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Influence of Nutrient Regimes on Growth of Strawberry *(Frigaria×ananassa)* under Ebb and Flow System of Hydroponics

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Abstract

To study the influence of different nutrient concentration of Hoagland solution (50, 80, 130 and 200 %) on growth of strawberry cv Sweet Sensation under ebb and flow system of hydroponics, an experiment was conducted at Soilless Agriculture Demonstration Unit, NSP, University of Agricultural Sciences, GKVK, Bengaluru. The results reveal that Treatment T_3 (Hoagland 130 %) displayed the tallest plant height (19.82 cm), highest leaf number (17.70), maximum plant spread (25.17 cm), highest total leaf area (1225.41 cm^2), longest petiole (11.36 cm), highest shoot fresh weight (32.07 g), shoot dry weight (7.21 g), longest roots (17.80 cm), highest root fresh weight (12.77 g) and root dry weight (5.74 g). Whereas, 50 per cent Hoagland or 200 per cent Hoagland produced lowest growth. Strawberry grown under ebb and flow system with 130 per cent of Hoagland solution produced optimum growth compared to other treatments. Hence, this treatment can be used for production of strawberry under ebb and flow system for maximum growth of plants.

Keywords : Strawberry, Hoagland, Soilless, Ebb & flow, Hydroponics

Soil is typically the most accessible growing medium for plants, providing essential support, nutrients, air and water for successful plant growth. However, soil can also present significant challenges for plant cultivation. It is projected that by 2050, approximately 50 per cent of the world's arable land will become unsuitable for farming, primarily due to global climate change (Annonymous, 2017). As a result, food production will need to increase by 110 per cent to meet the demands of the growing global population (Gashgari *et al*., 2018). The presence of pathogens, unsuitable soil pH, soil compaction, poor drainage and erosion further exacerbate these challenges. Additionally, traditional crop cultivation in soil or open-field agriculture, requires extensive space, labour and water resources. In some regions, particularly metropolitan areas, soil may be unavailable for crop production or fertile arable land may be scarce due to unfavourable geographic or topographical conditions (Sharma *et al*., 2022). Keeping these challenges in view, there is an urgent need to develop alternative food production methods that can meet the rising demand with lower costs and minimal use of natural resources.

Strawberry (*Fragaria* x*ananassa* Duch.) is an interspecific hybrid crop that originated from a cross between *Fragaria chiloensis*, native to Chile and *Fragaria virginiana*, native to eastern North America (Darrow, 1966), belongs to the Rosaceae family. Strawberries have an ancient origin with France considered their place of origin (Liston *et al*., 2014). Strawberries are one of the most economically significant and widely consumed fruit crops globally, valued for their high nutritional content, flavour and colour (Sturm *et al*., 2003).

Global strawberry production is approximately 9.57 million tonnes per year with China leading as the largest producer, contributing 33.64 lakh tonnes, followed by the United States with 14.20 lakh tonnes. Together, China and the USA account for 50 per cent of the world's total strawberry production. In India, the area under strawberry cultivation in 2021-22 spanned 3,031 hectares, producing a total of 19,840 metric tonnes (Annonymous, 2023). Haryana accounted for 31.50 per cent of this production, followed by Maharashtra with 24.50 per cent and Jammu and Kashmir contributing 20.93 per cent. Recently, it's cultivation has expanded to limited areas of Karnataka, namely Belgavi, Bengaluru Rural, Dharwad and Shivamogga.

With changing lifestyles and increasing awareness, there is a growing demand for healthy and nutritious food options globally. Strawberries are highly nutritious, rich in ascorbic acid, secondary metabolites, simple sugars, acids and antioxidants that promote health (Pe-Rez *et al*., 1997 and Kanupriya, 2002). A serving (100 g) of strawberries contains 89 g of water, 0.07 g of protein, 0.5 g of fats, 8.4 g of carbohydrates and 59 mg of ascorbic acid (Galletta and Bringhurst, 1995). Strawberries are consumed fresh and in processed forms such as ice cream, soft drinks, confections and preserved products like jam, jellies and squashes, which can be enjoyed out of season (Galletta and Bringhurst, 1995). Consumption of strawberries has been associated with numerous health benefits, including lowering cholesterol, improving vascular endothelial function, reducing inflammatory biomarkers and mitigating oxidative stress-related diseases like cancer (Giampieri *et al*., 2012; Hannum, 2004 and Zhang *et al*., 2008). Strawberries are also a good source of phenolics, which act as antioxidants and are valued in the diet for their role in preventing cardiovascular disease (CVD) and cancer (Hakkinen and Torronen, 2000).

Therefore, growing strawberries hydroponically can be an environmentally sustainable approach, requiring less water and pesticide use. Moreover, hydroponically grown strawberries may command higher prices and offer numerous health benefits to consumers. Keeping the above facts in mind the present investigation was carried out to examine the effect of nutrient concentration on growth of strawberry grown under Ebb and flow system of hydroponics.

Material and Methods

Site Description and Treatment Details

Strawberry plants (cv. Sweet Sensation) of similar growth were procured from KF Bioplants Ltd., Pune. These plants were planted under Ebb and flow system of hydroponics in soilless medium. The experiment was carried out at temperature-controlled greenhouse of Soilless Agriculture Demonstration Unit, National Seed Project, University of Agricultural Sciences, GKVK, Bengaluru. Geographically it is located in Eastern Dry Zone (Zone-5) of Karnataka at latitude $13^0 5'$ N and 77^0 34' E with an altitude of 923.3 m above mean sea level.

The soilless substrates (*viz.,* coco peat, perlite etc.) and water soluble plant nutrients were procured from Green Heaven, Rajiv Gandhinagar, Bengaluru. Four different nutrient concentrations were prepared namely, T_1: Hoagland solution (50 %), T_2: Hoagland solution (80 %), T_3: Hoagland solution (130 %), T_4: Hoagland solution (200 %). Following is the nutrient composition:

Hoagland solution (50 %) (ppm): N-105.00, P-15.50, K-117.00, Ca-100.00, Mg-17.00, S-32.00, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04

Hoagland solution (80 %) (ppm): N-168.00, P-24.80, K-187.20, Ca-160.00, Mg-27.20, S-51.20, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04

Hoagland solution (130 %) (ppm): N-273.00, P-40.30, K-304.20, Ca-260.00, Mg-44.20, S-83.20, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04

Hoagland solution (200 %) (ppm): N-420.00, P-62.00, K-468.00, Ca-400.00, Mg-68.00, S-128.00, Na-0.02, Cl-0.14, Fe-2.50, Mn-0.50, Zn-0.10, B-0.50, Cu-0.02, Mo-0.04

The temperature (23°C/17°C) and relative humidity inside the polyhouse was controlled by sensor-based technology.

Experimental Setup

For this experiment, strawberry plants (cv. Sweet Sensation) are grown using an ebb and flow hydroponics system, where each treatment receives a specific nutrient concentration. Each treatment is cultivated on separate ebb and flow tables, ensuring that the nutrient solutions applied to the plants remain independent for each group. To ensure accurate application of the different nutrient regimes, each ebb and flow table is provided with a dedicated nutrient reservoir. Strawberry plants are placed in individual pots filled with a mixture of soilless media, these pots allow the nutrient solution into the media during the flood cycle via capillary action. Each table had a drainage outlet to allow the nutrient solution to return to the dedicated reservoir after the flood cycle.

The pH and electrical conductivity (EC) of each nutrient solution are regularly monitored to ensure the nutrient levels remain optimal for plant growth. Adjustments are made as necessary to maintain the target nutrient concentration in each reservoir.

Methodology

Growth parameters like plant height, leaf number, total leaf area, petiole length, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight were recorded at 120 days after planting. The height of the plant was measured individually with the help of a measuring scale from the crown level to the apex of primary leaves and results were expressed as average height in centimetres (cm). The plant spread was measured in two directions *i.e.,* from north-south and east-west. The maximum horizontal spread of the plant was worked out by taking mean and measured in centimetre. Leaf area was computed by digital leaf area meter (LAM 211), this was then multiplied with number of leaves to get total leaf area and expressed in centimetre square (cm^2). Petiole length is measured from the base of the petiole, where it attaches to the crown of the plant, to the point where it connects with the leaf blade (lamina). The dry weights were recorded after drying the samples in hot air oven (80°C) to the point where it records same weight for 3 consecutive days.

The statistical design used for the experiment was Completely Randomized Design (CRD) with five replications. The overall significance of difference among the treatments was tested, using critical differences (C.D.) at 5 per cent level of significance. The results were statistically analysedusing OPSTAT.

Results and Discussion

The nutrition, growing medium, environment and variety can greatly influence the growth and yield of strawberry (Tomasi *et al*., 2015). In the current study results indicate that grow conditions such as amount of nutrient supplied affected the growth and yield of the strawberry under hydroponic system. The moderate increase in nutrient concentration had higher positive effect on growth and yield during whole cropping period.

Plant Height (cm)

The plant height varied significantly during the growth period of the plant. There was a pronounced difference observed in plant height at 120 DAT with T_3-(Hoagland solution 130 %) producing tallest plants at 19.82 cm which was followed by T_2 (19.34 cm; Hoagland solution 80 %), while, shortest plants (13.54 cm) were observed in T_1 (Hoagland solution 50 %) followed by T_4 (Hoagland solution 200 %). This suggests that nutrient concentration moderately higher (T_3) can benefit the plant growth in soilless medium. On the other hand extreme nutrient regimes can adversely hinder the plant growth may be due to deficiency ortoxicity. These results are in consistent the observations of Seema *et al*. (2023) and Roostaa and Hamidpor (2011), who reported that suboptimal nutrient levels can severely restrict the plant height and over all growth in hydroponic systems. Shah *et al*. (2011) was of the opinion that excessive nutrient levels can lead to negative effects on plant growth due to nutrient antagonism or osmotic stress (Fig. 1).

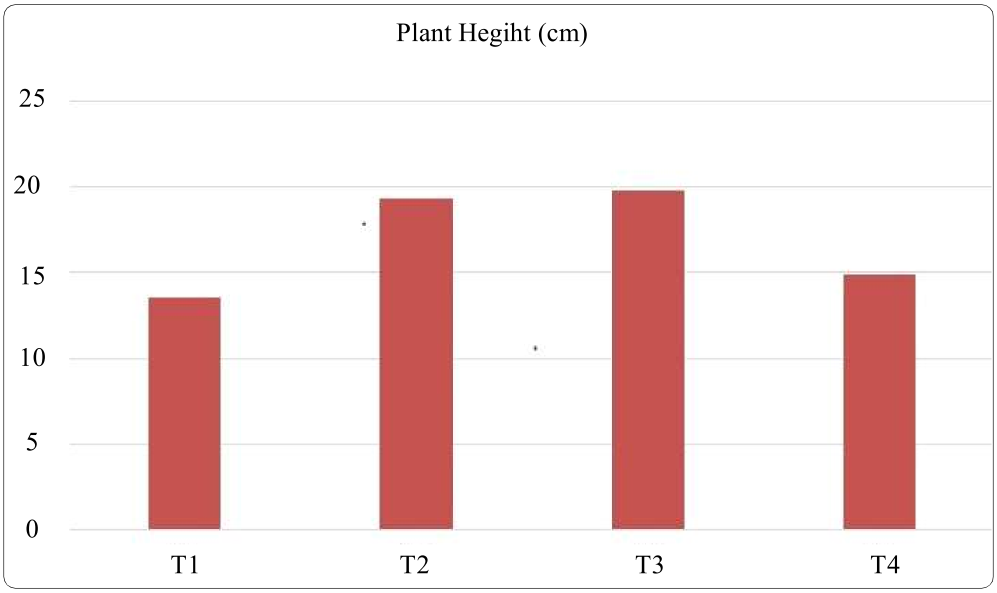

Fig. 1 : Influence of nutrient concentration of Hoagland solution of plant height of strawberry cv Sweet Sensation

Leaf Number

The evaluation of leaf number in strawberry cultivated under various nutrient regimes revealed significant variations across different growth stages (Fig. 2). The treatment T_3 produced highest number of leaves (17.70) which was followed by T_2 (15.50). These results are in line with the findings of Pezzarossa *et al*. (2014), who emphasized that maintaining optimum nutrient levels throughout the growth cycle is essential for maximising vegetative growth and preparing plant for reproductive stages. Despite having a higher concentration, T_4 recorded only 13.63 leaves, further reinforcing the idea that over supplying nutrients can hinder rather than enhance plant growth. Shah *et al*. (2011) opined that excessive nutrient levels could cause nutrient toxicity, leading to reduced growth rates

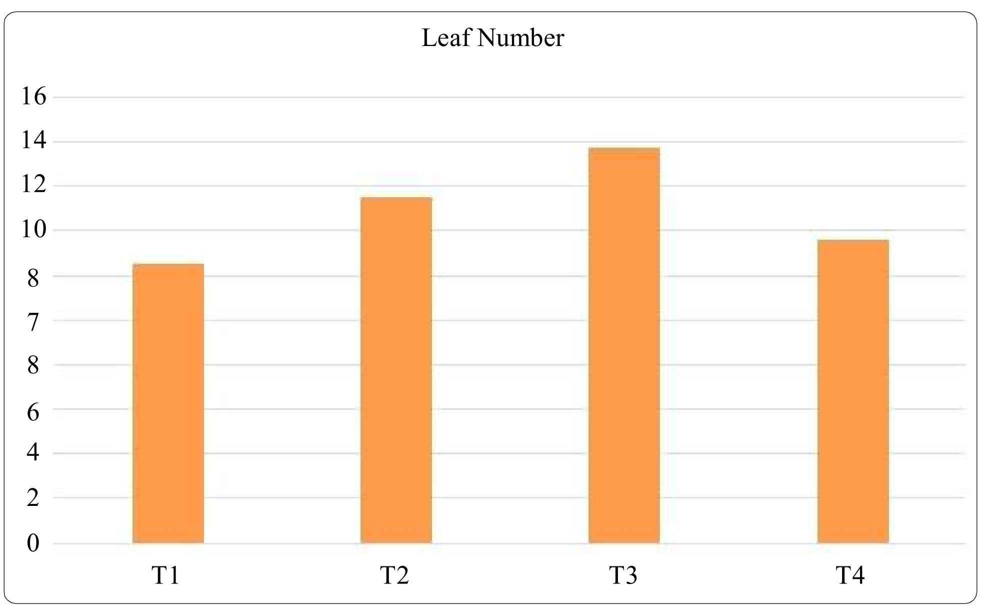

Fig 2 : Influence of nutrient concentration of Hoagland solution on leaf number of strawberry cv Sweet Sensation

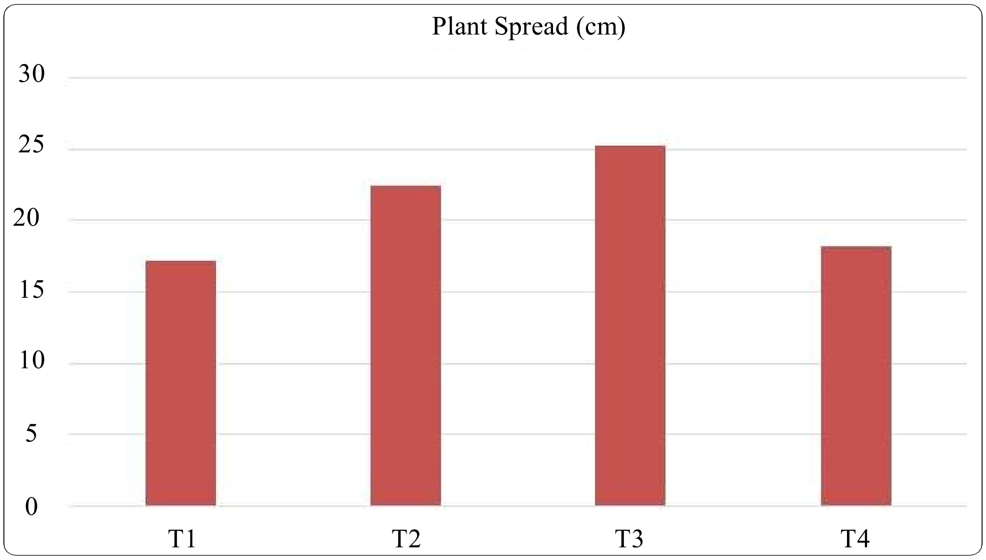

Fig. 3 : Influence of nutrient concentration of Hoagland solution on plant spread of strawberry cv Sweet Sensation

and lower leaf number, particularly in sensitive crops like strawberry.

Plant Spread

Significant differences were evident among the treatments (Fig. 3). The highest plant spread was observed in T_3 (25.17 cm) which was followed by T_2 (22.43 cm), while lowest plant spread was observed in T_1 (17.16 cm). This observation aligns with the findings of Borgognone *et al*. (2013), who reported that adequate nutrient availability is critical for encouraging the lateral expansion of plant in hydroponic systems. Conversely, the limited spread observed in T_1 indicates that reduced nutrient availability may constrain growth and limit plant's ability to expand laterally. Magwaza *et al*. (2020) similarly noted that suboptimum nutrient concentration can restrict vegetative growth, leading to smaller canopies and reduced plant spread.

Total Leaf Area

The evaluation of total leaf area in strawberry cultivated under various nutrient regime, revealed significant variations among the treatments (Fig. 4).

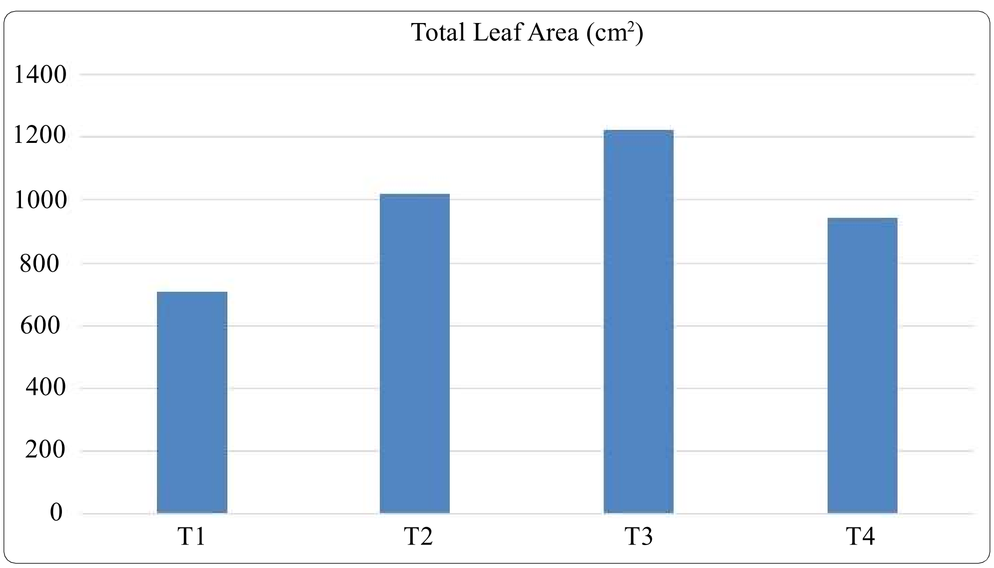

Fig 4 : Influence of nutrient concentration of Hoagland solution on total leaf area of strawberry cv Sweet Sensation

Treatment T_3 exhibited the largest leaf area (1225.41 cm^2), closely followed by T_2 (1018.61 cm^2). These results suggest that a nutrient concentration within this range is optimum for promoting leaf expansion, which is critical for establishing a strong photosynthetic foundation for the plant. The findings align with those of Giri *et al*. (2024), who reported that adequate nutrient supply during the early stages of growth is essential for maximizing leaf area and enhancing photosynthetic efficiency in hydroponic systems. In contrast, T_1 recorded the smallest leaf area (710.45 cm^2), indicating that reduced nutrient availability significantly limits leaf development. This limited leaf expansion likely results from insufficient nutrient supply, particularly of nitrogen, which is essential for chlorophyll production and cell division. This observation is supported by Telgote and Mishra (2024), who found that suboptimal nutrient concentrations can severely restrict leaf growth, reducing the plant's overall photosynthetic capacity.

Petiole Length

The petiole length of strawberry plants exhibited significant differences when cultivated under significant differences (Fig. 5). The treatment T_3 displayed longest petiole length (11.36 cm), followed by T_2 (11.28 cm). These results indicate that maintaining a nutrient concentration moderately high than standard Hoagland solution is optimum for supporting petiole elongation throughout the plant's growth cycle. The findings align with those of Singh *et al*. (2019), who emphasized that balanced nutrient availability is crucial for promoting optimal plant architecture and enhancing the plant's ability to intercept light effectively. In contrast, T_1 produced the shortest petioles (10.41 cm). This indicates that nutrient deficiency significantly limits petiole elongation, likely due to insufficient nutrients required for cell expansion and elongation.

Shoot Biomass

Shoot fresh weight is a direct measure of the vegetative biomass produced by the plant. The results showed that T_3 and T_2 produced the highest shoot fresh weights of 32.07 g and 31.88 g, respectively. These results suggest that nutrient concentrations within this range are optimal for maximizing vegetative growth and biomass accumulation. The findings are consistent with those of Giri *et al*. (2024), who reported that optimal nutrient supply enhances shoot growth by providing adequate nutrients for cell division and elongation, leading to increased biomass production.

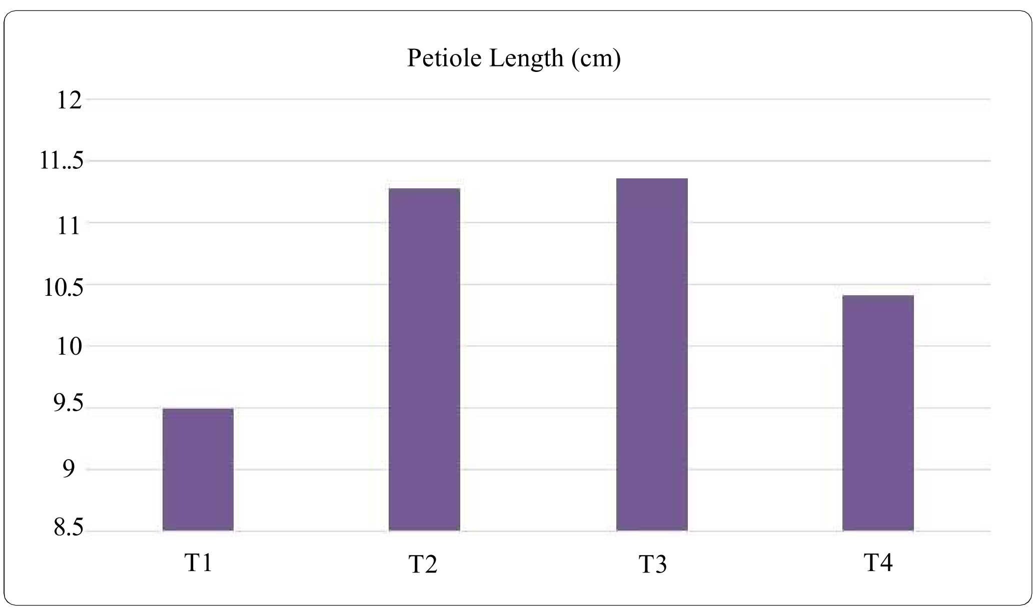

Fig. 5 : Influence of nutrient concentration of Hoagland solution on petiole length of strawberry cv Sweet Sensation

In contrast, T_1 and T_4 recorded significantly lower shoot fresh weights at 18.73 g and 19.74 g, respectively. The reduced fresh weight in T_1 is likely due to nutrient deficiency, which limits the availability of essential nutrients required for growth. This is supported by Borgognone *et al*. (2013), who found that suboptimal nutrient concentrations can severely restrict shoot growth due to inadequate nutrient supply. The lower fresh weight in T_4, despite the high nutrient concentration, may be attributed to nutrient imbalances or toxicity, which can inhibit growth. Shah *et al*. (2011) noted that excessively high nutrient levels could lead to nutrient antagonism, resulting in reduced biomass accumulation (Table 1).

Shoot dry weight represents the biomass remaining after water content is removed, providing a more accurate measure of the plant's structural and metabolic components. Similar to fresh weight, T_3 produced the highest dry weights of 7.21 g and was followed by T_2 6.48 g, respectively. The high dry weight in these treatments indicates that the nutrient concentrations in this range supported robust structural growth, contributing to a higher accumulation of dry matter. Magwaza *et al*. (2020) reported that optimal nutrient concentrations enhance the synthesis of structural components such as cellulose and lignin, leading to increased dry weight. On contrary, T_1 and T_4 recorded lower dry weights at 3.83 g and 5.36 g, respectively. The low dry weight in T_1 suggests that nutrient deficiency significantly limits the accumulation of structural biomass, while the reduced dry weight in T_4 indicates that excessive nutrients may lead to imbalances that affect dry matter synthesis. Telgote and Mishra (2024) highlighted that both nutrient deficiency and excess could impair the plant's ability to allocate resources towards structural growth, resulting in lower dry weight (Table 1).

The fresh weight to dry weight ratio (Sfw:Sdw) provides insights into the water content of the plant tissue with higher ratios indicating higher water content. T_1 had the highest Sfw:Sdw ratio (4.89), suggesting that the plants in this treatment retained more water relative to their structural biomass. This could be due to the reduced availability of nutrients, which may have limited the synthesis of structural components, leading to a higher proportion of water content. Pezzarossa *et al.* (2014) reported that plants under nutrient deficiency often exhibit higher water content relative to dry matter due to reduced growth and development of structural tissues. In contrast, T_4 had the lowest Sfw:Sdw ratio (4.15), indicating a higher proportion of structural biomass relative to water content. This lower ratio could be due to the high nutrient concentration promoting the synthesis

TABLE 1

Effect of various nutrient regimes on shoot fresh weight, shoot dry weight and shoot fresh weight to dry weight ratio (Sfw:Sdw) of strawberry cv. Sweet Sensation cultivated under ebb and flow system of hydroponics

Treatments	Shoot fresh weight (g)	Shoot dry weight (g)	Sfw:Sdw
T_1 - Hogland solution (50 %)	18.73	3.83	4.89
T_2 - Hogland solution (80 %)	31.88	6.48	4.48
T_3 - Hogland solution (130 %)	32.07	7.21	4.46
T_4 - Hogland solution (200 %)	19.74	5.36	4.15
F test	*	*	*
S. Em	0.23	0.12	0.04
CD @ 5%	0.68	0.35	0.13

*-Significant; S. Em - Standard error mean; CD - Critical difference; NS - Non significant

of structural components, leading to reduced water content in the tissue. However, the reduced Sfw:Sdw ratio in T_4 could also indicate potential stress conditions, as excessively high nutrient levels can cause osmotic stress, leading to reduced water uptake and retention. Hanic *et al*. (2011) suggested that nutrient imbalances could lead to physiological stress, resulting in altered water content and biomass allocation (Table 1).

Root Biomass

The evaluation of root length, root fresh weight, root dry weight and the root fresh weight to dry weight ratio in strawberry under various nutrient regime revealed significant differences across the treatments (Table 2). Root length is an important indicator of the plant's ability to explore the nutrient medium and access water and nutrients. T_3 produced the highest root length (17.80 cm), followed by T_2(14.94 cm). Giri *et al.* (2024) also reported that moderately high nutrient concentrations support root elongation by providing the necessary nutrients for cell division and expansion in root tissues. Conversely, T_1 recorded the shortest roots (8.62 cm), indicating that reduced nutrient availability severely limits root elongation. This limited root development likely results from insufficient nutrient supply, particularly of phosphorus and potassium, which are critical for root growth. Roostaa and Hamidpour (2011) observed that suboptimal nutrient concentrations can lead to stunted root systems, reducing the plant's ability to access nutrients and water efficiently.

Root fresh weight reflects the overall mass of the root system, including its water content, which is crucial for nutrient and water uptake. T_3 produced the highest root fresh weights (12.77g), followed by T_2 at 10.91g. The higher fresh weight in these treatments indicates that optimal nutrient concentrations support robust root biomass accumulation, which is essential for sustaining the plant's growth and productivity. Borgognone *et al*. (2013) and Vikas *et al*. (2017) emphasized that adequate nutrient supply during the growth period is crucial for maximizing root mass, which in turn supports higher nutrient uptake and overall plant health. Treatment T_1 had the lowest root fresh weight (6.63 g), highlighting the negative impact of nutrient deficiency on root biomass. The reduced root mass in T_1 suggests that insufficient nutrients lead to under developed root systems, limiting the ability of plant to sustain vigorous growth. Pezzarossa *et al*. (2014) noted that nutrient-deficient conditions often result in smaller root systems, which can impair the plant's ability to absorb water and nutrients, leading to suboptimal growth (Table 2).

TABLE 2

Effect of various nutrient regime on root length, root fresh weight, root dry weight and root fresh weight to root dry weight ratio (Rfw:Rdw) of strawberry cv. Sweet Sensation under Ebb and flow system of hydroponics

Treatments	Root length (cm)	Root fresh weight (g)	Root dry weight (g)	Rfw:Rdw
T_1 - Hogland solution (50 %)	8.62	6.63	2.38	2.78
T_2 - Hogland solution (80 %)	14.94	10.91	5.51	2.05
T_3 - Hogland solution (130 %)	17.80	12.77	5.74	2.22
T_4 - Hogland solution (200 %)	12.49	8.29	3.36	2.46
F test	*	*	*	*
S. Em	0.16	0.11	0.30	0.11
CD @ 5%	0.48	0.32	0.90	0.32

*-Significant; S. Em-Standard error mean; CD- Critical difference; NS- Non significant

Root dry weight represents the structural and metabolic components of the root system after the removal of water. Treatment T_3 recorded the highest dry weights (5.74 g) followed by T_2 (5.51 g). These results indicate that these nutrient concentrations support the development of a robust root structure, which is crucial for anchoring the plant and facilitating nutrient uptake. Magwaza *et al*. (2020) highlighted that optimal nutrient concentrations promote the synthesis of structural components in roots, such as cellulose and lignin, leading to increased dry weight and a stronger root system. In contrast, T_1 recorded the lowest root dry weight (2.38 g), further demonstrating the adverse effects of nutrient deficiency on root development. The low dry weight in T_1 indicates that reduced nutrient availability limits the ability of plant to build a strong root structure, which can negatively impact overall plant health and productivity. Shah *et al*. (2011) observed that nutrient-deficient plants often exhibit reduced dry weight in their root systems, leading to weakened structural integrity and lower efficiency in nutrient absorption (Table 2).

The root fresh weight to dry weight (Rfw/Rdw) ratio provides insights into the water content of the root system with higher ratios indicating higher water content relative to structural biomass. T_1 had the highest Rfw/Rdw ratio (2.78), suggesting that the roots in this treatment retained more water relative to their dry matter. This higher ratio could be due to the limited development of structural components in the roots, which is often associated with nutrient-deficient conditions. Hanic *et al*. (2011) reported that plants with inadequate nutrient supply might have higher water content in their roots due to under developed structural tissues. In contrast, T_2 had the lowest Rfw/Rdw ratio (2.05), indicating a higher proportion of structural biomass relative to water content. This lower ratio suggests that the nutrient concentration in T_2 was optimal for promoting the synthesis of structural components in the roots, resulting in a more balanced root system with adequate water content and strong structural integrity. This finding is consistent with Noh *et al*. (2017), who noted that optimal nutrient levels lead to well-developed root systems with appropriate water content and structural biomass (Table 2).

The results of this study underscore the importance of providing optimum amount of nutrients for adequate growth and development of strawberry cv. Sweet sensation under ebb and flow system of hydroponics. Under this hydroponic system moderately high amount of nutrient concentration (Hoagland 130 %) found to be the best for growth of strawberry plants.

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