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Integrative effects of nano and conventional fertilizers on performance and economics of onion (*Allium cepa* L.)

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Abstract
Onion productivity is often remains below the attainable levels inspite of its wide adaptability and high yield potential, largely due to inefficient nutrient management practices. Onion has a shallow and sparsely distributed root system, which limits its ability to absorb nutrients efficiently from the soil applied fertilizers, making it highly responsive to foliar application of nutrients. But only foliar application of nutrients will not able to meet the nutrients requirement of the crop. The integration of nano-fertilizers with conventional fertilizers offer a potential strategy to reduce conventional fertilizer inputs without compromising crop yield and quality. With this hypothesis, a field experiment was conducted during *Rabi* season of 2024-25 to evaluate the integrative effects of nano and conventional fertilizers on growth, yield, quality and economics of onion (*Allium cepa* L.) at Bengaluru conditions. Integrated application of 100% RDF with three foliar sprays of nano-fertilizers had recorded the highest plant height at 90 DAT (55.99 cm), maximum dry matter accumulation in onion bulb (11.27 g $bulb^{-1}$) and superior yield attributes, resulting in the highest bulb yield of 32.43 t ha^{-1}. This treatment also produced bigger bulbs with higher equatorial diameter (6.54 cm), more number of rings (12.1) and maximum average bulb weight (83.75 g). Besides, quality traits were markedly improved, with the highest total soluble solids (13.95 °Brix) under integrated nutrition. However, maximum ascorbic acid (76.00 mg $100g^{-1}$) and antioxidant activity (229.70 mg $100g^{-1}$) were observed in onion bulbs grown under only foliar application of nano-fertilizers and 100% RDF, respectively. Economically, integrated nutrient management recorded higher gross and net returns, whereas foliar application of nano-fertilizers alone had achieved the highest benefit-cost ratio due to lower input costs. The study demonstrates that combining foliar application of nano-fertilizers with soil application of conventional fertilizers is an efficient and economically viable strategy for enhancing growth, yield and quality of onion under Eastern Dry Zone conditions of Karnataka.

Keywords: Nano-fertilizers, conventional fertilizers, onion, growth, yield, quality, economics nano-fertilizers, conventional fertilizers, onion, growth, yield, quality, economics

1. Introduction
Onion (*Allium cepa* L.) is one of the most important and widely cultivated vegetable crops across temperate and tropical regions of the world, particularly in Asia, Europe and Africa. It belongs to the family *Alliaceae* with a diploid chromosome number of 2n = 16. Onion occupies a prominent place in human diet owing to its distinctive pungency, flavour and wide culinary applications and is often referred to as the "Queen of the Kitchen". In addition to its culinary importance, onion bulbs are nutritionally rich, containing appreciable amounts of carbohydrates, vitamins such as vitamin C and vitamin B_6 as well as minerals including calcium, potassium, phosphorus and iron (Nalegaonkar *et al.*, 2020) [1]. Onion is also known for its medicinal properties, particularly antioxidants, antimicrobial and cardioprotective effects attributed by sulphur-containing compounds and flavonoids. India is the second largest producer of onion in the world after China and contributes substantially to global onion production. The crop is grown throughout the year under diverse agro-climatic conditions, covering a significant area and playing a vital role in food security as well as export earnings (Tirlapur *et al.*, 2017) [2]. Despite its wide adaptability and high yield potential, onion productivity often remains below attainable levels, largely due to inefficient nutrient management practices.
Onion has a shallow and sparsely distributed root system, which limits its ability to absorb

nutrients efficiently from the soil applied fertilizers, making it highly responsive to foliar application of nutrients. The nutrient use efficiency of conventional nitrogenous fertilizers is generally low. It has been reported that only about 30-40 per cent of applied nitrogen is utilized by crops, while the remaining portion is lost through runoff, leaching, volatilization and denitrification. Same is the case in case of phosphatic and potassic fertilizers and their use efficiencies are hardly 15 - 20 and 50 - 60 per cent, respectively. To compensate for low nutrients use efficiencies of conventional fertilizers, farmers often apply higher doses of fertilizers, leading to increased production costs and adverse environmental impacts. Therefore, improving the nutrients use efficiencies of conventional fertilizers while reducing their losses has become a major challenge in sustainable onion production. In recent years, nano-fertilizers have emerged as a promising supplement to conventional fertilizers for improving their nutrients use efficiencies.

Nano-fertilizers are characterized by particle sizes of less than 100 nm and possess a much higher surface area to volume ratio compared to conventional fertilizers. These properties enable better interaction with plant surfaces and facilitate efficient nutrient delivery (Ahmed *et al*., 2025) [3]. Foliar-applied nano-fertilizers can enter plant tissues through stomatal openings and nano-pores, leading to improved nutrient uptake and translocation within the plant system which further stimulate the plants to uptake nutrients from soil. The integration of nano-fertilizers with conventional fertilizers offer a potential strategy to reduce fertilizer inputs without compromising crop yield and quality (Gopinath *et al*., 2025) [4]. Such integrated nutrient management approaches are expected to enhance crop performance and economic returns with minimal environmental implications. However, scientific information on the combined use of nano and conventional fertilizers in onion under field conditions, especially in the Eastern Dry Zone of Karnataka, is limited. Hence, the present study was undertaken to evaluate the integrative effects of nano and conventional fertilizers on growth, yield, quality and economics of onion cultivation.

2. Materials and Methods

The present field investigation was conducted during the *Rabi* season of 2024-25 at College of Horticulture, Bengaluru, located in the Eastern Dry Zone of Karnataka. The experiment was carried out to assess the integrative effects of nano and conventional fertilizers on growth, yield, quality and economics of onion. The experiment was conducted in red sandy loam soil at an altitude of 924 m above mean sea level, located at 13°08′ N latitude and 77°56′ E longitude. The experiment was laid out in a Randomized Complete Block Design comprising thirteen treatments and two replications. Onion variety 'Arka Kalyan' was used as the test crop. A forty days old seedlings were transplanted at a spacing of 15 cm × 10 cm, and all the recommended agronomic practices were uniformly followed across treatments. The treatments included different combinations of farmyard manure (FYM), 100 or 75 per cent recommended dose of fertilizers (RDF) and foliar application of nano-fertilizers at different growth stages (Table 1). Nano-fertilizers such as nano-urea (20% N @ 2 ml l^{-1} water), Nano-DAP (8% N + 16% P @ 2 ml l^{-1} water) and nano-K (20% K @ 1.5 ml l^{-1} water) each at the rate of 1250 ml ha^{-1} were applied as foliar sprays at specified intervals as per treatment schedule, while recommended dose of FYM (30 t ha^{-1}) and RDF (125:75:125 kg $N:P_2O_5:K_2O$ ha^{-1}) were applied to soil through conventional fertilizers as per treatment schedule.

Growth parameters were recorded using five randomly selected and tagged plants from each treatment and replication. Plant height was measured at 30, 60 and 90 days after transplanting (DAT) using a measuring scale from the base of the plant to tip of the longest leaf and expressed in centimeter while, the number of leaves per plant was recorded at 90 DAT. At crop maturity, the onion bulbs from five tagged plants in each treatment were harvested separately and oven-dried at 65-70 °C to a constant weight and average dry matter of onion bulb was calculated and expressed in grams. Bulb neck thickness was measured at harvest using a vernier caliper and expressed in centimeter. Yield attributes such as average polar and equatorial diameters of bulb, number of rings per bulb and average bulb weight were recorded from representative bulb samples. The polar and equatorial diameters of bulbs were measured using a vernier caliper to determine bulb size and shape. The number of rings per bulb was recorded by cutting representative bulbs horizontally and counting the concentric scales. The average bulb weight was calculated by weighing bulbs harvested from tagged plants and expressing the mean value in grams. The total bulb yield per plot was recorded by weighing the bulbs harvested from the net plot area and subsequently converted to yield per hectare (t ha^{-1}). The harvested bulbs from each treatment were weighed separately and stored for sixty days. The bulbs decayed or sprouted during sixty days of storage were discarded and only weight of the healthy bulbs were recorded. The marketable bulb recovery percentage was calculated by dividing the weight of healthy bulbs obtained at 60 days of storage by the initial weight of the bulbs stored and expressed in percentage by multifying with 100. Quality attributes of onion bulbs were analyzed using standard physical and biochemical methods. Bulb shape index was calculated as the ratio of polar to equatorial diameter and bulb firmness was measured using a texture analyzer to assess physical quality. Total soluble solids (TSS) was determined from fresh bulb juice using a hand refractometer and expressed as °Brix (Ranganna, 1986) [5]. Bulb pungency was assessed by estimating pyruvic acid content colorimetrically at 420 nm wavelength using 2,4-dinitrophenylhydrazine (DNPH) method (Ketter and Randle, 1998) [6]. Total flavonoid content in methanolic bulb extract was determined colorimetrically at 510 nm wavelength using aluminium chloride (Chun *et al*., 2004) [7]. Ascorbic acid content was estimated by extracting bulb tissue with 4 per cent oxalic acid and titrating against 2,6-dichlorophenol indophenol dye, as described by Ranganna (1986) [5]. Total antioxidant activity was estimated using the FRAP (Ferric Reducing Antioxidant Power) assay, which is based on the reduction of Fe^{3+} to Fe^{2+} by antioxidant compounds, and absorbance was measured at 593 nm following the method of Benzie and Strain (1996) [8].

The total cost of cultivation was estimated by accounting for all expenditures incurred from land preparation to crop harvest, including the cost of inputs, field operations, supervision and pre-farm to marketing expenses and expressed as rupees per hectare. Gross returns were calculated by multiplying the marketable yield obtained per hectare with the prevailing market price of the produce at harvest. Net returns were worked out by subtracting the total cost of cultivation from the gross returns. The benefit–cost (B:C) ratio for each treatment was computed as the ratio of net returns to the cost of cultivation. The experimental data were subjected to statistical analysis using analysis of variance (ANOVA) following Fisher's method and treatment effects were interpreted according to the procedures described by Sundararaj *et al.* (1972) [9].

Table 1: Treatment details

Treatments	Details
T_1	Absolute control
T_2	100% Recommended FYM only (30 t ha^{-1})
T_3	100% RDF (30 t FYM ha^{-1} + 125:75:125 kg N:P_2O_5:K_2O ha^{-1})
T_4	100% FYM + One spray of nano-fertilizers at 2 weeks after transplanting
T_5	100% FYM + Two sprays of nano-fertilizers at 2 and 4 weeks after transplanting
T_6	100% FYM + Three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting
T_7	100% RDF + One spray of nano-fertilizers at 2 weeks after transplanting
T_8	100% RDF + Two sprays of nano-fertilizers at 2 and 4 weeks after transplanting
T_9	100% RDF + Three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting
T_{10}	75% RDF + One spray of nano-fertilizers at 2 weeks after transplanting
T_{11}	75% RDF + Two sprays of nano-fertilizers at 2 and 4 weeks after transplanting
T_{12}	75% RDF + Three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting
T_{13}	Only foliar application of nano-fertilizers at 2, 4 and 6 weeks after transplanting

3. Results and Discussion

3.1 Growth parameters of onion crop

From the experimental results, it was observed the progressively increased plant height of onion with advancement of crop growth stages (Table 2). At 30 and 60 DAT, treatment T_3 (100% RDF) was recorded significantly taller plants with heights of 23.71 and 52.24 cm, respectively, which may be attributed to rapid and sustained nitrogen availability promoting cell division and internodal elongation during early and active growth phases. However, at 90 DAT, the maximum plant height of 55.99 cm was observed in treatment T_9 (100% RDF supplemented with three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting), highlighting the advantage of integrated soil and foliar nutrition in maintaining continuous nutrients supply by sustaining photosynthetic activity during later stages of crop growth. The enhanced vegetative growth under these treatments is in agreement with earlier findings of Sharmin and Rahman (2019) [10], Navya *et al*. (2022) [11], Sharma *et al*. (2022) [12] and Subramani *et al*. (2023) [13].

Significantly highest number of leaves per plant at 90 days after transplanting (Table 2) was recorded in treatment T_3 which received 100% RDF (10.5 leaves $plant^{-1}$), which may be attributed to balanced nutrients availability, particularly nitrogen, that might have enhanced the chlorophyll synthesis, leaf initiation and expansion (Sharmin and Rahman, 2019) [14]. Whereas, the maximum average dry matter accumulation in onion bulb (11.27 g $bulb^{-1}$) was recorded in treatment T_9 (100% RDF supplemented with three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting), this improvement may be attributed to enhanced nutrients availability, higher photosynthetic efficiency and efficient assimilate partitioning towards bulb development under integrated soil and foliar nutrition (Singh *et al.*, 2018) [15]. Significantly maximum bulb neck thickness of 1.74 cm was recorded in treatment T_3 (100% RDF), which may be attributed to balanced and adequate availability of primary nutrients that promoted vigorous vegetative growth and enhanced assimilate translocation to the neck region (Singh *et al*., 2017 and Meena *et al*., 2019) [16, 17].

Table 2: Growth parameters of onion at different crop growth stages as influenced different by levels of nano and conventional fertilizers

Treatments	Plant height (cm)			No. of leaves per plant at 90 DAT	Average bulb dry matter (g)	Bulb neck thickness (cm)
	30 DAT	60 DAT	90 DAT			
T_1	17.10	32.95	35.18	7.4	4.61	1.04
T_2	17.31	35.33	38.24	7.7	7.35	1.15
T_3	23.71	52.24	53.20	10.5	10.13	1.74
T_4	17.77	38.93	40.58	6.0	8.13	0.74
T_5	15.91	35.43	42.17	7.6	10.10	0.83
T_6	19.39	36.99	48.99	9.5	10.71	1.26
T_7	21.63	41.36	43.04	8.7	10.29	0.86
T_8	22.01	43.07	48.44	9.7	11.08	1.28
T_9	22.48	41.51	55.99	8.4	11.27	1.58
T_{10}	16.90	33.69	36.15	7.4	9.60	0.93
T_{11}	18.78	38.39	42.44	7.2	10.18	1.10
T_{12}	16.96	27.79	43.66	7.5	10.39	1.49
T_{13}	13.71	35.39	47.33	8.0	5.42	0.95
S. Em ±	0.59	1.10	1.63	0.50	0.41	0.06
CD @ 5%	1.82	3.38	5.02	1.54	1.27	0.18

3.2 Yield parameters of onion crop

The significantly highest equatorial diameter (6.54 cm), number of rings per bulb (12.10), average bulb weight (83.75 g) and total bulb yield (32.43 t ha^{-1}) were recorded in treatment T_9, which received 100% RDF + three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting (Table 3). Whereas, significantly highest polar diameter of 5.95 cm was recorded in onion bulbs grown under treatment T_8 (100% RDF + two sprays of nano-fertilizers at 2 and 4 weeks after transplanting). The highest marketable bulb yield recovery of 82.19 per cent was recorded due to treatment T_4 (100% FYM + one spray of nano-fertilizers at 2 weeks after transplanting). The superior yield and bulb size (Plate 1) under these treatments may be attributed to balanced and continuous nutrients availability through combined soil and foliar nutrition, which might have enhanced the photosynthetic efficiency, assimilate production and effective translocation of photosynthates towards bulb development, resulting in improved bulb growth and yield (Subramanian *et al*., 2015 and Souri *et al*., 2017) [18, 19].

Table 3: Yield attributes and yield of onion as influenced by different levels of nano and conventional fertilizers application

Treatments	Polar diameter of bulb (cm)	Equatorial diameter of bulb (cm)	No. of rings per bulb	Average bulb weight (g)	Total bulb yield		Marketable bulb yield (%)
					(kg plot^{-1})	(t ha^{-1})	
T_1	3.86	3.88	8.30	29.50	8.06	13.43	72.28
T_2	4.65	4.20	9.90	46.25	13.23	22.05	76.10
T_3	5.10	5.70	10.50	74.25	18.18	30.30	73.17
T_4	4.26	3.58	8.50	38.00	14.24	23.73	82.19
T_5	4.89	5.27	9.30	48.75	14.58	24.30	81.07
T_6	5.15	4.97	9.30	61.50	15.89	26.49	66.69
T_7	4.69	4.93	10.00	47.50	16.10	26.83	80.71
T_8	5.95	6.12	11.10	80.50	17.53	29.22	77.49
T_9	5.72	6.54	12.10	83.75	19.46	32.43	69.84
T_{10}	4.78	4.66	9.30	53.50	13.40	22.34	75.39
T_{11}	4.96	5.49	8.80	63.25	15.59	25.98	70.56
T_{12}	5.25	5.48	10.30	58.75	16.93	28.20	67.10
T_{13}	4.56	4.39	8.80	36.00	14.68	24.46	79.88
S. Em ±	0.20	0.25	0.26	4.54	0.93	1.55	2.41
CD @ 5%	0.61	0.77	0.80	14.00	2.86	4.77	7.43

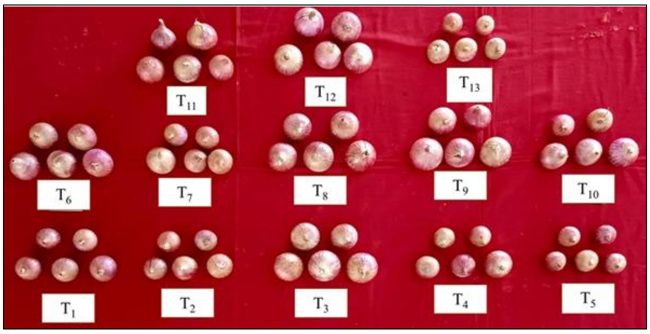

Plate 1: Effect of different levels of nano and conventional fertilizers on onion bulb size

3.3 Quality parameters of onion crop

Quality attributes of onion bulbs varied significantly among treatments (Table 4). The highest bulb shape index of 1.20 was recorded due to treatment T_4 (100% FYM supplemented with single spray of nano-fertilizers at 2 weeks after transplanting), which may be attributed to gradual and balanced nutrients release from FYM that might have favoured the uniform radial and longitudinal bulb development. The maximum bulb firmness was observed in treatment T_{13} (Only foliar application of nano-fertilizers at 2, 4 and 6 weeks after transplanting), possibly due to restricted vegetative growth and reduced bulb succulence caused by the absence of basal soil fertilization, resulting in compact bulbs with denser tissue structure. The highest total soluble solids content of 13.95 °Brix was recorded in onion bulb grown under treatment T_9 (100% RDF + three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting), indicating enhanced sugar accumulation under integrated nutrient management. In contrast, the maximum pyruvic acid content of 9.46 µmoles g^{-1}, reflecting higher pungency, was observed in onion bulbs grown under treatment T_{12} (75% RDF + three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting), while the highest flavonoid content of 129.62 mg 100g^{-1} was recorded in onion bulbs grown under treatment T_8 (100% RDF + two sprays of nano-fertilizers at 2 and 4 weeks after transplanting). Improvement in these quality traits under nano-fertilizers and RDF-based treatments may be attributed to enhanced photosynthetic efficiency, better nutrients assimilation and increased metabolic activity, which might have favoured the synthesis of sugars, organic acids, phenolics and antioxidant compounds. The maximum ascorbic acid content of 76.00 mg 100g^{-1} was recorded in onion bulbs grown with only foliar application of nano-fertilizers at 2, 4 and 6 weeks after transplanting (T_{13}), which may be associated with mild nutrients stress induced by the absence of basal soil fertilization. Such stress conditions are known to stimulate ascorbic acid synthesis as a protective response against oxidative stress, while direct foliar absorption of nano-primary nutrients might have further enhanced the uptake of micronutrients from soil which are involved in ascorbic acid biosynthesis. The highest total antioxidant activity of 229.70 mg 100g^{-1} was observed in onion bulbs grown under treatment T_3 (100% RDF), possibly due to moderate and gradual nutrients availability during later growth stages, which can induce mild physiological stress and redirect assimilates towards the synthesis of antioxidant metabolites (Ketter and Randle, 1998 and Sharma *et al.*, 2018) [6, 20].

Table 4: Quality parameters of onion as influenced by different levels of nano and conventional fertilizers application

Treatments	Bulb shape index	Firmness of bulb (kg cm^{-2})	TSS (^{0}Brix)	Pyruvic acid (µmoles g^{-1})	Flavonoids (mg 100g^{-1})	Ascorbic acid (mg 100g^{-1})	Total anti-oxidants (mg 100g^{-1})
T_1	1.00	6.07	12.53	6.52	126.01	37.33	123.97
T_2	1.11	5.70	12.90	3.81	128.97	44.00	137.26
T_3	0.89	5.56	13.65	4.51	116.61	50.67	229.70
T_4	1.20	5.25	12.78	8.97	118.12	46.67	121.37
T_5	0.93	6.63	13.13	4.79	128.09	52.00	151.54
T_6	1.04	5.89	13.53	2.75	128.89	60.00	152.18
T_7	0.95	7.55	13.00	6.94	128.44	65.33	125.26
T_8	0.97	6.42	13.37	7.44	129.62	56.00	203.76
T_9	0.87	7.19	13.95	6.94	128.92	70.67	128.51
T_{10}	1.03	6.78	12.95	5.32	121.63	62.67	182.67
T_{11}	0.90	6.38	12.91	5.89	116.65	46.67	227.10
T_{12}	0.96	6.66	13.85	9.46	116.73	65.33	145.70
T_{13}	1.04	9.24	13.19	7.77	116.28	76.00	162.24
S. Em ±	0.04	0.19	0.16	0.08	1.03	2.82	2.65
CD @ 5%	0.12	0.55	0.49	0.25	3.02	8.24	7.73

3.4 Economics of onion cultivation

The maximum gross returns (₹. 6,48,600 ha^{-1}) and net returns (₹. 4,60,279.5 ha^{-1}) were realized from treatment T_9, which received 100% RDF + three sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting. The increased profitability under treatment T_9 may be attributed to effective integration of soil and foliar nutrition, which ensured optimum nutrients availability during critical growth stages, resulting in enhanced productivity and economic returns (Table 5). However, the highest benefit-cost ratio of 3.57 was obtained due to treatment T_{13} (Only foliar application of nano-fertilizers at 2, 4 and 6 weeks after transplanting), which may be due to substantially lower cost of cultivation coupled with reasonable yield performance by utilizing the native soil nutrients, thereby improving economic efficiency per unit investment (Attri *et al*., 2022 and Kannoj *et al*., 2022) [21, 22].

Table 5: Economics of onion cultivation as influenced by different levels of nano and conventional fertilizers application

Treatments	Cost of cultivation (Rs. ha^{-1})			Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B: C ratio
	Common cost	Treatment cost	Total cost			
T_1	92,105	-	92,105.0	2,68,600	1,76,495.0	1.92
T_2	94,710	75,000.00	1,69,710.0	4,41,000	2,71,290.0	1.60
T_3	94,710	81,198.00	1,75,908.0	6,06,000	4,30,092.0	2.44
T_4	94,710	79,137.50	1,73,847.5	4,74,600	3,00,752.5	1.73
T_5	94,710	83,275.00	1,77,985.0	4,86,000	3,08,015.0	1.73
T_6	94,710	87,412.50	1,82,122.5	5,29,800	3,47,677.5	1.91
T_7	94,710	85,335.50	1,80,045.5	5,36,600	3,56,554.5	1.98
T_8	94,710	89,473.00	1,84,183.0	5,84,400	4,00,217.0	2.17
T_9	94,710	93,610.50	1,88,320.5	6,48,600	4,60,279.5	2.44
T_{10}	94,710	64,992.50	1,59,702.5	4,46,800	2,87,097.5	1.80
T_{11}	94,710	69,130.00	1,63,840.0	5,19,600	3,55,760.0	2.17
T_{12}	94,710	73,267.50	1,67,977.5	5,64,200	3,96,222.5	2.36
T_{13}	94,710	12,412.50	1,07,122.5	4,89,200	3,82,077.5	3.57

4. Conclusion

On the basis of the results emerged from the present field experiment, it can be conclusively stated that integrated application of conventional fertilizers to soil and foliar sprays of nano-fertilizers at different crop growth stages had a pronounced and significant influence on growth, yield and quality parameters. Among the various nutrient management practices evaluated, the treatment involving soil application of 100% RDF + three foliar sprays of nano-fertilizers at 2, 4 and 6 weeks after transplanting (T_9) was found agronomically superior. This treatment consistently recorded higher plant height at later growth stages, maximum dry matter accumulation, superior bulb size, higher average bulb weight and the highest total bulb yield per hectare. Whereas, the highest benefit-cost ratio (3.57) was obtained in treatment T_{13} (Only foliar application of nano-fertilizers at 2, 4 and 6 weeks after transplanting), indicating superior economic efficiency due to lower cost of cultivation. However, in long run once native nutrients have been exhausted, its efficiency should be tested.

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