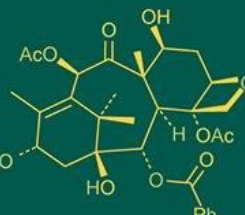
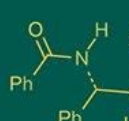


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Optimization of drone-based foliar application of VSI liquid fertilizers for enhanced growth and yield of sugarcane

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Abstract

Sugarcane (*Saccharum officinarum* L.) productivity depends on efficient nutrient management throughout its long growth period. Soil-applied fertilizers alone are often insufficient due to nutrient losses, making foliar nutrition an effective supplement. A field experiment was conducted during the suru season of 2023-24 at Lonarwadi Farm to evaluate manual and drone-based foliar application of VSI liquid fertilizers and to optimize their dose and schedule in sugarcane (var. Co 86032). The experiment was laid out in a randomized block design with eight treatments and three replications. Foliar sprays of Vasanturja, VSI Plant Health, macronutrients, and micronutrients were applied at 60, 75, and 90 days after planting through manual and drone spraying at different spray volumes. Results showed that drone spraying at 1.0 m height using 45 L ha⁻¹ produced cane yield (143.2 t ha⁻¹) and CCS yield (20.79 t ha⁻¹) comparable to conventional manual spraying. Growth parameters were significantly improved, while juice quality remained unaffected. Drone-based foliar nutrition also recorded a high benefit-cost ratio (2.62), indicating its economic feasibility. Optimized drone-based foliar fertilization proved to be an efficient and sustainable approach for sugarcane production.

Keywords: Sugarcane, foliar nutrition, drone spraying, liquid fertilizers, cane yield

Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the most important commercial crops in India, contributing significantly to agricultural income, rural employment, and the sugar-based industry. Achieving high cane productivity and juice quality requires efficient nutrient management throughout the long duration of the crop. Conventional soil-applied fertilizers alone are often insufficient to meet the crop's dynamic nutrient demand, especially under conditions of nutrient fixation, leaching losses, and uneven field application (Andrade, J.J.d. *et al.*, 2024) ^[1]. In this context, foliar application of liquid fertilizers has emerged as an effective strategy to supplement soil nutrition, enhance nutrient use efficiency, and improve crop performance, as foliar sprays can rapidly supply nutrients directly to leaves and improve physiological functions (Roohi. *et al.*, 2021) ^[10].

The Vasantdada Sugar Institute (VSI) has developed a range of liquid nutrient formulations such as Vasanturja, VSI Multinutrient, and VSI Plant Health liquid fertilizer, which are designed to supply macro- and micronutrients along with growth-promoting substances. These inputs have shown promising results in improving vegetative growth, stress tolerance, and yield attributes of sugarcane when applied through conventional manual spraying. However, manual spraying is often constrained by labour scarcity, non-uniform spray coverage, operator fatigue, and inconsistent droplet deposition, especially in tall and dense sugarcane canopies.

Recent advancements in precision agriculture, particularly the use of unmanned aerial vehicles (UAVs) or drones, offer new opportunities for improving the efficiency and precision of foliar nutrient application. Drone-based spraying enables uniform coverage, controlled droplet size, optimal droplet density, and targeted application, while significantly reducing labor requirements and operational time also reduce the amount of fertilizer used in agricultural field and also increase crop yield. (Gayathri Devi. K. *et al.*, 2020) ^[7]. Moreover, drone technology allows for timely interventions during critical growth stages, which is essential for maximizing nutrient uptake and crop response (emerging precision agronomy

research). Despite the growing adoption of drone technology in crop protection and nutrient management, systematic research on its use for foliar application of liquid fertilizers in sugarcane — particularly for optimizing doses and spray schedules of VSI inputs remains limited. Comparative information on spray characteristics such as coverage, droplet density, and droplet size between manual and drone-based application methods is also scarce. Furthermore, the agronomic response of sugarcane to drone-applied VSI inputs in terms of growth, yield, juice quality, and economic returns under field conditions needs thorough evaluation. Nutrients applied through foliage are reported to be absorbed 8-20 times more efficiently than soil application, resulting in improved physiological activity, cane growth and sugar accumulation. (Arun Kumar, R., and Singh, S. (2021) ^[2].

Therefore, the present investigation was undertaken to optimize the dose and application schedule of VSI liquid fertilizers for sugarcane using drone technology, to compare spray efficiency between manual and drone spraying, and to assess their effects on crop performance and economic feasibility. The findings of this study are expected to contribute to the development of a scientifically validated, cost-effective, and precision-based foliar nutrition strategy for sustainable sugarcane production.

Materials and Methods

A field experiment was conducted during the suru season at Lonarwadi Farm to evaluate manual and drone-based application of VSI liquid inputs in sugarcane. The experiment was initiated in 2023-24 using sugarcane variety Co 86032. The study was laid out in a Randomized Block Design (RBD) with eight treatments and three replications.

The treatments comprised foliar application of Vasanturja, VSI Plant Health, VSI Multimicro, and VSI Multimacro through manual spraying and drone spraying at different spray volumes and drone heights (1.0 and 1.5 m above crop canopy). An absolute control and a water spray treatment were included for comparison. Three foliar sprays were applied at 60, 75, and 90 days after planting (DAP). Manual spraying was carried out using conventional knapsack sprayers with 500-750 L ha⁻¹ spray volume, while drone spraying was performed using 20 or 45 L ha⁻¹ of water with calibrated nozzles and uniform flight parameters.

Spray efficiency was assessed by measuring spray coverage, droplet density, and droplet size using water-sensitive papers placed at different canopy levels. The field observations of biometric, growth and yield parameters were taken at different stages of the crop and at harvest. Sugarcane juice quality for brix and pol percentage was analyzed by using ICUMSA methods. The field and laboratory analysis data was statistically analyzed by methods of Gomez and Gomez (1984).

Cane yield and commercial cane sugar (CCS) yield

Cane yield and commercial cane sugar (CCS) yield were significantly affected by foliar application of VSI liquid inputs applied through manual and drone-based spraying (Table 1). The highest cane yield (145.0 t ha⁻¹) and CCS yield (20.83 t ha⁻¹) were recorded in T₃, which involved hand spraying of Vasanturja and Plant Health at 60 DAP, followed by Vasanturja combined with macronutrients at 75 DAP and micronutrients at 90 DAP using 500 L water ha⁻¹. However, T₃ was statistically at par with T₆, where drone

spraying at 1.0 m height using 45 L ha⁻¹ spray volume resulted in cane and CCS yields of 143.2 t ha⁻¹ and 20.78 t ha⁻¹, respectively. This clearly indicates that drone-based application with substantially reduced spray volume can achieve yields comparable to conventional high-volume manual spraying. Similarly, T₂ (manual spray with combined macro-and micronutrients) and T₇ (drone spray at 1.5 m height with 45 L ha⁻¹) also produced comparable cane yields (142.6 and 139.3 t ha⁻¹) and CCS yields (20.36 and 20.25 t ha⁻¹, respectively).

Drone application with a very low spray volume of 20 L ha⁻¹ (T₄ and T₅) resulted in relatively lower cane and CCS yields, although these treatments remained significantly superior to the control. The reduced performance under ultra-low spray volume may be attributed to inadequate droplet deposition and limited canopy penetration in the tall sugarcane crop, leading to reduced nutrient absorption efficiency.

The enhanced cane and CCS yields observed under optimized foliar nutrient schedules can be attributed to improved physiological efficiency, enhanced photosynthate translocation, and balanced supply of macro-and micronutrients during critical growth stages (Orlando Filho 1993; Singh *et al.* 2018) ^[9, 11]. Similar improvements in sugarcane productivity due to foliar nutrition and precision application technologies have also been reported earlier (Gopalasundaram *et al.* 2012; Kumar *et al.* 2021) ^[3, 2]. The present study demonstrates that optimized drone-based foliar fertilization is a viable and efficient alternative to conventional manual spraying in sugarcane.

Growth Observation

The application of split foliar nutrients significantly influenced sugarcane growth, including millable cane number, height, internodes, and girth. Among the treatments, T₃ consistently recorded the highest growth parameters. Specifically, hand-sprayed T₃, which received Vasanturja @ 2.5 L ha⁻¹ + Plant Health @ 2.5 L ha⁻¹ at 60 DAP, followed by Vasanturja @ 2.5 L ha⁻¹ + macronutrient @ 7.5 L ha⁻¹ at 75 DAP and Vasanturja @ 2.5 L ha⁻¹ + micronutrient @ 7.5 L ha⁻¹ at 90 DAP, recorded 97.9 thousand millable canes ha⁻¹, a cane height of 257.1 cm, 23.2 internodes, and 10.2 cm girth. This was statistically at par with T₂, which received slightly lower nutrient concentrations at 75 DAP, resulting in 95.1 thousand millable canes ha⁻¹, cane height of 254.0 cm, 22.9 internodes, and 10.1 cm girth. Drone-based foliar treatments also produced comparable results, with T₆ recording 94.3 thousand millable canes ha⁻¹, 252.8 cm height, 22.7 internodes, and 10.0 cm girth, T₄ achieving 92.9 thousand canes ha⁻¹, 248.3 cm height, 22.1 internodes, and 9.9 cm girth, T₇ showing 92.1 thousand canes ha⁻¹, 247.2 cm height, 22.2 internodes, and 9.8 cm girth, and T₅ with 90.3 thousand canes ha⁻¹, 243.2 cm height, 21.9 internodes, and 9.7 cm girth.

The enhanced growth under T₃ and similar treatments can be attributed to the timely and balanced foliar supply of macro-and micronutrients, which is critical during key growth phases such as tillering, elongation, and internode formation. Foliar application improves nutrient uptake efficiency, photosynthetic performance, and nitrogen assimilation, while regulating plant hormones such as cytokinins and gibberellins, leading to greater tiller survival, internode elongation, and stem thickening. Furthermore,

drone-based foliar applications ensured uniform canopy coverage and effective nutrient deposition, even at lower spray volumes, maintaining physiological efficiency comparable to hand spraying. The combination of optimized nutrient timing and delivery method promoted assimilate partitioning toward the stalk, resulting in increased millable cane numbers, height, internodes, and girth, confirming the benefits of split foliar nutrient management in sugarcane (Andrade, J.J.d. *et al.*, 2024; Henderson *et al.*, 2025) ^[1, 4].

Juice Quality

The application of VSI input fertilizers through drone did not significantly affect juice quality parameters of sugarcane. Measurements of Brix, Pol, Purity, and Commercial Cane Sugar (CCS) percentage remained statistically similar across all treatments, indicating that foliar nutrient sprays, whether applied by hand or drone, did not alter the inherent sugar content or quality of the cane

juice.

Economic evaluation

In terms of economic returns, the highest benefit-cost (B:C) ratio was observed in T₃ (2.66), which received foliar application of Vasanturja @ 2.5 L ha⁻¹ + Plant Health @ 2.5 L ha⁻¹ in 500 L water at 60 DAP, followed by Vasanturja @ 2.5 L ha⁻¹ + macronutrient @ 7.5 L ha⁻¹ at 75 DAP and Vasanturja @ 2.5 L ha⁻¹ + micronutrient @ 7.5 L ha⁻¹ at 90 DAP through hand spraying. This was statistically comparable to T₆, which involved drone-based foliar application at 1.0 m height using 45 L ha⁻¹ water, resulting in a B:C ratio of 2.62. These results indicate that optimized split foliar nutrient applications, whether applied manually or via drone, can enhance crop profitability without compromising juice quality, highlighting the economic feasibility of precision foliar nutrition in sugarcane production.

Table 1: Effect of Drone-Based Application of VSI Liquid Fertilizers on Cane Yield, CCS Yield, and Number of Millable Canes in Sugarcane

Treatments	Cane Yield (t ha ⁻¹)	CCS yield (t ha ⁻¹)	No. of millable Cane ('000'ha ⁻¹)
T ₁ -Absolute control	122.6	17.80	79.4
T ₂ -hand Spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient garde II @ 7.5 lit/ha each in 750 lit water at 90 DAP	142.6	20.36	95.1
T ₃ -hand spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient garde II @ 7.5 lit/ha each in 750 lit water at 90 DAP	145.0	20.83	97.9
T ₄ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha in 20 lit water at 60 DAP Oligochitosan and Multimacronutrient @ 2.5 lit/ha in 20 lit water at 75 DAP Oligochitosan and micronutrient grade II @ 2.5 lit/ha 20 lit water at 90 DAP	138.2	20.23	92.9
T ₅ -drone spray at 1.5 m Height + T ₄	130.8	19.21	90.3
T ₆ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	143.2	20.78	94.3
T ₇ -dorne spray at 1.5 m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	139.3	20.25	92.1
T ₈ -water spray	127.8	18.01	86.5
S.E. ±	3.74	0.62	3.31
CD at 5%	11.37	1.89	10.04

Table 2: Effect of Drone-Based Application of VSI Liquid Fertilizers on Growth observation and economic evaluation

Treatments	Millable cane Height (cm)	Internode	Cane Girth (cm)	B: C ratio
T ₁ -Absolute control	226.0	18.7	9.0	2.40
T ₂ -hand Spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 7.5 lit/ha each in 750 lit water at 90 DAP	254.0	22.9	10.1	2.61
T ₃ -hand spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 7.5 lit/ha each in 750 lit water at 90 DAP	257.1	23.2	10.2	2.66
T ₄ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha in 20 lit water at 60 DAP Oligochitosan and Multimacronutrient @ 2.5 lit/ha in 20 lit water at 75 DAP Oligochitosan and micronutrient grade II @ 2.5 lit/ha 20 lit water at 90 DAP	248.3	22.1	9.9	2.59
T ₅ -drone spray at 1.5 m Height + T ₄	243.2	21.9	9.7	2.45
T ₆ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	252.8	22.7	10.0	2.62
T ₇ -drone spray at 1.5 m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	247.2	22.2	9.8	2.54
T ₈ -water spray	229.1	19.9	9.3	2.48
S.E. ±	5.96	0.50	0.19	
CD at 5%	18.10	1.54	0.57	

Table 3: Effect of Drone-Based Application of VSI Liquid Fertilizers on Juice Quality

Treatments	Brix (%)	Pol (%)	Purity (%)	CCS (%)
T ₁ -Absolute control	20.6	18.9	91.9	14.5
T ₂ -hand Spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75 DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 7.5 lit/ha each in 750 lit water at 90 DAP	20.0	18.7	94.1	14.2
T ₃ -hand spray Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 500 lit water at 60 DAP Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 5 lit/ha in 500 lit water at 75 DAP and Oligochitosan @ 2.5 lit/ha + macronutrient & micronutrient grade II @ 7.5 lit/ha each in 750 lit water at 90 DAP	20.3	18.8	92.9	14.4
T ₄ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha in 20 lit water at 60 DAP Oligochitosan and Multimacronutrient @ 2.5 lit/ha in 20 lit water at 75 DAP Oligochitosan and micronutrient grade II @ 2.5 lit/ha 20 lit water at 90 DAP	20.8	19.1	92.0	14.7
T ₅ -drone spray at 1.5 m Height + T ₄	20.6	19.3	93.5	14.7
T ₆ -drone spray at 1m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	20.0	18.4	91.8	14.5
T ₇ -drone spray at 1.5 m Height Oligochitosan and Consortia of endophytes @ 2.5 lit/ha each in 45 lit water at 60 DAP Oligochitosan and multimacronutrient @ 2.5 lit/ha each in 45 lit water at 75 DAP Oligochitosan @ 2.5 lit/ha and micronutrient grade II @ 2.5 lit/ha each in 45 lit water at 90 DAP	20.7	19.2	93.3	14.7
T ₈ -water spray	20.7	19.5	94.3	14.1
S.E. ±	0.27	0.26	0.99	0.22
CD at 5%	NS	NS	NS	NS

Conclusion

The results revealed that foliar application of Vasanturja @ 2.5 L ha⁻¹ + Plant Health @ 2.5 L ha⁻¹ in 45 L water at 60 days after planting (DAP), followed by Vasanturja @ 2.5 L ha⁻¹ + macronutrient @ 2.5 L ha⁻¹ in 45 L water at

75 DAP and Vasanturja @ 2.5 L ha⁻¹ + micronutrient @ 2.5 L ha⁻¹ in 45 L water at 90 DAP using drone spray at 1 m height, was highly beneficial for sugarcane production. This treatment resulted in the highest cane yield (143.2 t ha⁻¹), CCS yield (20.79 t ha⁻¹), millable cane number

(94.3 thousand ha⁻¹), and a high benefit-cost ratio (2.62), demonstrating that drone-based split foliar nutrient management can effectively enhance both productivity and profitability in sugarcane.

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