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Integrated nutrient management in strawberry (*Fragaria × ananassa*) under semi-arid region of Haryana

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Abstract

The study was carried out at the Crop Research Centre, Kaliwas Farm, SGT University, Gurugram (Haryana) to evaluate the influence of different combinations of inorganic fertilizers, Azotobacter, phosphate- solubilizing bacteria, and humic acid on growth, physiology, flowering, fruit quality, and yield of strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn, during winter season of 2023–24. Eight treatment combinations, including control, RDF alone, and various biofertilizer and humic acid integrations, were evaluated under a randomized block design with three replications. The integrated nutrient treatments significantly enhanced plant height, number of leaves, leaf area, and plant spread. The chlorophyll content improved remarkably, indicating enhanced photosynthetic efficiency. The number of runners, days to first flowering, fruit setting percentage, and fruit/ plant, showed notable improvement with the application of biofertilizers and humic acid. Fruit physical characteristics (length, width weight, and volume) also improved progressively with enhanced nutrient combinations. The highest fruit yield per plant (575.50 g) and per hectare (12.11 t/ha) were obtained under T_8 (RDF 100% + Azotobacter + PSB + 2% humic acid), establishing it as the most effective INM treatment. The overall findings suggest that integrated nutrient management that combines chemical fertilizers with biological and organic sources enhances strawberry growth, productivity, and quality, and contributes to sustainable soil health.

Key words: Integrated nutrient management, Azotobacter, Humic acid, Growth, Yield, Winter Dawn

Strawberry (*Fragaria × ananassa* Duch.) belonging to family Rosaceae, 56 chromosomes (2n = 8x = 56) is rich in nutritional profile and health-promoting compounds (Singh *et al.*,2021).Its productivity is highly sensitive to climatic conditions, mineral nutrition, cultivar type, irrigation regime, and cultural practices (Nestby *et al.,* 2004). Due to its rapid growth and shallow root system, its crop requires continuous and balanced nutrient supply (Li *et al.,* 2010). Suboptimal nutrition not only limits yield but also compromises fruit texture, flavour, and shelf life. Therefore, nutrient management plays a central role in improving strawberry production efficiency and maintaining soil fertility. The Integrated Nutrient Management (INM), including the combined use of inorganic fertilizers, organic amendments, and microbial inoculants, has emerged as a promising strategy for sustainable strawberry cultivation. Biofertilizers, consisting of beneficial microorganisms, enhance soil nutrient availability and contribute to improved plant growth. Their use also reduces dependency on chemical fertilizers, lowers production costs, and minimizes environmental pollution (Beer *et al.,* 2017). Azotobacter colonizes rhizosphere of fruit crops and improves nitrogen availability, thereby enhancing metabolic processes and overall plant vigour (Verma and Rao, 2013). Similarly, phosphate solubilizing bacteria (PSB) play an essential role in converting the otherwise unavailable insoluble phosphate—constituting nearly 95–99% of total soil phosphorus—into plant-available forms through the secretion of organic acids and enzymes such as phytase (Gupta *et al.,* 1994). The humic acid enhances vegetative growth, nutrient mobility, and fruit yield, often showing synergistic effects when combined with biofertilizers (Martinez-Dela Crruz, 2022). The, combining chemical fertilizers with bioorganic sources improves nutrient availability while reducing nutrient losses, enhancing soil fertility, and sustaining long-term productivity (Macit *et al.,* 2007). Hence, an experiment was conducted to evaluate integrated nutrient management on strawberry in semi- arid Haryana.

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MATERIALS AND METHODS

A field experiment was conducted at Kaliwas Farm of SGT University, Gurugram, Haryana, during winter season of 2023–24. The experimental field is geographically located at 28.48° N latitude and 76.89° E longitude, at an altitude of 217 meters above mean sea-level. The site falls under North-Western agroclimatic zone, characterized by a semi-arid climate, hot dry summers, and cool winters, with sandy loam soils predominating in the region. The experiment was laid out in a randomized block design along with Azotobacter, phosphate solubilizing bacteria, and 2% humic acid, either alone or in consortium. The details of treatments were: T_1: control, T_2: RDF 100% + *Azotobacter*, T_3: RDF 100% + PSB, T_4: RDF 100% + 2% humic acid, T_5: RDF 100% + *Azotobacter* + PSB, T_6: RDF 100% + PSB + 2% humic acid, T_7: RDF 100% + *Azotobacter* + 2% humic acid, T_8: RDF 100% + *Azotobacter* + PSB + 2% humic acid.

Strawberry Winter Dawn was used. Healthy runners were transplanted in raised beds at a spacing of 45 cm × 30 cm, maintaining optimum plant population. Routine cultural operations, irrigation, mulching, weeding, and plant protection measures were carried out uniformly. Treatments to ensure proper crop growth and minimize environmental variation. During randomly selected tagged plants within each plot. The recorded data were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for the randomized block design, and significance of treatment differences was tested at the 5 per cent level.

RESULTS AND DISCUSSION

Integrated nutrient management (INM) treatments enhanced plant height at all stages of growth (Table 1). At 30 DAP, maximum plant height (8.50 cm) was recorded under treatment T_8 (RDF 100% + Azotobacter + PSB + 2% humic acid), followed by T_7 (7.61 cm) and T_6 (6.72 cm). The minimum plant height (4.38 cm) was observed in the control (T_1). A similar trend was observed at 60 DAP, where T_8 again exhibited highest plant height (13.23 cm), followed by T_7 (12.17 cm), while lowest value (7.02 cm) continued to be recorded under T_1. At 90 DAP, treatment T_8 maintained its superiority with a plant height of 16.94 cm, followed by T_7 (15.55 cm) and T_6 (14.57 cm). The control (10.79 cm) recorded lowest growth. By 120 DAP, maximum plant height (22.15 cm) was again attained under T_8, with the next highest value noted in T_7 (21.46 cm). The minimum plant height (13.51 cm) remained in the control treatment. Similar improvements in vegetative growth under integrated nutrient management have been reported by Singh *et al.* (2017), Mor *et al.* (2022) and Das *et al.*(2017).

The number of leaves was positively influenced by the application of integrated nutrient management (INM) practices (Table 1). At 30 DAP, the highest leaf count (7.64) was recorded under T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (7.49), whereas the control (T_1) produced minimum (4.24). A similar trend continued at 60 DAP, where T_8 recorded the maximum number of leaves (13.47), while T_1 again showed the lowest value (7.56). At 90 DAP, leaf production increased across treatments, with T_7 (19.74) and T_8 (19.65) producing the highest counts, compared to the control (15.59). By 120 DAP, T_8 remained superior with 22.41 leaves, followed by T_7 (21.87), while T_1 recorded the lowest number (17.64). Similar findings on improved vegetative growth in strawberry under INM have been reported by Singh *et al.*(2017) Mor *et al.* (2024)and Das *et al.* (2017).

Plant spread in north–south direction increased consistently with the application of integrated nutrient management treatments (Table 1). At 30 DAP, maximum plant spread (15.59 cm) was recorded under T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed closely by T_7 (15.55 cm), whereas minimum spread (7.26 cm) was observed in the control (T_1). At 60 DAP, T_8 again produced the highest plant spread (20.49 cm), followed by T_7 (20.33 cm), while T_1 recorded the lowest (11.56 cm). A similar trend continued at 90 DAP, with T_8 (25.12 cm) and T_7 (25.01 cm) showing greater canopy expansion compared to other treatments. The control treatment exhibited the least spread (17.05 cm). By 120 DAP, the maximum spread (31.82 cm) was obtained under T_8, followed by T_7 (30.65 cm). The minimum spread (21.94 cm) remained under the control. The superior performance of T_8 may be attributed to synergistic effect of biofertilizers and humic acid, which enhance nutrient uptake, root activity, and vegetative growth. Sangwan *et al.* (2025) and Thumar *et al.* (2026).

The plant spread in east–west direction showed a notable improvement with the application of integrated nutrient management treatments (Table 1). At 30 DAP, maximum spread (14.69 cm) was observed in T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (14.25 cm) and T_6 (14.11 cm), while lowest spread (7.48 cm) was recorded under the control (T_1). At 60 DAP, T_8 continued to record the highest plant spread (18.87 cm), closely followed by T_7 (18.56 cm), whereas T_1 again showed the minimum (11.26 cm). A similar trend was observed at 90 DAP, where T_8 produced the greatest canopy spread (22.64 cm), followed by T_7 (22.41 cm). The control treatment remained the lowest (13.69 cm). By 120 DAP, T_8 maintained its superiority with the highest plant spread (32.12 cm), while T_7 (31.84 cm) also showed substantial improvement. The minimum spread (25.69 cm) continued to be recorded in T_1. The superior performance of T_8 can be attributed to the combined effects of *Azotobacter*, PSB, and humic acid, which together enhance nutrient availability, photosynthetic efficiency, and vegetative expansion. Similar improvements in canopy spread of strawberry under INM have been reported by Singh *et al.* (2017) and Das *et al.* (2017).

Table 1: Effect of INM practices on plant growth parameters, leaf area, and chlorophyll content of strawberry at different days after planting (DAP).

Treatment	Plant height (cm) DAP				Number of leaves (DAP)				Plant spread (cm) N-S DAP				Plant spread (cm) E-W DAP				Leaf area (cm^2) DAP				Chlorophyll contains (mg/g)		
	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120	Chl A	Chl B	Chl.con.
T_1	4.38	7.02	10.79	13.51	4.24	7.56	15.59	17.64	7.26	11.56	17.05	21.94	7.48	11.26	13.69	25.69	19.56	29.53	37.58	40.21	1.05	0.30	2.18
T_2	5.32	8.22	11.88	14.91	5.57	10.64	17.08	19.37	8.58	14.03	19.36	23.54	9.63	13.65	16.87	27.54	21.54	31.52	39.36	46.51	1.08	0.41	2.35
T_3	4.97	7.93	11.6	14.46	5.02	9.58	16.98	18.47	8.01	13.51	18.52	22.62	8.47	12.47	15.45	26.45	20.14	30.48	38.58	44.25	1.06	0.36	2.36
T_4	5.71	9.55	12.85	16.21	6.54	11.48	17.47	19.87	10.36	15.05	21.36	25.48	12.64	15.96	20.96	28.85	22.41	32.43	40.47	48.84	1.09	0.45	2.55
T_5	6.49	10.5	13.69	17.98	6.85	12.36	18.65	20.65	11.68	18.87	23.46	26.58	13.96	16.58	20.84	30.68	23.68	33.45	42.69	51.52	1.11	0.51	2.75
T_6	6.72	11.2	14.57	18.97	7.12	11.47	18.84	20.84	12.79	19.94	24.67	28.64	14.11	17.87	21.47	28.78	24.72	35.46	44.41	52.08	1.13	0.56	2.85
T_7	7.61	12.17	15.55	21.46	7.49	12.42	19.74	21.87	15.55	20.33	25.01	30.65	14.25	18.56	22.41	31.84	25.85	36.21	45.03	52.32	1.16	0.58	2.95
T_8	8.5	13.23	16.94	22.15	7.64	13.47	19.65	22.41	15.59	20.49	25.12	31.82	14.69	18.87	22.64	32.12	26.64	36.58	45.22	52.69	1.18	0.62	3.56
C.D.	4.38	7.02	10.79	13.51	0.37	1.06	0.77	1.04	0.40	0.26	0.36	1.82	0.48	0.48	0.55	1.02	1.90	4.00	0.98	0.007	N/A	0.07	0.26

Table 2: Effect of different INM treatments on runner production, flowering, harvesting, fruit yield attributes, and yield of strawberry.

Treatment	No. of runner/ plant	Days of first flowering	Days of first harvesting	No. of fruits/ plant	Fruit set (%)	Fruit length (cm)	Fruit width (cm)	Fruit wt. (g)	Fruit vol. (ml)	Fruit yield (g/plant)	Fruit yield (tonnes/ha)
T_1	2.51	47.54	85.62	13.56	67.81	2.92	2.64	11.54	16.84	556.48	9.22
T_2	2.35	49.84	87.53	12.84	67.26	2.88	2.56	11.36	16.59	545.86	8.65
T_3	3.48	44.84	82.13	14.13	69.55	3.35	3.12	13.67	17.46	533.15	9.13
T_4	3.41	42.87	79.35	15.57	71.48	3.52	3.37	14.51	18.22	538.92	10.01
T_5	3.78	44.32	75.48	16.64	73.36	3.74	3.46	15.34	18.87	545.08	10.71
T_6	4.24	43.89	72.82	17.41	75.45	3.91	3.51	16.57	19.55	567.48	11.58
T_7	5.75	42.78	70.24	18.05	85.00	4.39	4.13	17.46	20.43	575.50	12.11
T_8	1.72	0.56	0.13	0.005	0.63	0.59	0.37	0.70	0.73	10.84	1.78
C.D.	2.35	58.54	89.21	12.51	65.87	2.64	2.15	10.15	15.47	526.97	8.17

T_1-Control; T_2-RDF 100%+ Azotobacter; T_3-RDF 100% +PSB; T_4-RDF 100% +2% HA; T_5-RDF 100%+ AZ+PSB; T_6-RDF 100% +PSB+2% HA; T_7-RDF 100%+ AZ +2% HA; T_8-RDF 100%+ AZ +2% HA+PSB

Leaf area increased steadily under different integrated nutrient management (INM) treatments (Table 1). At 30 DAP, the largest leaf area (26.64 cm^2) was observed in T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (25.85 cm^2), while the control recorded the minimum (19.56 cm^2). A similar trend continued at 60 DAP, where T_8 and T_7 reported the highest leaf areas (36.58 cm^2 and 36.21 cm^2, respectively), compared with the control (29.53 cm^2). At 90 DAP, leaf expansion was highest under T_8 (45.22 cm^2), followed closely by T_7 (45.03 cm^2), whereas lowest value (37.58 cm^2) remained in the control. By 120 DAP, T_8 maintained its superiority (52.69 cm^2), with T_7 (52.32 cm^2) and T_6 (52.08 cm^2) also showing notable improvements. The control had the smallest leaf area (40.21 cm^2). Similar observations of increased leaf area due to biofertilizers and humic substances in strawberry and other horticultural crops have been reported by Rana *et al.* (2015), Khalid *et al.*(2017), Mor *et al.* (2025), Kumar and Singh, (2020).

The chlorophyll content of leaves increased progressively with the application of integrated nutrient management treatments (Table 1). For chlorophyll a, the highest value (1.18 mg/g) was observed in T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (1.16 mg/g) and T_6 (1.13 mg/g). The lowest chlorophyll a content (1.05 mg/g) occurred in the control (T_1). A similar pattern was recorded for chlorophyll b, where T_8 exhibited the maximum value (0.62 mg/g), followed by T_7 (0.58 mg/g). The minimum value (0.30 mg/g) remained in the control treatment. Total chlorophyll content also followed the same trend, with T_8 recording the highest (3.56 mg/g), indicating better photosynthetic capacity, while T_1 recorded the lowest (2.18 mg/g). The substantial increase in chlorophyll under INM treatments can be attributed to the combined action of *Azotobacter*, PSB, and humic acid, which improve nutrient uptake, enhance nitrogen metabolism, and stimulate chlorophyll synthesis. Earlier studies by Bhat (2021), and Akash *et al.* (2013) also reported that biofertilizers and humic substances significantly enhance chlorophyll content and photosynthetic efficiency in strawberry and other horticultural crops.

Integrated nutrient management had a significant influence on growth and flowering behaviour in strawberry (Table 2). The number of runners/plant increased consistently with the addition of biofertilizers and humic acid. The maximum number of runners (5.75) was produced under T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (4.24), while the control (T_1) recorded the lowest (2.35). The days to first flowering showed a decreasing trend with improved nutrient management. The earliest flowering was observed under T_8 (42.78 days), indicating accelerated floral initiation due to enhanced nutrient uptake and hormonal activity, whereas the control exhibited the latest flowering (58.54 days). A similar trend was observed for first harvesting, with T_8 recording the earliest harvest (70.24 days) and the control the latest (89.21 days).

Fruit production was also positively influenced by INM treatments. The maximum number of fruits per plant (18.05) was observed in T_8, followed by T_7 (17.41), while the control produced the least (12.51). Fruit set percentage was highest under T_8 (85.00%), indicating improved pollination efficiency and flower fertility, whereas the lowest value was recorded in the control (65.87%). The overall improvement in flowering, runner production, and fruit set under T_8 could be attributed to the synergistic effect of *Azotobacter*, PSB, and humic acid, which enhance nitrogen fixation, phosphorus availability, root vigor, and synthesis of growth-promoting substances. Similar enhancements in strawberry reproductive traits under integrated nutrient management have been reported by Yadav *et al.* (2019), Mohamed *et al.* (2017), Mor *et al.* (2021) and Petre and Selaru (2020).

The physical characteristics of fruits improved noticeably under integrated nutrient management practices (Table 2). Fruit length increased progressively with enhanced nutrient combinations, with the maximum length (4.39 cm) recorded under T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (3.91 cm) and T_6 (3.74 cm), whereas control exhibited the lowest value (2.64 cm). A similar trend was observed for fruit width, where T_8 registered the highest measurement (4.13 cm), followed by T_7 (3.51 cm). The lowest fruit width (2.15 cm) was obtained under the control.

The gradual increase in both fruit length and width across INM treatments reflects better cell expansion and nutrient accumulation influenced by microbial inoculants and humic substances. Fruit weight also improved significantly under integrated nutrient practices. The heaviest fruits (17.46 g) were recorded in T_8, followed by T_7 (16.57 g) and T_6 (15.34 g), whereas minimum fruit weight (10.15 g) occurred in the control. A similar increasing pattern was recorded for fruit volume, with T_8 producing the maximum volume (20.43 ml) compared to the lowest (15.47 ml) in the control treatment. Earlier studies by Kumar *et al.* (2018), Lopez-Garcia *et al* (2016), and Suleiman *et al.* (2021), who reported that the combined application of biofertilizers and organic amendments enhances fruit morphology and marketable yield in strawberry.

Fruit yield showed a remarkable increase with the application of integrated nutrient managemen treatments (Table 2). The maximum fruit yield per plant (575.50 g) was recorded under T_8 (RDF + Azotobacter + PSB + 2% humic acid), followed by T_7 (567.48 g) and T_2 (556.48 g). The lowest yield (526.97 g) was recorded in the control (T_1). This indicates that the combined application of microbial inoculants and humic acid substantially enhances plant productivity. A similar trend was observed for yield per hectare. The highest fruit yield (12.11 t/ha) was produced under T_8, followed by T_7 (11.58 t/ha) and T_6 (10.71 t/ha). The lowest yield (8.17 t/ha) was obtained in the control. The improvement in yield under T_8 can be attributed to enhanced nutrient uptake, improved photosynthetic activity, increased fruit set, and overall better plant health resulting from the combined effects of Azotobacter, PSB, and humic acid. Earlier studies by Wani *et al.* (2013), and Iqbal *et al.* (2008) have similarly reported.

CONCLUSION

Thus, integrated nutrient management using biofertilizers and humic acid along with recommended chemical fertilizers is a sustainable, cost-effective, and environment friendly nutrient strategy for strawberry growers. Adoption of T_8-type INM treatments can significantly enhance strawberry productivity and profitability, especially under semi-arid conditions of Haryana and similar agroclimatic regions.

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