Journal of Advances in Biology & Biotechnology

Volume 27, Issue 7, Page 1297-1306, 2024; Article no.JABB.119312
ISSN: 2394-1081

Impact of Integrated Nutrient Management (INM) on Growth Attributes of Strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn

Harish Chandra Yadav [a], Anand Singh [a*], Akhilesh Kumar Srivastava [a], Bijendra Kumar Singh [a], Balaji Vikram [a], Ashutosh Rai [a], Hari Bakash [b] and Paramanand Prajapati [a]

[a] *Department of Fruit Science, College of Horticulture, Banda University of Agriculture and Technology, Banda-210 001, U.P., India.*
[b] *Department of Horticulture, Tilak Dhari PG College, Jaunpur -222 002, U.P., India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i71091

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/119312

Original Research Article

Received: 26/04/2024
Accepted: 30/06/2024
Published: 02/07/2024

**Corresponding author: E-mail: buathortanand@gmail.com;*

Cite as: *Yadav, Harish Chandra, Anand Singh, Akhilesh Kumar Srivastava, Bijendra Kumar Singh, Balaji Vikram, Ashutosh Rai, Hari Bakash, and Paramanand Prajapati. 2024. "Impact of Integrated Nutrient Management (INM) on Growth Attributes of Strawberry (Fragaria × Ananassa Duch.) Cv. Winter Dawn". Journal of Advances in Biology & Biotechnology 27 (7):1297-1306. https://doi.org/10.9734/jabb/2024/v27i71091.*

ABSTRACT

A study entitled Impact of Integrated Nutrient Management (INM) on growth attributes of strawberry (*Fragaria* × *ananassa* Duch*.)* in district Banda, Uttar Pradesh was carried out at the "Green shade Net house" located in the Department of Fruit Science, College of Horticulture, Banda University of Agriculture & Technology, Banda (U.P.), during the academic years of 2022-23 and 2023-24. Eleven treatments using various combinations of N, P, K, nano urea, bio fertilizers, and organic manures were tested in a Randomised Block Design with three replicates. The experiment's primary objective was to determine the effect of nano technology on the vegetative growth traits of strawberry cv. Winter Dawn. According to the findings of 2 years study and pooled results, application of treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] proved to be most effective treatment to increase growth attributes of strawberry *i.e*., plant height 9.09 cm, 13.61 cm and 17.78 cm at 30, 60 and 90 DAP, respectively; plant spread *i.e*., 12.75 cm, 21.32 cm, and 23.44 cm at 30 ,60 and 90 DAP, respectively;number of leaves *i.e*., 5.75, 13.81 and 17.87 at30, 60 and 90 DAP, respectively; leaf length *i.e*., 4.70 cm, 5.80 cm and 8.29 cm at 30, 60 and 90 DAP, respectively; leaf width *i.e*., 5.94 cm, 7.53 cm and 11.60 cm at 30, 60 and 90 DAP, respectively; Leaf area (cm^2) *i.e*., 40.31 cm^2, 51.93 cm^2,66.38 cm^2 number of runners per plant *i.e*., 5.27, number of crowns per plant *i.e*., 4.39, biomass of fresh weight (g) *i.e*., 147.37 g and Biomass of dry weight (g) *i.e*., 36.84 g. Therefore, application of 75%N (Nano Urea) + 75% PK (Basal) + 250 Kg VC + AZO + PSB] proved to be most effective treatment to increase growth attributes of strawberry and same can be recommended to the growers.

Keywords: Azotobacter; bio-fertilizer; nano urea; organic manure; phosphorus solubilizing bacteria; strawberry; winter dawn; etc.

1. INTRODUCTION

The strawberry, scientifically known as *Fragaria × ananassa* Duch., belongs to the Rosaceae family [1]. It is classified as a "false fruit" and is renowned for being one of the most delectable, invigorating, and nourishing soft fruits in the world [2]. Originally native to America, the strawberry has gained widespread popularity [3]. The development of this particular hybrid took place in France during the seventeenth century. It is worth noting that this hybrid is a monoecious combination of two American octaploid species, namely *Fragaria chiloensis* Duch. And *Fragaria virginiana* Duch [4]. This fruit thrives in temperate climates with temperatures below 26°C, which is necessary for flowering to occur [5]. According to Chattopadhyay [6], it is possible to cultivate it in subtropical climates and at high altitudes in tropical regions. Currently, strawberries are cultivated in various climatic zones thanks to their diverse genotypes.

From a nutritional standpoint, strawberries are considered a low-calorie carbohydrate fruit. They are also packed with vitamin A, providing 60 International Unit per 100g of edible portion. Additionally, strawberries are a good source of fiber and contain a high amount of pectin, specifically calcium pectate [7]. Strawberry fruit is rimarily composed of water, making up approximately 90% of its composition. The strawberry fruit contains a significant amount of vitamin C (40-120mg/100g fruit), protein, and various minerals such as phosphorus, potassium, calcium, and iron [8]. It also contains phenolics and flavonoids [9]. Strawberries have gained popularity as a nutritious and delicious fruit enjoyed by millions worldwide [10]. Strawberries are known for their abundance of bioactive compounds, including anthocyanins, carotenoids, vitamins, flavonoids, and phenolics. These compounds have been found to possess strong antioxidant properties [11].

In recent years, the presence of unauthorized fertilizers, pesticides, and the results of biological monitoring have led to environmental contamination in strawberry agriculture [12]. Chemical fertilisers have been found to enhance crop productivity, but they also bring about the presence of detrimental residues that can have adverse effects on human health, compromise sustainability, and contribute to water pollution [13]. Therefore, nanotechnologies offer a promising solution to enhance agricultural production and promote sustainability. In 1974, Professor Norio Taniguichi of Tokyo University of Science introduced the term 'nanotechnology' [14]. Nano fertilizers are designed to release nutrients at the right time, preventing any early interaction with the soil, water, and microbes.

The nutrients quickly come together and integrate into the plant system. According to a study conducted by De Rosa et al*.* [15], certain traits have the potential to enhance crop nutrient efficiency.

Strawberry plants thrive in regions with optimal nutrition and carefully regulated nutrient supply, resulting in increased yield. Nano mixed foliar sprays, when integrated with bio fertilizers and organic manures, offer enhanced field usage production, superior sustainability, and reduced plant mobility. Foliar nano fertilizers have been found to reduce the toxicity of macro and micro engineered elements applied to the soil, as demonstrated by Abbasifar et al*.* [16]. Keeping in view the above facts this experiment titled Impact of Integrated Nutrient Management (INM) on growth attributes of strawberry *(Fragaria × ananassa* Duch.) in district Banda, Uttar Pradesh was designed and carried out.

2. MATERIALS AND METHODS

The experiment mentioned above was conducted during the years 2022-23 and 2023-24 under net house conditions located in the Department of Fruit Science, College of Horticulture, Banda University of Agriculture and Technology, Banda (U.P.). The experimental site is situated within the latitudes of 24° 53°–24° 55° N and longitudes of 80° 07°-81° 34° E. District Banda is geographically surrounded by the Madhya Pradesh districts of Satna, Panna, and Chhatarpur to the south, and the districts of Fathepur to the north, Chitrakoot to the east, and Hamirpur and Mahoba to the west. The soil of the experimental site contains slightly alkaline pH of 7.91 and low organic matter of 0.49%, EC (1.41 dSm^{-1}), Available N (106 kg/ha), Available P (9.44 kg/ha) and Available K (302 kg/ha).

The plants were treated with different treatments, *i.e*., T_1: 100% NPK Basal dose of fertilizers, T_2: 100% N (Nano Urea) + 100% PK Basal dose of fertilizers, T_3: 75% N (Nano Urea) + 75% PK (Basal) + 500 kg FYM + AZO + PSB, T_4: 75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB, T_5: 75% N (Nano Urea) + 75% PK (Basal) + 100 kg NOC + AZO + PSB, T_6: 50% N (Nano Urea) + 50% PK (Basal) + 750 kg FYM + AZO + PSB, T_7: 50% N (Nano Urea) + 50% PK (Basal) + 500 kg VC + AZO + PSB, T_8: 50% N (Nano Urea) + 50% PK (Basal) + 150 kg NOC + AZO + PSB, T_9: 25% N (Nano Urea) + 25% PK (Basal) + 1000 kg FYM + AZO + PSB, T_{10}: 25% N (Nano Urea) + 25% PK (Basal) + 750 kg VC + AZO + PSB and T_{11}: 25% N (Nano Urea) + 25% PK (Basal) + 200 kg NOC + AZO + PSB.

Prepared bed with the help of spade and transplanting of runners in 45×30 cm spacing. Recommended dose of NPK @ 100:120:80 kg/ha along with FYM, Vermicompost (VC) & Neem oil cake (NOC) were applied as basal dose and rest doses were applied 15 days before planting of runners as per treatment combination. Bio-fertilizers AZO (Azotobacter) and PSB (phosphorus solubilizing bacteria) were used in the experimental field to fulfill the recommended dose of bio-fertilizers. Calculated amount of bio-fertilizers were applied before mulching of the beds according to various treatment combinations. The nano urea was given immediately after transplantation, followed by three more at 20-day intervals. The experiment conducted in Randomized Block Design as per method suggested by Panes and Sukhatme, 1985 with three replications.

3. RESULTS AND DISCUSSION

A statistical analysis was conducted to study the growth characteristics of Strawberry (*Fragaria × ananassa*) cv. Winter Dawn based on the findings; the inclusion of different treatments led to a significant improvement in all the characteristics. Based on the comparison of F Cal. and F Tab, it can be concluded that the variances exhibited statistically significant differences.

3.1 Growth Attributes

Fruit weight (g): According to results pertaining to Table 1, it was found that the treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best compared to other treatments. It was found significantly the maximum plant height *i.e*., [8.83 cm (2022-23), 9.36 cm (2023-24) and 9.09 cm (pooled)] cm at 30 DAP, [13.21 cm (2022-23), 14.00 cm (2023-24) and 13.61 cm (pooled)] cm at 60 DAP and [17.43 cm (2022-23), 18.13 cm (2023-24) and 17.78 cm (pooled)] cm at 90 DAP whereas, least plant height *i.e*., [5.94 cm (2022-23), 6.30 cm (2023-24) and 6.12 cm (pooled)] cm at 30 DAP, [8.42 cm (2022-23), 8.93 cm (2023-24) and 8.67 cm (pooled)] cm at 60 DAP and [12.91 cm (2022-23), 13.43 cm (2023-24) and 13.17 cm (pooled)] cm at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Table 1. Impact of integrated nutrient management on plant height (cm) of strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn

Treatments	Plant height (cm)								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	5.94	6.30	6.12	8.42	8.93	8.67	12.91	13.43	13.17
T_2	6.02	6.38	6.20	8.81	9.34	9.07	13.21	13.74	13.47
T_3	8.71	9.23	8.97	12.81	13.58	13.19	17.09	17.77	17.43
T_4	8.83	9.36	9.09	13.21	14.00	13.61	17.43	18.13	17.78
T_5	8.09	8.58	8.33	11.64	12.34	11.99	15.94	16.58	16.26
T_6	7.84	8.31	8.08	11.26	11.94	11.60	15.58	16.20	15.89
T_7	8.57	9.08	8.83	12.19	12.92	12.56	16.51	17.17	16.84
T_8	7.42	7.87	7.64	10.87	11.52	11.20	15.01	15.61	15.31
T_9	7.18	7.61	7.40	9.86	10.45	10.16	14.09	14.65	14.37
T_{10}	7.31	7.75	7.53	10.26	10.88	10.57	14.42	15.00	14.71
T_{11}	6.19	6.56	6.38	9.43	10.00	9.71	13.77	14.32	14.05
S.E. (m) (±)	0.11	0.13	0.09	0.16	0.17	0.12	0.16	0.17	0.12
C.D. @ 5%	0.34	0.37	0.24	0.48	0.52	0.34	0.46	0.52	0.34

Plant spread (cm): As per the data regarding plant spread (Table 2), effect of treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB]was found best with significantly maximum plant spread *i.e*., [12.44 cm (2022-23), 13.06 cm (2023-24) and 12.75 cm (pooled)] cm at 30 DAP, [20.21 cm (2022-23), 22.43 cm (2023-24) and 21.32 cm (pooled)] cm at 60 DAP and [23.21 cm (2022-23), 23.67 cm (2023-24) and 23.44 cm (pooled)] cm at 90 DAP whereas, least plant spread *i.e*., [8.85 cm (2022-23), 9.29 cm (2023-24) and 9.07 cm (pooled)] cm at 30 DAP, [13.49 cm (2022-23), 14.97 cm (2023-24) and 14.23 cm (pooled)] cm at 60 DAP and [19.09 cm (2022-23), 19.47 cm (2023-24) and 19.28 cm (pooled)] cm at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers]

Number of leaves: The results indicating to number of leaves (Table 3) as effected by Integrated Nutrient Management shows that treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB]was found best with significantly maximum number of leaves i.e., [5.45 (2022-23), 6.05 (2023-24) and 5.75 (pooled)] at 30 DAP, [13.67 (2022-23), 13.94 (2023-24) and 13.81 (pooled)] at 60 DAP and [17.78 (2022-23), 17.96 (2023-24) and 17.87(pooled)] at 90 DAP whereas least number of leaves *i.e*., [4.15 (2022-23), 4.61 (2023-24) and 4.38 (pooled)] at 30 DAP, [9.55 (2022-23), 9.74 (2023-24) and 9.65 (pooled)] at 60 DAP and [14.04 (2022-23), 14.18 (2023-24) and 14.11 (pooled)] at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Table 2. Impact of integrated nutrient management on plant spread (cm) of strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn

Treatments	Plant spread (cm)								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	8.85	9.29	9.07	13.49	14.97	14.23	19.09	19.47	19.28
T_2	9.02	9.47	9.25	14.01	15.55	14.78	19.37	19.76	19.56
T_3	12.21	12.82	12.52	19.66	21.82	20.74	22.93	23.39	23.16
T_4	12.44	13.06	12.75	20.21	22.43	21.32	23.21	23.67	23.44
T_5	11.21	11.77	11.49	17.95	19.92	18.94	21.68	22.11	21.90
T_6	10.89	11.43	11.16	17.41	19.33	18.37	21.40	21.83	21.61
T_7	12.09	12.69	12.39	18.81	20.88	19.84	22.31	22.76	22.53
T_8	10.34	10.86	10.60	16.86	18.71	17.79	21.09	21.51	21.30
T_9	10.02	10.52	10.27	15.38	17.07	16.23	20.13	20.53	20.33
T_{10}	10.18	10.69	10.43	15.95	17.70	16.83	20.44	20.85	20.64
T_{11}	9.21	9.67	9.44	14.83	16.46	15.65	19.85	20.25	20.05
S.E. (m) (±)	0.14	0.15	0.10	0.22	0.17	0.16	0.13	0.15	0.10
C.D. @ 5%	0.41	0.44	0.29	0.64	0.52	0.46	0.39	0.44	0.29

Table 3. Impact of integrated nutrient management on number of leaves of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	Number of leaves								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	4.15	4.61	4.38	9.55	9.74	9.65	14.04	14.18	14.11
T_2	4.22	4.68	4.45	9.86	10.06	9.96	14.43	14.57	14.50
T_3	5.38	5.97	5.68	13.38	13.65	13.51	17.42	17.59	17.51
T_4	5.45	6.05	5.75	13.67	13.94	13.81	17.78	17.96	17.87
T_5	4.94	5.48	5.21	12.20	12.44	12.32	16.20	16.36	16.28
T_6	4.87	5.41	5.14	11.91	12.15	12.03	15.81	15.97	15.89
T_7	5.16	5.73	5.44	12.79	13.05	12.92	16.76	16.93	16.84
T_8	4.80	5.33	5.06	11.62	11.85	11.74	16.36	16.52	16.44
T_9	4.51	5.01	4.76	10.74	10.95	10.85	15.28	15.43	15.36
T_{10}	4.58	5.08	4.83	11.03	11.25	11.14	15.64	15.80	15.72
T_{11}	4.44	4.93	4.68	10.45	10.66	10.55	14.90	15.05	14.97
S.E. (m) (±)	0.04	0.05	0.03	0.14	0.16	0.11	0.16	0.17	0.12
C.D. @ 5%	0.12	0.16	0.10	0.41	0.48	0.31	0.46	0.50	0.33

Leaf length (cm): The experimental result regarding leaf length (Table 4) indicate that effect of treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best with significantly maximum leaf length *i.e*., [4.67 cm (2022-23), 4.72 cm (2023-24) and 4.70 cm (pooled)] cm at 30 DAP, [5.77 cm (2022-23), 5.83 cm (2023-24) and 5.80 cm (pooled)] cm at 60 DAP and [8.24 cm (2022-23), 8.35 cm (2023-24) and 8.29 cm (pooled)] cm at 90 DAP whereas least leaf length *i.e*., [3.39 cm (2022-23), 3.43 cm (2023-24) and 3.41 cm (pooled)] cm at 30 DAP, [4.19 cm (2022-23), 4.23 cm (2023-24) and 4.21 cm (pooled)] cm at 60 DAP and [5.98 cm (2022-23), 6.06 cm (2023-24) and 6.02 cm (pooled)] cm at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Leaf width (cm): Significant differences were observed regarding data indication leaf width (Table 5) of strawberry. Treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best with significantly maximum leaf width *i.e*., [5.93 cm (2022-23), 5.96 cm (2023-24) and 5.94 cm (pooled)] cm at 30 DAP, [7.51 cm (2022-23), 7.56 cm (2023-24) and 7.53 cm (pooled)] cm at 60 DAP and [11.55 cm (2022-23), 11.65 cm (2023-24) and 11.60 cm (pooled)] cm at 90 DAP whereas least leaf width (cm) *i.e*., [4.09 cm (2022-23), 4.11 cm (2023-24) and 4.10 cm (pooled)] cm at 30 DAP, [5.18 cm (2022-23), 5.22 cm (2023-24) and 5.20 cm (pooled)] cm at 60 DAP and [7.97 cm (2022-23), 8.04 cm (2023-24) and 8.01 cm (pooled)] cm at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Table 4. Impact of integrated nutrient management on leaf length (cm) of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	leaf length (cm)								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	3.39	3.43	3.41	4.19	4.23	4.21	5.98	6.06	6.02
T_2	3.49	3.53	3.51	4.31	4.35	4.33	6.15	6.23	6.19
T_3	4.58	4.63	4.61	5.66	5.72	5.69	8.08	8.18	8.13
T_4	4.67	4.72	4.70	5.77	5.83	5.80	8.24	8.35	8.29
T_5	4.23	4.28	4.25	5.22	5.28	5.25	7.46	7.56	7.51
T_6	4.14	4.19	4.16	5.11	5.17	5.14	7.30	7.39	7.35
T_7	4.41	4.45	4.43	5.44	5.50	5.47	7.77	7.87	7.82
T_8	4.05	4.09	4.07	5.00	5.05	5.03	7.14	7.23	7.19
T_9	3.78	3.82	3.80	4.67	4.72	4.69	6.67	6.76	6.71
T_{10}	3.87	3.92	3.89	4.78	4.83	4.81	6.83	6.92	6.87
T_{11}	3.69	3.73	3.71	4.56	4.61	4.58	6.51	6.59	6.55
S.E. (m) (±)	0.01	0.02	0.01	0.03	0.04	0.03	0.07	0.08	0.06
C.D. @ 5%	0.04	0.05	0.03	0.09	0.12	0.07	0.21	0.25	0.16

Table 5. Impact of integrated nutrient management on leaf width (cm) of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	Leaf width (cm)								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	4.09	4.11	4.10	5.18	5.22	5.20	7.97	8.04	8.01
T_2	4.23	4.25	4.24	5.36	5.39	5.37	8.24	8.31	8.28
T_3	5.81	5.84	5.83	7.36	7.41	7.38	11.32	11.42	11.37
T_4	5.93	5.96	5.94	7.51	7.56	7.53	11.55	11.65	11.60
T_5	5.27	5.29	5.28	6.67	6.72	6.69	10.26	10.35	10.31
T_6	5.15	5.18	5.16	6.52	6.56	6.54	10.03	10.12	10.07
T_7	5.54	5.57	5.55	7.01	7.06	7.04	10.79	10.89	10.84
T_8	5.03	5.06	5.04	6.37	6.41	6.39	9.80	9.89	9.84
T_9	4.64	4.66	4.65	5.88	5.92	5.90	9.04	9.12	9.08
T_{10}	4.76	4.78	4.77	6.03	6.07	6.05	9.27	9.35	9.31
T_{11}	4.52	4.55	4.53	5.73	5.77	5.75	8.81	8.89	8.85
S.E. (m) (±)	0.02	0.03	0.02	0.04	0.05	0.03	0.11	0.14	0.09
C.D. @ 5%	0.06	0.09	0.05	0.12	0.16	0.10	0.34	0.41	0.26

Leaf area (cm^2): As per the data regarding leaf area (Table 6), effect of treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best with significantly maximum leaf area *i.e*., [40.24 cm^2 (2022-23), 40.38 cm^2 (2023-24) and 40.31 cm^2 (pooled)] cm^2 at 30 DAP, [51.51 cm^2 (2022-23), 52.35 cm^2 (2023-24) and 51.93 cm^2 (pooled)] cm^2 at 60 DAP and [65.52 cm^2 (2022-23), 67.25 cm^2 (2023-24) and 66.38 cm^2 (pooled)] cm^2 at 90 DAP whereas least leaf area (cm^2) *i.e*., [30.04 cm^2 (2022-23), 30.14 cm^2 (2023-24) and 30.09 cm^2 (pooled)] cm^2 at 30 DAP, [41.37 cm^2 (2022-23), 42.05 cm^2 (2023-24) and 41.71 cm^2 (pooled)] at 60 DAP and [49.44 cm^2 (2022-23), 50.75 cm^2 (2023-24) and 50.09 cm^2 (pooled)] at 90 DAP was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Number of runners per plant: The results indicating to number of runners per plant (Table 7) as effected by Integrated Nutrient Management shows that treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best with significantly maximum number of runners per plant *i.e*., [5.05 (2022-23), 5.48 (2023-24) and 5.27 (pooled)] whereas least number of runners per plant *i.e*., [1.12 (2022-23), 1.24 (2023-24) and 1.18 (pooled)] was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Table 6. Impact of integrated nutrient management on leaf area (cm^2) of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	Leaf area (cm^2)								
	30 DAP			60 DAP			90 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	30.04	30.14	30.09	41.37	42.05	41.71	49.44	50.75	50.09
T_2	31.27	31.38	31.32	42.69	43.39	43.04	51.24	52.59	51.92
T_3	39.71	39.85	39.78	50.89	51.72	51.31	64.84	66.55	65.70
T_4	40.24	40.38	40.31	51.51	52.35	51.93	65.52	67.25	66.38
T_5	37.25	37.38	37.31	48.23	49.02	48.63	60.48	62.08	61.28
T_6	36.72	36.84	36.78	47.61	48.39	48.00	59.80	61.38	60.59
T_7	38.48	38.61	38.55	49.55	50.36	49.96	62.66	64.31	63.49
T_8	35.49	35.61	35.55	46.29	47.05	46.67	57.62	59.14	58.38
T_9	33.73	33.84	33.79	44.35	45.08	44.71	54.76	56.21	55.48
T_{10}	34.26	34.38	34.32	44.97	45.71	45.34	55.44	56.90	56.17
T_{11}	32.50	32.61	32.56	43.01	43.72	43.36	52.58	53.97	53.27
S.E. (m) (±)	0.25	0.25	0.18	0.28	0.30	0.20	0.40	0.43	0.29
C.D. @ 5%	0.73	0.75	0.51	0.82	0.87	0.58	1.17	1.26	0.84

Table 7. Impact of integrated nutrient management on number of runners and number of crowns per plant of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	Number of runners per plant			Number of crowns per plant		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T_1	1.12	1.24	1.18	2.37	2.44	2.41
T_2	1.53	1.66	1.59	2.49	2.56	2.53
T_3	4.80	5.23	5.02	4.19	4.32	4.25
T_4	5.05	5.48	5.27	4.33	4.46	4.39
T_5	3.70	4.04	3.87	3.66	3.77	3.71
T_6	3.45	3.74	3.60	3.52	3.63	3.57
T_7	4.25	4.64	4.44	3.91	4.03	3.97
T_8	2.90	3.15	3.02	3.38	3.48	3.43
T_9	2.10	2.30	2.20	2.96	3.05	3.00
T_{10}	2.38	2.58	2.48	3.09	3.18	3.14
T_{11}	1.98	2.17	2.08	2.82	2.90	2.86
S.E. (m) (±)	0.14	0.14	0.10	0.07	0.08	0.05
C.D. @ 5%	0.41	0.42	0.29	0.20	0.23	0.15

Number of crowns per plant: According to results pertaining to Table 7, it was found that the treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best compared to other treatments. It was found significantly the maximum number of crowns per plant *i.e*., [4.33 (2022-23), 4.46 (2023-24) and 4.39(pooled)] whereas least number of crowns per plant *i.e*., [2.37 (2022-23), 2.44 (2023-24) and 2.41 (pooled)] was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Biomass of fresh weight (g): The data regarding Biomass of fresh weight is shown in Table 8. From the data it was depicted that treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best compared to other treatments. It was found significantly the maximum biomass of fresh weight (g) *i.e*., [145.45 g (2022-23), 149.29 g (2023-24) and 147.37 g (pooled)] whereas least biomass of fresh weight (g) *i.e*., [118.74 g (2022-23), 121.87 g (2023-24) and 120.31 g (pooled)] was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Biomass of dry weight (g): As per the data regarding biomass of dry weight (Table 8), effect of treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was found best with significantly maximum biomass of dry weight *i.e*., [36.36 g (2022-23), 37.32 g (2023-24) and 36.84 g (pooled)] g whereas least biomass of dry weight *i.e*., [29.69 g (2022-23), 30.47 g (2023-24) and 30.08 (pooled)] g was found under the effect of treatment T_1 [100% NPK Basal dose of fertilizers].

Table 8. Impact of integrated nutrient management on biomass of fresh plant (g) and biomass of dry plant (g) of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn

Treatments	Biomass of fresh plant (g)			Biomass of dry plant (g)		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T_1	118.74	121.87	120.31	29.69	30.47	30.08
T_2	121.85	125.07	123.46	30.46	31.27	30.86
T_3	143.84	147.64	145.74	35.96	36.91	36.43
T_4	145.45	149.29	147.37	36.36	37.32	36.84
T_5	137.62	141.25	139.44	34.41	35.31	34.86
T_6	136.00	139.59	137.80	34.00	34.90	34.45
T_7	140.73	144.45	142.59	35.18	36.11	35.65
T_8	132.89	136.40	134.64	33.22	34.10	33.66
T_9	128.07	131.45	129.76	32.02	32.86	32.44
T_{10}	129.78	133.21	131.49	32.45	33.30	32.87
T_{11}	124.96	128.26	126.61	31.24	32.06	31.65
S.E. (m) (±)	0.68	0.73	0.50	0.21	0.23	0.16
C.D. @ 5%	1.99	2.15	1.42	0.62	0.68	0.45

4. DISCUSSION

Treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] had the greatest effect and was the most significant in increasing vegetative growth of strawberry. There were significant differences in the impact of treatments on the height and spread of the plants, highest number of leaves, as well as the largest leaf size and leaf area. Maximum number of runners per plant, number of crowns per plant and biomass fresh and dry weight both in the individual years of observation and pooled data. It is possible that the presence of urea nano particles allows for easier penetration into leaf cells and stomata, resulting in an enhanced availability of nitrogen to the plant cells [17]. According to Sun et al*.* [18], the rise in nitrogen availability could have resulted in the rapid synthesis of chlorophyll, crucial enzymes, and proteins. According to Gajbhiye et al*.* (2003), the heightened metabolic pathways could have resulted in accelerated cell elongation and multiplication, resulting in an overall increase in plant height and spread. Other studies have also documented similar results in guava [19-22] in strawberry. The increased availability of nutrients was attributed to the penetration of nano N through the stomata of leaves via gas uptake, as discussed by Rajasekar et al*.* [23]. In addition, the application of vermicompost with bio-fertilizers such as PSB and Azotobacter may have played a role in promoting plant growth. Studies conducted by Bhatti et al*.* [19] on guava, Singh et al*.* [21] and Kalil et al*.* [24] on strawberry have reported a significant increase in the number of leaves and leaf area as a result of using nano urea.

The subsequent increase in the number of runners per plant can also be attributed to the enhanced plant growth in terms of height and leaf count. This leads to the accumulation of additional photosynthesis, resulting in an increase in both runners and leaf area per plant. The results align entirely with Upadhyay et al. [25] study on strawberries, which reported the largest number of runners per plant when PM + Azotobacter + wood ash + vermicompost + oil cake were applied. Strawberry plant biomass might have increased due to the fact that synergistic effect of Nano Urea, Vermicompost, Azotobacter and PSB along with basal dose of P and K led to the sustained release of nutrients and in biovailable form to the plants [26,27]. This leads to more biomass production of the strawberry plants. Similar results were reported by Singh et al. [22], Singh et al*.* [21] and Al-Aareji (2022) in strawberry [28,29].

5. CONCLUSION

Based on the results, treatment T_4 [75% N (Nano Urea) + 75% PK (Basal) + 250 kg VC + AZO + PSB] was the most efficient treatment at boosting vegetative growth characteristics. This integrated approach combines advanced nano-urea technology, optimized basal nutrient provision, and the enriching properties of vermicompost and beneficial microorganisms to maximize the benefits. The combination of these components likely fostered an optimal environment for absorbing nutrients and promoting plant growth, leading to exceptional vegetative growth measurements. The results highlight the importance of customized nutrient management techniques in enhancing plant growth, leading to higher crop yields and increased sustainability in strawberry farming. This production practice can be shared with strawberry farmers to improve their production and productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Gupta AK, Tripathi VK. Efficacy of Azotobacter and vermicompost alone and in combination on vegetative growth, flowering and yield of strawberry (Fragaria x ananassa Duch.) Cv. Chandler; Progressive Horticulture. 2012;44(2):256-261.
2. Sparacino A, Ollani S, Baima L, Oliviero M, Borra D, Rui M, Mastromonaco G. Analyzing Strawberry Preferences: Best–Worst Scaling Methodology and Purchase Styles; Foods. 2024;13(10): 1474.
3. Galletta GJ, Lawrence FJ, Scott DH. Strawberry breeding work of the United

States Department of Agriculture. Hortic. Sci. 1990;25:895–96.
4. Galletta GJ, Bringhust RS. Strawberry management (in): Small Fruit Crops Management. Galletta GJ, Mimmelrick (eds.) Prentice Hall. Englewood Cliff, New jersy. 1990;3.
5. Jackson D, Looney N, Morley B, Thiele G. Temperate and subtropical fruit production, Butterworths publication 1987, New Zealand. 2011:202-25.
6. Chattopadhyay TK. A Textbook on Pomology. Kalyani Publishers, New Delhi. 2013:88-147.
7. Singh SK, Saravanan S. Effect of bio-fertilizers and micronutrients on yield and quality of strawberry (*Fragaria x ananassa* Duch) cv. Chandler; The Asian Journal of Horticulture. 2012;7(2):533-536.
8. Kanupriya. Crop Scan (strawberry). Agriculture Today. 2002:48-49.
9. Hakkinen S, Torronen R. Content of Flavonols and Selected Phenolic Acids in Strawberries Vaccinium Species: Influence of Cultivar, Cultivation Site and Technique; Food Reviews International. 2000;33:517-524.
10. Sharma RR, Singh SK. Strawberry cultivation- A highly remunerative farming enterprise. Agro Indian. 1999;3(2):29-31.
11. Giampieri F, Forbes-Hernandez TY, Gasparrini M, Afrin S, Cianciosi D, Reboredo-Rodriguez P. The healthy effects of strawberry bioactive compounds on molecular pathways related to chronic diseases. Ann. NY. Acad. Sci. 2017; 1398(1):62-71.
12. Galagarza OA, Ramirez-Hernandez A, Oliver HF, Álvarez Rodríguez MV, Valdez Ortiz MC, Vera EP, Cereceda Y, Diaz-Valencia YK, Deering AJ. Occurrence of Chemical Contaminants in Peruvian Produce: A Food-Safety Perspective; Foods. 2021;10(7):1461.
13. Shukla AK, Behera SK, Chaudhari SK, Singh G. Fertilizer Use in Indian Agriculture andits Impact on Human Health and Environment; Indian Journal of Fertilisers. 2022;18(3):218-237.
14. Khan MR, Rizvi TF. Nanotechnology: Scope and application in plant disease management. Plant Pathol. J. 2014; 13:214–231.
15. De Rosa G, Lopez-Moreno ML, De Haro D, Botez CE, Peralta Videa JE, Gardea Torresdey JL. Effects of ZnO NPs nanoparticles in alfalfa, tomato, and cucumber at the germination stage. Root development and X-ray absorption spectroscopy studies. Pure Appl. Chem. 2013;85(12): 2161–2174.
16. Abbasifar A, Shahrabadi F, ValizadehKaji B. Effects of green synthesized zinc and copper nano-fertilizers on the morphological and biochemical attributes of basil plant, J. Plant Nutr. 2020;43: 1104–1118.
17. Abdel-Aziz HMM, Hasaneen MNA, Omer AM. Foliar application of nano chitosan NPK fertilizer improves the yield of wheat plants grown on two different soils. Egypt. J. Exp. Biol., (Bot.). 2018;14(1):63-72.
18. Sun J, Jin L, Li R, Meng X, Jin N, Wang S, Xu Z, Liu Z, Lyu J, Yu J. Effects of Different Forms and Proportions of Nitrogen on the Growth, Photosynthetic Characteristics, and Carbon and Nitrogen Metabolism in Tomato. Plants. 2023;12(24):4175.
19. Bhatti D, Varu DK, Dudhat M. Effect of different doses of urea and nano-urea on growth and yield of guava (*Psidium guajava* L.) Cv. Lucknow-49. Pharma Innovation Journal. 2023;12(7): 464-468.
20. Kumar A, Joseph AV, Bahadur V. Effect of Foliar Application of Nano Urea, Boron and Zinc Sulphate on Growth, Yield and Quality of Guava (*Psidium guajava* L.) cv. Allahabad Surkha. Journal of Advances in Biology & Biotechnology. 2024;27(6):285-292.
21. Singh BK, Pal AK, Singh AK, Verma A. Impact of integrated nutrient management on vegetative growth and yield of strawberry. Annals of Plant and Soil Research. 2016;18(1):43-46.
22. Singh L, Dhaliwal JS, Shaifali MB. Effect of Nano Urea in Combination with Azotobacter on Growth and Yield of Strawberry (*Fragaria x ananassa* Dutch.) cv. Winter Dawn in Trans-Gangetic Region. Journal of Food Chemistry & Nanotechnology. 2023;9(1):16-20.
23. Rajasekar M, Nandhini DU, Suganthi S. Supplementation of mineral nutrients through foliar spray-A review. International Journal of Current Microbiology and Applied Sciences. 2017;6(3): 2504-2513.
24. Kalil AT, Al-Aareji JM. Role of foliar spray with selenium and urea on growth, flowering, and yield of strawberry (*Fragaria x ananassa* Duch.) CV. Albion. British Journal of Global Ecology and Sustainable Development. 2022;5:1-11.

25. Upadhyay PK, Singh VK, Rajanna GA, Dwivedi BS, Dey A, Singh RK, Rathore SS, Shekhawat K, Babu S, Singh T, Kumar Y. Unveiling the combined effect of nano fertilizers and conventional fertilizers on crop productivity, profitability, and soil well-being. Frontiers in Sustainable Food Systems. 2023;*7*:1260178.
26. Kumar, Abhishek, Naval Chandel, Barkha. Organic Farming Vs. Integrated Nutrient Management: A Comparative Review of Agricultural Productivity and Sustainability. International Journal of Plant & Soil Science. 2024;36(6):460-73. Available:https://doi.org/10.9734/ijpss/2024/v36i64648
27. Kaur Gurvinder, Ishwar Singh RK, Behl, Amit Dhankar. Effect of Different Integrated Nutrient Management Approaches on Growth, Yield Attributes and Yield of Wheat (*Triticum aestivum* L.) Crop: A Review. Asian Journal of Soil Science and Plant Nutrition. 2024;10(1): 457-68. Available:https://doi.org/10.9734/ajsspn/2024/v10i1252
28. Selim MM. Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. International Journal of Agronomy. 2020;2020(1):2821678.
29. Wu W, Ma B. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Science of the Total Environment. 2015;512:415-27.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119312