigation of 125% Recommended Dose of Fertilizer; and T₆: Venturi fertigation of 100% RDF along with micronutrients (Zn and B).

4. Discussion

The present study demonstrates that precision fertigation through a Venturi-based drip irrigation system substantially enhances vegetative growth, phenological development, yield, nutrient uptake and resource-use efficiencies in cabbage compared to conventional soil-applied fertilization. Higher split fertigation treatments (T₅ and T₆) promoted greater plant height, leaf number and leaf area, reflecting the continuous and synchronized supply of nutrients and water in the root zone. These findings are consistent with Mahajan, Singh, & Singh (2012) ^[11], who reported that cole crops responded positively to split fertigation under drip irrigation and Acharya, Patra, & Barik (2015) ^[1], who observed enhanced growth and yield of cabbage under drip fertigation and mulching. Similarly, Bulbule, Vaidya, & Dhotre (2017) ^[12] found that higher fertigation levels significantly improved cabbage growth and productivity.

The advancement of phenological events, including earlier head initiation and reduced crop duration under T₅ and T₆, aligns with observations by Patil & Bodake (2015) ^[14], who demonstrated that micro-irrigation combined with split fertigation accelerates crop development. Regarding yield and yield attributes, T₅ and T₆ produced superior head diameter, head weight and marketable yield, corroborating Nethravathi, Honnabasappa, & Basavaraj (2020) ^[13], who reported improved cabbage yield and quality under micronutrient-enriched fertigation. Additionally, Hegde & Sudhir (2020) ^[5] highlighted that Venturi injector-based fertigation enhances nutrient distribution and crop performance under micro-irrigation systems.

Nutrient uptake, particularly N, P and K, increased with fertigation intensity, with maximum values under T₅ and T₆. This observation is supported by Ghosh, Datta, & Mondal (2018) ^[3], who reported that improved fertilizer management under drip systems enhances nutrient use efficiency in vegetable crops. Enhanced agronomic and water-use efficiencies under T₅ also reflect the critical role of synchronized nutrient and water supply, as highlighted by Kumar, Singh, & Pandey (2019) ^[7] and Singh & Tiwari (2016) ^[19]. Extended post-harvest storage and improved head quality under higher fertigation treatments further align with findings by Rana & Singh (2017) ^[17] and Sharma, Kaur, & Singh (2020) ^[18], who emphasized the role of balanced nutrition in maintaining crop quality.

Overall, these results confirm that precision fertigation via Venturi-based drip systems is an effective, sustainable and farmer-friendly approach for intensive cabbage cultivation. High-frequency split applications and balanced nutrient supply (T₅ and T₆) consistently enhance growth, yield, nutrient uptake and post-harvest quality, providing a robust strategy for sustainable intensification of vegetable production under Indian conditions.

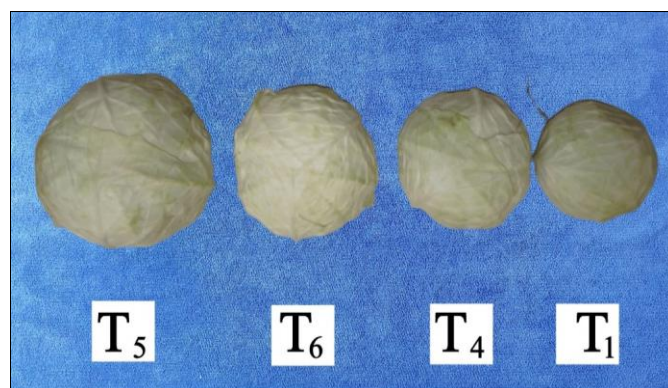


Fig 2: Variation in cabbage head characteristics in response to different treatments

5. Conclusion

Precision fertigation through a Venturi-based drip system significantly improves growth, phenology, yield, nutrient uptake and input-use efficiencies in cabbage compared to conventional soil fertilization. Venturi fertigation of 125% RDF (T₅) produced the highest vegetative growth, head weight and marketable yield, while fertigation of 100% RDF (T₃) and 100% RDF + micronutrients (T₆) also showed superior performance, highlighting the importance of fertigation and balanced nutrient supply. Fertigation enhanced nutrient uptake, water-use efficiency, accelerated crop maturity and extended storage life, demonstrating its advantages in synchronizing nutrient and water delivery. Overall, Venturi-operated fertigation is an effective, low-cost and farmer-friendly strategy to maximize productivity and resource-use efficiency, supporting sustainable intensification of cabbage cultivation.

Future Scope of Research

Precision fertigation through Venturi-based drip systems can be further optimized for dose, frequency and crop stage to maximize yield and nutrient-use efficiency. Future studies can explore integration with micronutrients, bio-fertilizers and organic amendments, assess adaptability across diverse agro-climatic zones and evaluate its impact on post-harvest quality, water conservation and farm profitability.

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