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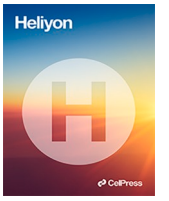

Research article

Assessing the impact of varied nitrogen dosages on the vegetative and reproductive parameters of 'Sweet Sensation' and 'Rubygem' strawberry in Morang, Nepal

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ABSTRACT

Between 2020 and 2021, an experimental investigation was conducted in Tropical conditions to assess the effects of varying levels of nitrogen fertilization (0 $kgNha^{-1}$, 0.5 $kgNha^{-1}$, 1 $kgNha^{-1}$, 1.5 $kgNha^{-1}$, and 2 $kgNha^{-1}$) on the growth and yield parameters of two strawberry cultivars (Sweet Sensation and Rubygem) in a sandy loam soil. The results demonstrated that the application of nitrogen positively influenced both vegetative (such as plant height, leaf number per plant, canopy spread, and crown diameter) and reproductive (such as number of flowers and fruits per plant, fruit yield, and TSS content) traits of both strawberry cultivars. Furthermore, the findings indicated that Sweet Sensation responded more positively to higher nitrogen doses than Rubygem in all aspects. The data showed that the utilization of 2 $kgNha^{-1}$ resulted in the highest fruit yield (0.390–0.508 t/ha) and quality traits, including TSS (7.89–9.21%). While there were no significant variations in TSS content among the plants treated with different nitrogen levels, significant differences were observed between the two strawberry cultivars.

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is a low growing herbaceous perennial plant that belongs to the Rosaceae family [1–3]. The commonly cultivated strawberry is a hybrid plant derived from two native American species *Fragaria chiloensis* of Western North and South America and *Fragaria virginiana* of Eastern North America. It is a popular temperate and subtropical fruit crop, grown all over the world, including Europe, the United States, Canada, South America, and even Asia and South East Asia [3–5]. Strawberry is one of the most popular healthy fruits in the world due to its high nutritional value, color, flavor, and taste [6,7]. Its fruit is high in Vitamin C (40–120 mg/100 g of fruit), protein, and minerals like potassium, phosphorus, calcium, and iron [8]. It has a fibrous root system that grows quickly and is heavily influenced by fertilization. Strawberry grows quickly and is heavily influenced by environmental factors such as light salinity, water quality, temperature, nutrients, air pollution, wind, and carbon dioxide [9,10]. Strawberry cultivation demands a favorable root environment as well as the availability of important nutrients such as micronutrients, nitrogen (N), phosphorus (P), and potassium (K). The cultivation of strawberries is known to exhibit relatively lower nitrogen requirements when compared to other crops. Therefore, the efficient management of nitrogen supply in strawberry plants is of paramount importance for

Abbreviations: TSS, Total Soluble Soild.

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their optimal growth and development [11,12]. Nitrogen is the element that greatly impacts plant vegetative activity encouraging robust plant growth, which enables substantial yields [21]. Nitrogen is important not only for plant growth and development, but also for fruit quality parameters like fruit firmness, size, fruit health, and correction of fruit disorders, chemical components, and shipping qualities [5]. However, if too much Nitrogen and potash are applied plants are likely to produce excess vegetative growth, have a lower fruit set, are more susceptible to diseases, and have a generally poorer plant performance [11,13]. The yield and fruit quality of strawberries are significantly impacted by the availability of nitrogen. Insufficient nitrogen levels can result in suboptimal growth and yield, whereas proper nitrogen fertilization has been demonstrated to enhance the output and quality of strawberries [14]. During periods of rapid growth, nitrogen-deficient plant leaves remain small and change from green to light green and yellow. The leaf stalk reddens and the leaf blades become vivid red as the leaves age. When the Nitrogen requirements of the strawberry plants are high, the response of vegetative plant development to increased availability of Nitrogen is usually positive [15]. discovered that the response of vegetative plant development to increased Nitrogen fertilization is largely determined by the readily available Nitrogen in the rooting zone. There was no need for micronutrient NPK in the past because trace elements were naturally supplied by the soil. However, due to intensive agriculture and an increase in salinity and soil pH, most soils contain these nutrients but are inaccessible to plants [16]. Strawberry reaction to the nitrogen rate is also cultivar-dependent [17]. Nepalese farmers face a significant challenge in improving strawberry production due to the scarcity of suitable varieties [18].

Integrated nutrient management entails using both inorganic and organic sources of nutrients to achieve balanced nutrient proportions while improving nutrient response efficiency and maximizing crop productivity of desired quality [19]. Strawberry has a long harvest duration which requires frequent and intensive fertilizers, especially nitrogen (N) which is generally the most limiting nutrient for crop production [20]. Nitrogen application is essential for crop production because it is an essential component of plant constituents such as proteins, amino acids, nucleotides, nucleic acids, and chlorophyll content, all of which are involved in several metabolic processes influencing growth, yield, and quality [22]. Nitrogen is one of the most limiting nutrients in strawberry production, so farmers use high nitrogen fertilization rates to achieve exceptional yields. So, the primary goal of the study was to find the most effective Nitrogen concentrations and their effect or performance on vegetative growth and reproductive stage in strawberry cultivars.

2. Methods and methodology

The field experiment was carried out in the farm of Samira Agrotech Private Limited, Morang, from October 2020 to April 2021 at 26° 30′ N latitude and 87° 28′ E longitude, at an altitude of approximately 75 masl. The climate of the research location is characterized as humid subtropical, with an average annual temperature of 24.30 °C and a precipitation of approximately 1900 mm. Detailed meteorological data throughout the research study is available in Table 1, which provides a comprehensive overview of the weather conditions observed during the study period. The plant materials used in the study were two varieties of low chilling strawberry i.e., 'Sweet Sensation', and 'Rubygem'. Planting material consisted of bare root strawberry transplants. Those cultivars lack registration and are currently unavailable in Nepal. Samira Agrotech Private Limited obtained planting materials from California and Spain.

The detail of the soil analysis is presented in Table 2. The soil was sandy loam with neutral pH and low in organic matter and nitrogen content and high in phosphorous and potassium content.

2.1. Experimental layout

A two-factor randomized complete block design (RCBD) was used in the field experiment. Two low chilling cultivars, Sweet Sensation and Rubygem, were tested with five different nitrogen doses (0.5 $kgNha^{-1}$, 1 $kgNha^{-1}$, 1.5 $kgNha^{-1}$, 2 $kgNha^{-1}$, and control, or 0 $kgNha^{-1}$) and were replicated four times each. The total experimental unit was 570 m^2 with a plot size of 8.4 m^2. Each plot has two rows with a 60 cm between-rows distance and a row of plants with a 30 cm between-plants to plant distance. There was a gap of 1 m between the blocks (replication) and 0.5 m between the plots. Strawberries (bare rooted) were planted in a raised bed with a double-row system covered with mulching (Polythene sheet). The planting was completed on October 27, 2020. One week of overhead sprinkler irrigation for 20 min every two days was administered to enable plant establishment, followed by drip irrigation with

Table 1
Meteorological data of research site from October 2020 to April 2021.

Months	Temperature (0C)								
	Maximum			Minimum			Total rainfall (mm)		
	Actual	Normal	DN**	Actual	Normal	DN**	Actual	Normal	DN**
Oct.	34.3	34.4	−0.1	20.6	22	−1.4	42	41	1
Nov.	29.3	29.1	0.2	15.00	15.4	−0.4	0	0.4	−0.4
Dec.	22.19	22	0.19	9.13	7	2.13	0.8	0.3	−0.5
Jan.	19.6	19.1	0.5	7.5	8.1	−0.6	0	0.3	−0.3
Feb.	26.3	27.1	0.8	11.5	12.2	−0.7	0	1.2	−1.2
Mar.	31.6	31.2	0.4	15.4	14.5	0.9	4.8	3.4	1.4
Apr.	34.6	35.2	−0.6	18.5	19.4	−0.9	28.7	26.3	−2.4

Note: Actual: Recorded during the experimental period, Normal: Average of the last 10 years DN**: Deviation from normal.
Source: Meteorological Station of Biratnagar Airport, Morang.

Table 2
Physical and chemical properties of soil at experimental site during 2020/21.

Properties	Content	Remark	Method Used
1 Physical properties			
Sand (%)	60.5		Hydrometer
Silt (%)	34		
Clay (%)	5.5		
2 Chemical properties			
Organic matter (%)	0.45	Low	Walkey and Black
Nitrogen (%)	0.02	Low	Kjeldahl method
Phosphorous (Kg/ha)	37	Medium	Olsen's
Potassium % (Kg/ha)	78	Low	Ammonium acetate
Soil pH	6.3	Alkaline	Potentiometric
Texture		Sandy loam	Textural Matrix

fertilizer. To ensure consistent plant establishment in each plot, dead or incorrectly established plants were removed and replanted with supplied plants. 11 plants per plot out of 25 plants were selected randomly for recording observations for different morphological characters.

2.2. Parameters studied

Various Morphological, reproductive and quality parameters of randomly selected and properly tagged sample plants were evaluated.

a. Plant Height

The height of plant was measured after 45 days of transplanting from ground level (point of emergence of plant) to top of plant with the help of scale in centimeters and average height was calculated.

b. Number of leaves per plant

The total number of true leaves existing at real-time were counted from tagged plants and average number of leaves was worked out.

c. Crown diameter

Crown diameter of plant was measured at the end of harvesting using Vernier's calipers in centimeters and average was worked out.

d. Canopy spread

Canopy spread was recorded from 45 days after transplanting in two directions using scale measuring in centimeters and average was worked out.

e. Number of flowers per plant

Total number of flowers borne in tagged (sample) plants were counted. Since the flowers were removed till 60 days of transplantation for plant to attain proper vegetative growth flower count started from 105 days after transplantation.

f. Number of fruits per plant

Total number of fruits was counted from the tagged/sample plants.

g. Total fruit yield from sample plant

Total yield from the tagged/sample plants at different picking were calculated and average was worked out.

h. Total Soluble Solid (TSS)

The sample strawberry fruits were harvested and taken to laboratory of G.P. Koirala College of Agriculture and Research Centre (GPCAR) Gothgaun, Morang for testing total soluble sugar content in Strawberry. Sample strawberry from each treatment was homogenized in a blender and juice was extracted. TSS was measured with hand held refractometer (ERMA Inc., Tokyo, Japan) using

juice extracted from strawberry fruit and expressed as °Brix.

2.3. Statistical analysis

The significant difference for each parameter was tested using an analysis of variance (ANOVA). The calculation was performed at a 5% level of significance. For mean separation, all collected data were subjected to analysis of variance and Duncan's Multiple Range Test (DMRT). Microsoft Word 2016 was utilized for word processing. The data of various parameters were analyzed using Gen-Stat (15th Edition).

3. Results

3.1. Morphological parameters

a. Plant height

The present study indicates that there is a statistically significant difference in the plant height of strawberry cultivars across various time points following transplanting. Specifically, the cultivar 'Sweet Sensation' demonstrated the greatest height when compared to the 'Rubygem' variety at 45, 60, and 90 days after transplanting, as illustrated in Table 3. Additionally, the application of 2 $kgNha^{-1}$ resulted in the greatest plant height at 45, 60, and 90 DAT (17.86 cm, 19.33 cm, and 23.77 cm, respectively), while the control treatment exhibited the lowest plant height (15.39 cm, 17.05 cm, and 22.46 cm, respectively).

b. Leaf Number per plant

The results of the study indicate that at 45, 60, and 90 DAT, the 'Sweet Sensation' variety demonstrated a significantly higher number of leaves per plant compared to the 'Rubygem' variety, as depicted in Table 4. This result indicates that the 'Sweet Sensation' variety performs better. The variability in the number of leaves per plant could be attributed to differences in photoperiod, light intensity, soil nutrient availability, metabolic processes, and resource allocation to above-ground plant structures across various cultivars. Furthermore, the application of 2 $kgNha^{-1}$ resulted in the maximum number of leaves per plant at 45, 60, and 90 DAT (9.723, 13.69, and 23.29, respectively). In contrast, the control treatment exhibited the lowest number of leaves per plant (8.030, 10.79, and 17.05, respectively) during the same time periods.

c. Canopy Spread (cm)

The results of the study demonstrate that the 'Sweet Sensation' variety exhibited the greatest canopy spread while the 'Rubygem' variety demonstrated the smallest canopy spread. Additionally, at 45, 60, and 90 DAT, the application of 2 $kgNha^{-1}$ resulted in the maximum area of canopy spread (21.80 cm, 27.63 cm, and 33.11 cm, respectively), shown in Table 5. Conversely, the control treatment showed the lowest surface area of canopy spread (16.99 cm, 23.18 cm, and 29.30 cm, respectively) during the same time periods.

d. Crown Diameter (cm)

Table 3
Differences in plant height (cm) of strawberry cultivars under varied nitrogen doses at DATs 2020/21.

Variety	Plant Height (cm)		
	45 DAT	60 DAT	90 DAT
Sweet Sensation	17.68	19.55	24.50
Rubygem	15.68	17.40	21.50
Grand mean	16.68	18.48	23.00
SEM±	0.354	0.320	0.223
$LSD_{0.05}$	1.026	0.927	0.647
F- test	**	**	**
0 $kgNha^{-1}$ (Control)	15.39^{c}	17.05^{b}	22.46^{b}
0.5 $kgNha^{-1}$	15.87^{bc}	18.57^{a}	22.58^{b}
1 $kgNha^{-1}$	16.77^{abc}	18.71^{a}	22.69^{b}
1.5 $kgNha^{-1}$	17.49^{ab}	18.73^{a}	23.49^{ab}
2 $kgNha^{-1}$	17.86^{a}	19.33^{a}	23.77^{a}
SEM±	0.559	0.505	0.353
$LSD_{0.05}$	1.622	1.466	1.023
CV(%)	9.5	7.7	4.3
F- test	*	*	*

Note: NS means "Non-Significant", Significant "*"; Days after transplanting "DAT". Treatments means followed by common letters/letters within a column are not differently based on DMRT at 0.05.

Table 4
Differences in leaf number per plant (cm) of strawberry cultivars under varied nitrogen doses at DATs, 2020/21.

Variety	Leaf Number per plant		
	45 DAT	60 DAT	90 DAT
Sweet Sensation	12.37	16.65	27.84
Rubygem	5.57	7.72	13.91
Grand mean	8.97	12.19	20.87
SEM±	0.293	0.312	1.065
$LSD_{0.05}$	0.852	0.906	2.186
F-test	**	**	**
Nitrogen Dose			
0 $kgNha^{-1}$ (Control)	8.030^{b}	10.79^{c}	17.05^{b}
0.5 $kgNha^{-1}$	8.783^{ab}	11.37^{bc}	20.57^{a}
1 $kgNha^{-1}$	8.859^{ab}	12.31^{ab}	20.77^{a}
1.5 $kgNha^{-1}$	9.461^{ab}	12.77^{ab}	22.68^{a}
2 $kgNha^{-1}$	9.723^{a}	13.69^{a}	23.29^{a}
SEM±	0.464	0.494	1.684
$LSD_{0.05}$	1.346	1.433	3.456
CV(%)	14.6	11.5	16.1
F-test	*	*	*

Note: NS means “Non-Significant”, Significant "*"; Days after transplanting “DAT”. Treatments means followed by common letters/letters within a column are not differently based on DMRT at 0.05.

Table 5
Differences in Canopy spread (cm) of strawberry cultivars under varied nitrogen doses at DATs, 2020/21.

ety	Canopy Spread (cm)		
	45 DAT	60 DAT	90 DAT
Sweet Sensation	21.70	28.03	32.94
Rubygem	17.21	22.86	30.10
Grand mean	19.45	25.45	31.52
SEM±	0.617	0.616	0.632
$LSD_{0.05}$	1.791	1.786	1.833
F-test	**	**	*
Nitrogen Dose			
0 $kgNha^{-1}$ (Control)	16.99^{a}	23.18^{a}	29.30^{a}
0.5 $kgNha^{-1}$	18.08^{ab}	23.30^{a}	30.03^{ab}
1 $kgNha^{-1}$	19.93^{abc}	26.03^{ab}	32.11^{ab}
1.5 $kgNha^{-1}$	20.46^{bc}	27.10^{b}	33.05^{b}
2 $kgNha^{-1}$	21.80^{c}	27.63^{b}	33.11^{b}
SEM±	0.976	0.973	0.999
CV (%)	14.2	10.8	9.0
$LSD_{0.05}$	2.833	2.824	2.899
F-test	*	*	*

Note: NS means “Non-Significant”, Significant "*"; Days after transplanting “DAT”. Treatments means followed by common letters/letters within a column are not differently based on DMRT at 0.05.

A greater number of leaves producing more photosynthates may be the reason for the larger crown diameter observed in Sweet sensation variety. Furthermore, the application of 2 $kgNha^{-1}$ resulted in the highest crown diameter at 45, 60, and 90 DAT (0.9037 cm, 1.363 cm, and 2.476 cm, respectively), while the lowest crown diameter (0.7937 cm, 1.022 cm, and 1.880 cm, respectively) was observed in the control treatment, shown in Table 6.

4.2. Reproductive parameters

a. Number of flowers per plant

The study found significant variations among different cultivars and different doses of nitrogen fertilizers at 105, 119, and 133 DAT in terms of the number of flowers per plant. The data in Table 7 present the number of flowers per plant of different varieties and nitrogen fertilizers at different DAT. At 105 DAT, the ‘Sweet Sensation’ variety had the most flowers per plant (1.414), while the ‘Rubygem’ variety had the fewest flowers (0.076). The highest number of flowers per plant (0.97) was found in the 1.5 $kgNha^{-1}$ treatment, which was statistically similar to the 2 $kgNha^{-1}$ and 1 $kgNha^{-1}$ treatments. The control application showed the lowest number of flowers per plant (0.26). At 119 DAT, the highest number of flowers per plant was recorded in the ‘Sweet Sensation’ variety (4.26), while the least flowers were recorded in the ‘Rubygem’ variety (1.68). The highest number of flowers per plant (4.21) was found in the 2 $kgNha^{-1}$ treatment, while the control application showed the lowest number of flowers per plant (2.04). The 2 $kgNha^{-1}$

Table 6
Differences in crown diameter (cm) of strawberry cultivars under varied nitrogen doses at DATs, 2020/21.

Variety	Crown diameter (cm)		
	45 DAT	60 DAT	90 DAT
Sweet Sensation	1.024	1.333	2.601
Rubygem	0.711	1.010	1.901
Grand mean	0.867	1.171	2.251
SEM±	0.0312	0.0540	0.0791
$LSD_{0.05}$	0.0906	0.1568	0.2296
F-test	**	**	**
Nitrogen Dose			
0 $kgNha^{-1}$ (Control)	0.7937^{a}	1.022^{b}	1.880^{b}
0.5 $kgNha^{-1}$	0.8612^{a}	1.081^{b}	2.275^{a}
1 $kgNha^{-1}$	0.8837^{a}	1.114^{ab}	2.291^{a}
1.5 $kgNha^{-1}$	0.8950^{a}	1.275^{ab}	2.331^{a}
2 $kgNha^{-1}$	0.9037^{a}	1.363^{a}	2.476^{a}
SEM±	0.0494	0.0854	0.1251
CV (%)	16.1	20.6	15.7
$LSD_{0.05}$	0.1433	0.2479	0.3631
F-test	NS	*	*

Note: NS means "Non-Significant", Significant "*"; Days after transplanting "DAT". Treatments means followed by common letters/letters within a column are not differently based on DMRT at 0.05.

Table 7
Differences in number of flowers per plant of strawberry cultivars under varied nitrogen doses at DATs, 2020/21.

S.N.	105 DAT	119 DAT	133 DAT
Sweet Sensation	1.414	4.26	3.34
Rubygem	0.076	1.68	2.61
Grand Mean	0.745	2.97	3.31
SEM±	0.1352	0.329	0.31
$LSD_{0.05}$	0.2775	0.676	0.33
F test	***	***	***
0 $kgNha^{-1}$ (Control)	0.26^{a}	2.04^{a}	2.63^{b}
0.5 $kgNha^{-1}$	0.66^{ab}	2.6^{a}	2.99^{ab}
1 $kgNha^{-1}$	0.89^{b}	2.87^{a}	2.75^{b}
1.5 $kgNha^{-1}$	0.97^{b}	3.09^{a}	3.15^{ab}
2 $kgNha^{-1}$	0.93^{b}	4.21^{b}	3.37^{a}
SEM±	0.21	0.52	0.5
$LSD_{0.05}$	0.43	1.06	0.53
CV (%)	57.4	35.1	17.3
F test	*	*	*

Note: Significant "*"; very highly significant "***"; Days after transplanting "DAT". Treatments means followed by common letters/letters within column are not differently among based on DMRT at 0.05.

Table 8
Differences in the number of fruits per plants of strawberry cultivars under varied nitrogen doses at DATs, 2020/21.

S.N.	119 DAT	133 DAT	145 DAT
Sweet Sensation	5.59	10.67	14.49
Rubygem	1.82	4.39	7.86
Grand Mean	3.70	7.53	11.17
SEM±	0.339	0.772	1.199
$LSD_{0.05}$	0.696	1.584	2.461
F test	***	***	***
0 $kgNha^{-1}$ (control)	3.08^{a}	5.44^{a}	7.12^{a}
0.5 $kgNha^{-1}$	3.17^{a}	6.91^{ab}	11.89^{b}
1 $kgNha^{-1}$	3.69^{ab}	6.96^{ab}	11.63^{b}
1.5 $kgNha^{-1}$	3.91^{ab}	8.99^{b}	13.13^{b}
2 $kgNha^{-1}$	4.63^{b}	9.34^{b}	12.07^{b}
SEM±	0.53	1.22	1.89
$LSD_{0.05}$	1.10	2.50	3.89
CV(%)	29.0	32.4	34.0
F test	*	*	*

Note: Significant "*"; very highly significant "***"; Days after transplanting "DAT". Treatments means followed by common letters/letters within column are not differently among based on DMRT at 0.05.

treatment was statistically similar to the 0.5 kgNha^{-1}, 1 kgNha^{-1}, and 0.1 kgNha^{-1} treatments. At 133 DAT, the highest number of flowers per plant was recorded in the 'Sweet Sensation' variety (3.34), while the least flowers were recorded in the 'Rubygem' variety (2.61). The highest number of flowers per plant (3.37) was found in the 2 kgNha^{-1} treatment, while the control application showed the lowest number of flowers per plant (2.63). The 2 kgNha^{-1} treatment was statistically similar to the 0.5 kgNha^{-1} and 1 kgNha^{-1} treatments.

b. Number of fruits per plant

Statistically significant variation was observed among different cultivars and Nitrogen fertilization levels at 119, 133, and 145 DAT in terms of the number of fruits per plant. The results are presented in Table 8.

At 105 DAT, the 'Sweet Sensation' variety had the most fruits per plant (5.59), while the 'Rubygem' variety had the fewest fruits (1.82). The application of 2 kgNha^{-1} resulted in the highest number of fruits (4.63), whereas the control application showed the lowest number of fruits (3.08), which was statistically similar to the application of 1 kgNha^{-1}. Similarly, the application of 1 kgNha^{-1} and 1.5 kgNha^{-1} showed no significant difference. At 133 DAT, the highest number of fruits per plant (10.67) was recorded in the 'Sweet Sensation' variety, while the lowest (4.39) was recorded in the 'Rubygem' variety. The application of 2 kgNha^{-1} resulted in the highest number of fruits (9.34), which was statistically similar to the applications of 0.5 kgNha^{-1}, 1 kgNha^{-1}, and 1.5 kgNha^{-1}. On the other hand, the control application showed the lowest number of fruits (5.44). At 145 DAT, the highest number of fruits per plant (14.49) was recorded in the 'Sweet Sensation' variety, while the lowest (7.86) was recorded in the 'Rubygem' variety. The application of 1.5 kgNha^{-1} resulted in the highest number of fruits (13.13), which was statistically similar to the applications of 0.5 kgNha^{-1}, 1 kgNha^{-1}, and 2 kgNha^{-1}. The control application showed the lowest number of fruits (7.12). These results suggest that different cultivars and Nitrogen fertilization levels can significantly impact the fruit numbers of strawberry plants.

c. Fruit yield (t/ha)

Table 9 displays the fruit yield (in metric tons per hectare) of multiple strawberry cultivars across the first, second, and third picking periods. Our findings reveal substantial inter-cultivar variation in fruit yield across these harvests. Specifically, the fruit yield of each cultivar during the individual picking periods as well as the cumulative yield are presented in the aforementioned table. During the first picking, 'Sweet Sensation' variety exhibited the highest fruit yield (0.944 t/ha) while 'Rubygem' showed the lowest yield (0.072 t/ha). The application of 2 kgNha^{-1}resulted in the highest yield of 0.65 t/ha, which is statistically at par with 1 kgNha^{-1}and 1.5 kgNha^{-1}. The control application produced the lowest yield of 0.25 t/ha, which is at par with 0.5 kgNha^{-1} · During the second picking, 'Sweet Sensation' variety again displayed the highest fruit yield (0.877 t/ha) while 'Rubygem' had the lowest yield (0.024 t/ha). The application of 2 kgNha^{-1} resulted in the highest yield of 0.62 t/ha, which is statistically at par with 1 kgNha^{-1} and 1.5 kgNha^{-1}. The control application produced the lowest yield of 0.24 t/ha, which is at par with 0.5 kgNha^{-1}. During the third picking, 'Sweet Sensation' variety exhibited the highest fruit yield (0.46 t/ha) while 'Rubygem' had the lowest yield (0.311 t/ha). The application of 1.5 kgNha^{-1} resulted in the highest yield of 0.36 t/ha whereas the control application produced the lowest yield of 0.24 tha^{-1}, which is at par with 0.5 kgNha^{-1}, 1 kgNha^{-1}, and 2 kgNha^{-1}.

d. Total Soluble Solid (TSS)

A significant variation was observed among different cultivars of strawberry at first, second, and third picking with respect to the total soluble sugar (TSS %) content. The total soluble sugar (TSS %) content of different varieties in each picking is presented in Table 10. At the first picking, the variety 'Sweet Sensation' and 'Star' showed the highest TSS content (8.638), while the variety 'Rubygem' showed the lowest TSS content (8.179). At the second picking, the variety 'Rubygem' showed the highest TSS content (7.70), whereas the variety 'Sweet Sensation' exhibited the least TSS content (7.70). At the third picking, the variety 'Sweet Sensation' showed the highest TSS content (9.61), whereas the variety 'Rubygem' exhibited the least TSS content (8.81). Furthermore, no significant differences were observed among the treatments applied to the strawberry plants during the first, second, and third pickings.

5. Discussion

In a field experiment, [23], reported that the growth, yield, and nutritional status of strawberry plants are significantly influenced by the application of Azotobacter and Azospirillum coupled with 60 kgNha^{-1}, and 100 ppm GA3. This seems to resemble with the present study. Under a similar vein, [24], discovered that increasing N rates early in the growing season seems to be a successful tactic for increasing the productivity of winter strawberry. Further, [25], demonstrated that there is a significant impact on the majority of plant growth and yield characteristics, including plant height, number of leaves per plant, crown diameter, leaf area, dry weight per plant, average fruit length, diameter, weight, and firmness, and chemical fruit constituents, including TSS, vitamin C, titratable acidity, and anthocyanins content when full dose of NPK (200 kg/fed) + 10-ton compost fed-1 were applied. While [26] demonstrated that potassium (1.67 g/plant) provided the strongest stimulation for the enhancement of the variables (plant height, number of leaves, fresh fruit mass, number of fruits, total soluble solids, and titratable acidity) at the highest concentrations of nitrogen and phosphorus fertilizers (1.6 g/plant and 2.1 g/plant, respectively). Similarly, [27], showed that the growth and fruit characteristics, such as the quantity of flowers, berries, fruit yield, were recorded at their highest levels in treatments with Azotobacter inoculation and 50% N substitution by vermicompost (0.5% N) and the remaining 50% through inorganic fertilizer (1% N). Moreover, [28], reported that

Table 9
Differences in terms of yield of strawberry cultivars under varied nitrogen doses, 2020/21.

S.N	First Picking	Second Picking	Third Picking
Sweet Sensation	0.944	0.877	0.469
Rubygem	0.072	0.024	0.311
Grand Mean	0.508	0.450	0.390
SEM±	0.0516	0.0594	0.0699
$LSD_{0.05}$	0.1059	0.1219	0.1434
F test	***	***	*
0 $kgNha^{-1}$ (control)	0.28^{b}	0.24^{b}	0.24^{b}
0.5 $kgNha^{-1}$	0.37^{b}	0.28^{b}	0.34^{b}
1 $kgNha^{-1}$	0.55^{a}	0.53^{a}	0.34^{b}
1.5 $kgNha^{-1}$	0.66^{a}	0.55^{a}	0.36^{b}
2 $kgNha^{-1}$	0.65^{a}	0.62^{a}	0.65^{a}
SEM±	0.081	0.094	0.11
$LSD_{0.05}$	0.167	0.19	0.22
CV(%)	32.1	41.7	56.7
F test	***	***	*

Note: Significant "*"; very highly significant "***"; Days after transplanting "DAT". Treatments means followed by common letters/letters within column are not differently among based on DMRT at 0.05.

Table 10
Differences in total soluble sugar (TSS) at different picking of strawberry cultivars, under varied nitrogen doses, 2020/21.

S. N.	First picking	Second picking	Third picking
Sweet Sensation	8.638	7.70	9.61
Rubygem	8.179	8.07	8.81
Grand Mean	8.408	7.89	9.21
SEM±	0.1936	0.234	0.296
$LSD_{0.05}$	0.3972	0.481	0.607
F test	*	*	*
0 kg N (control)	8.135	7.595	8.015
0.5 $kgNha^{-1}$	8.155	7.315	8.895
1 $kgNha^{-1}$	8.681	7.960	9.535
1.5 $kgNha^{-1}$	8.470	8.137	9.787
2 $kgNha^{-1}$	8.600	8.437	9.828
SEM±	0.3061	0.371	0.468
$LSD_{0.05}$	0.6280	0.761	0.960
CV(%)	7.3	9.4	10.2
F test	Ns	Ns	Ns

Note: "NS" Non-significant, Significant "*"; very highly significant "***"; Days after transplanting "DAT". Treatments means followed by common letters/letters within column are not differently among based on DMRT at 0.05.

regardless of the N source, daily low-dose N application is essential to achieve excellent strawberry yields. Similar results were also observed by Ref. [29] when they looked into how various fertilizers affected strawberry fruit yield and quality. Although it has been demonstrated that nitrogen fertilization increases strawberry output, this finding is also similar with the finding of [30]). After thoroughly analyzing the result obtained from this research, we came to a conclusion that at 2 kg/ha nitrogen application the vegetative parameters (plant height, leaf number per plant, canopy spread, and crown diameter) and reproductive parameters (number of flowers per plant, number of fruits per plant, fruit yield, and TSS content) are significantly affected that seems to be similar to the outcome obtained by Ref. [31].

6. Conclusions

The present study reveals that the cultivar "Sweet Sensation" exhibits a greater responsiveness to nitrogen application compared to the cultivar "Rubygem". Conversely, the application of 2 kg/ha nitrogen has been observed to promote growth, increase the number of leaves, and enlarge the crown diameter without adversely affecting fruit quality. Therefore, optimizing nitrogen fertilizer use is an essential strategy to enhance the profitability of strawberry production. Furthermore, fertilizer management practices should be adjusted according to cultivar and dose response to minimize environmental risks and loss of fruit quality. The results also indicate that "Sweet Sensation" is significantly more sensitive to nitrogen application than "Rubygem". In summary, our findings demonstrate that an application of 2 kg/ha nitrogen can be utilized to increase yield, while the application of nitrogen in the required dose significantly enhances strawberry yield. However, further investigations are needed to evaluate the effects of nitrogen fertilization on various fruit quality attributes over multiple seasons.

Author contribution statement

Shambhu Katel, Honey Raj Mandal, Sandipa Timsina, Amrit Katuwal, Sumit Kumar Sah, Bishnu Yadav, Shubh Pravat Singh Yadav and Nirmal Adhikari: Conceived and designed the experiments and Performed the experiments.

Shambhu Katel, Shubh Pravat Singh Yadav and Nirmal Adhikari: Analyzed and interpreted the data and Contributed materials and analysis tools or data.

Shambhu Katel, Honey Raj Mandal, Sandipa Timsina, Amrit Katuwal, Shubh Pravat Singh Yadav: Wrote the paper.

Data availability statement

Data associated with this study has been deposited at https://drive.google.com/drive/folders/10VsXOkLUVyXdlZ92Y23ipzM5fccHGBvo?usp=sharing

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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