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RESEARCH ARTICLE

Hydroponic system of cultivation and runner removal enhanced plant growth and yield of strawberry cultivars

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Abstract

Hydroponics is gaining popularity among growers due to changing climatic conditions and the shrinking of resources, particularly land and water. The present study was conducted at SKUAST-K, Shalimar during the months of February to June of 2021 and 2022 to determine the effects of hydroponics and runner removal on plant growth traits of strawberry cultivars with 8 treatment combinations comprised of 3 factors with 2 levels of each *viz.*, variety, growing system and runner removal. The NFT system of hydroponic was used to grow strawberry plants. Treatments were arranged in RCBD with 4 replications. Findings revealed that V2 (Camarosa) had higher plant growth compared to V1 (Sweet Charlie). Significantly higher plant growth was also recorded under a hydroponic system (S2) than a traditional one (S1). Runner removal (R1) additionally benefitted the plant by diverting food energy used in runner growth to the main shoot and resulted in better shoot and root growth. Second-order interaction of treatments further clarified that V2 × S2 × R1 resulted in maximum shoot growth (plant height - 20.15 cm, shoot biomass - 7.20 g/plant and RGR - 0.58 g/g/week) compared to the minimum values of these parameters recorded with V1 × S1 × R0. The highest number of runners (7.92/plant) with maximum runner length (85.32 cm) was recorded with V1 × S1 while their minimum values were evident with V2 × S1. However, V2 × S1 registered the highest fresh weight (6.13 g/plant) and dry weight (0.45 g/plant) of runners along with the number of propagules (6.93/runner) against their minimum values recorded with V1 × S1. V1 × S2 × R1 resulted in the highest number of fruits (23.32/plant), fruit breadth (3.31 cm) and fruit yield (288.00 g/plant) compared to other interactions.

Keywords

biomass; hydroponics; RGR; runner removal; strawberry

Introduction

Soil is generally the most available growing medium for plants. It provides anchorage, nutrients, air, water, etc., to the plant for its growth and successful completion of life. However, at the same time, soils also pose serious limitations to plant growth and potential productivity. It has been estimated that about 50% of the arable land around the world will become unusable for cultivation by 2050, chiefly due the global climate change (1). Consequently, food production has to be increased by 110% to meet the high demand of the increasing world population (2). The presence of diseasecausing organisms, unsuitable soil reaction, unfavourable soil compaction, poor drainage, degradation due to erosion, etc., further aggravate the situation. Conventional crop growing in soil (Open Field Agriculture) is becoming somewhat difficult as it requires large space, a lot of labour and a large volume of water (3). In addition, in some places, like metropolitan areas, soil is not available at all for crop growing or in some areas, there is a scarcity of arable lands due to their unfavourable geographical or topographical conditions (4). Because of all these problems, there is a need to develop some other viable options for food production that cover the fast-growing demand of the increasing world population with less cost and minimum use of natural resources.

Efforts have been made to develop efficient food production techniques that enable to fulfil the current and future needs of healthy food for the general population. One of them is the soilless farming system, called hydroponics, which may be defined as the practice of growing plants in a nutrient solution with or without a soilless substrate to provide physical support (5-8). Hydroponic food production systems significantly reduce the consumption of resources with increased quantity and quality of food due to increased cropping intensity and better growing conditions for nutrient uptake and plant growth, especially under greenhouse structures (9). Moreover, hydroponic products are almost free from hazardous chemicals as there is no or minimum use of weedicides and pesticides. This system of cultivation also offers unique benefits such as the capability to control water availability, pH and nutrient concentrations in the root zone (9, 10). Being a sustainable food source, soilless food-producing systems have been gaining momentum and drawing the attention of many producers, consumers and scientists (10-13). In addition to the growing system, the removal of runners in strawberries is a key crop management practice to manipulate the sink/source ratio for improved yield and quality (8, 14). Plant growth, yield and quality traits of strawberry cultivars also varied greatly under traditional cultivation systems (15). However, information available on varietal variation in these traits under a hydroponic system of cultivation is scanty, particularly in Kashmir conditions, as no such work has been done so far under a hydroponic system. Therefore, the present study was conducted to determine the effects of hydroponics, runner removal and cultivars on plant growth and yield attributes of strawberry cultivars.

Materials and Methods

Location

The experiment was conducted during the months of February to June of 2021 and 2022 at the Division of Basic Science and Humanities, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar (Jammu and Kashmir). The experimental site was situated at an elevation of 1600 m (5249 feet) above mean sea level (MSL) with an average annual rainfall of around 645 mm (25.4"). The experimental area can be generally described as cool in the Spring and Autumn, mild in the summer and cold in the winter. July is the hottest month in this region with mean minimum and maximum temperatures of 16 °C and 32 °C respectively. December-January is considered the coldest months with a mean minimum temperature of -1.6 °C to -3.0 °C and a mean maximum temperature of 1.6 °C to 7.3 °C.

Plant materials and conduct of the trial

Two strawberry cultivars viz., Sweet Charlie (V1) and Camarosa (V2) were grown traditionally (S1) as well as under the NFT (Nutrient Film Technique) system of hydroponics (S2), where in a very shallow stream (film) of water containing all nutrients required for plant growth circulates between the growing channels (troughs) and the nutrient reservoir. The NFT system used in the present experiment was a 3-layered structure run on a framework made up of PVC pipes and iron angle. Each layer of the NFT had four PVC pipes with 13 holes of 2.5-inch diameter (Plate 1). Uniform size and vigour of strawberry propagules having 2-3 true leaves of Sweet Charlie and Camarosa cultivars were obtained from the division of Fruit Science, Faculty of Horticulture (SKUAST-K), Shalimar. All the propagules were divided into 2 sets for growing them hydroponically and traditionally under a field. Propagules were dipped in 0.2 % solution of Bavistin for 10 min and transplanted in the netted cups already filled with cocopeat, vermiculite and perlite with a 1:1:1 ratio (Plate 2). Transplanted netted cups were kept in the trays having half standard hydroponic nutrient solution (16) containing all the essential (macro and micro) nutrients required by the plants for their growth and development, maintained in the laboratory till the establishment of the plant. After establishment, the

Plate 1a. Nutrient film technique (NFT) of hydroponics used for the present study.

Plate 1b. Strawberry crops grown under the NFT system of hydroponics.

Plate 1c. Hydroponically grown strawberry crops in bearing.

cups were transferred to a hydroponic system where in supply of half-standard hydroponic solution was continued for up to 20 days. Thereafter, full strength of nutrient solution was supplied throughout the course of plant growth. Pre-treated strawberry propagules were also transplanted in the field at a spacing of 30 × 30 cm. Circulation of the nutrient solution was made 4 times daily for 1 h. Intercultural operations like irrigation and weeding, in field-grown crops were carried out regularly as needed. Half of the plants were allowed to produce and grow their runners (R0) while the other half of the plants were not allowed to grow runners (R1) i.e., they were removed as and when appeared on plants. The experiment was laid down in randomized complete block design (RCBD) with 4 replications.

Recording of data and statistical analysis

Plant height was measured from the base of the crown to the growing tip of the plant at the time of final picking. Plant spread was measured from North to South and East to West directions and the average of both directions was taken as spread of the plants. Above-ground plant biomass was recorded by drying them in an oven at 80 °C till obtaining a constant dry weight. Plant relative growth rate (RGR) for the initial slow growth, vigorous vegetative growth and reproductive growth phases was calculated following the standard method (17).

$$\text{RGR (g/g/day)} = \frac{2.302(\text{loge } W_2 - \text{loge } W_1)}{T_2 - T_1}$$

Where, W_1= plant dry weight (g) at time T_1; W_2= plant dry weight (g) at time T_2; Loge = natural logarithms (Logarithms to the base of 2.3026).

Root volume was determined by the water displacement method using a graduated cylindrical flask (18). The root length was measured from the collar to the tip of the root. Root dry weight was estimated by drying them in a hot air oven at 60 °C till the constant weight was obtained. The number of trusses on fully developed plants was counted and averaged as per plant. Numbers, length, fresh weight and dry weight of runners per plant were estimated

Plate 2. Strawberry crop grown under field condition.

where in runners were allowed to produce and grow. In addition, the number of propagules per runner was also recorded by simple counting. Data were subjected to statistical analysis using R software with analysis of variance. Means were compared at P≤0.05 level of significance.

Results

Plant growth traits

Experimental evidence indicated that above-ground plant growth was significantly influenced (p≤ 0.05) due to the treatments. The main effects of the treatments (Fig. 1) clarified that the variety Sweet Charlie (V2) showed higher plant height (17.42 cm), plant spread (22.79 cm) and plant biomass (6.05 g/plant) compared to lesser plant height (15.99 cm), spread (20.53 cm) and biomass (4.80 g/plant) of Camarosa (V1). Likewise, hydroponically grown plants (S2) exhibited higher plant height (17.69 cm), spread (25.02 cm) and biomass (6.22 g/plant) compared to a plant height (15.72 cm), spread (18.29 cm) and biomass (4.62 g/plant) in the traditional growing system (S1). Also, runner removal (R1) resulted in a higher plant height (18.20 cm), spread (23.16 cm) and biomass (5.70 g/plant) compared to lesser plant height (15.20 cm), spread (20.15 cm) and biomass (5.15 g/plant) in plants with no runner removal (R0).

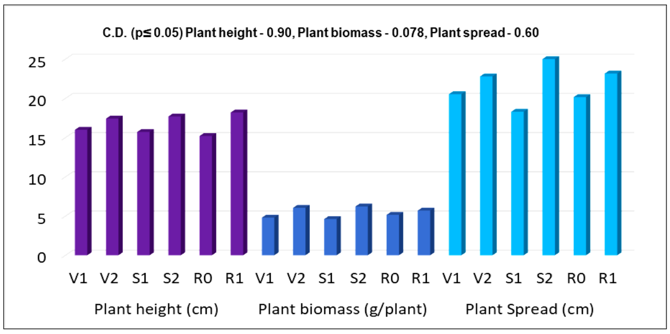

Fig. 1. Individual effects of variety, growing system and runner removal on above ground plant growth of strawberry.

The first-order interactions of different treatments (Table 1) also indicated significant differences (p ≤ 0.05) with respect to plant height, plant spread and biomass. Data with respect to V × S revealed that V2 × S2 resulted in the highest plant height (18.69 cm), spread (25.72 cm) and biomass (7.00 g/plant) followed by V1 × S1 with plant height, spread and biomass of 16.68 cm, 24.32 cm and 5.45 g/plant respectively against the minimum plant height (15.29 cm), spread (16.73 cm) and biomass (4.15 g/plant)

Table 1. Effects of First-order interaction of treatments on above-ground plant growth of strawberry

Treatments	Plant height (cm)	Plant biomass (g/plant)	Plant Spread (cm)	RGR (g/g/week)		
				(0-15 days)	(15-30 days)	(30-45 days)
First order interaction of treatments						
V1 × S1	15.29	4.15	16.73	0.36	0.44	0.24
V1 × S2	16.68	5.45	24.32	0.45	0.54	0.35
V2 × S1	16.15	5.10	19.86	0.44	0.53	0.31
V2 × S2	18.69	7.00	25.72	0.55	0.65	0.45
CD (p≤ 0.05)	**0.81**	**0.11**	**0.84**	**0.013**	**0.014**	**0.011**
V1 × R0	14.70	4.50	19.41	0.39	0.47	0.25
V1 × R1	17.28	5.10	21.64	0.43	0.52	0.30
V2 × R0	15.70	5.80	20.89	0.47	0.57	0.38
V2 × R1	19.14	6.30	24.69	0.52	0.61	0.42
CD (p≤ 0.05)	**0.81**	**NS**	**0.84**	**NS**	**NS**	**NS**
S1 × R0	14.17	4.30	17.24	0.38	0.47	0.28
S1 × R1	17.27	4.95	19.35	0.42	0.50	0.31
S2 × R0	16.23	6.00	23.06	0.48	0.57	0.35
S2 × R1	19.14	6.45	26.98	0.53	0.62	0.41
CD (p≤ 0.05)	**0.81**	**0.11**	**0.84**	**NS**	**NS**	**NS**

recorded with V1 × S1. Interaction of V × R indicated that V2 × R1 registered the highest plant height (19.14 cm) and spread (24.69 cm) followed by V1 × R1 against the minimum plant height (14.70) and spread (19.41 cm) registered with V1 × R0. So far as S × R interaction is concerned, S2 × R1 produced greater plant height (19.14 cm), spread (26.98 cm) and biomass (6.45 g/plant). Interaction of S1 × R1 exhibited the second highest plant height (17.27 cm), however, S2 × R0 ranked second with a recorded plant spread and plant biomass of 23.06 cm and 6.00 g/plant respectively against the minimum plant height (14.17 cm), plant spread (17.24 cm) and plant biomass (4.30 g/plant) of S1 × R0.

Data with respect to second-order interactions of V × S × R (Fig. 2) further revealed that maximum plant height (20.15 cm) and spread (28.81 cm) were observed with V2 × S2 × R1. Whereas, the treatment combination V2 × S2 × R1 was significantly followed by V1 × S2 × R1 and registered the plant height and spread value of 18.14 and 25.15 cm respectively. Interaction of V1 × S1 × R0 resulted in minimum plant height (14.17 cm) and spread (15.34 cm).

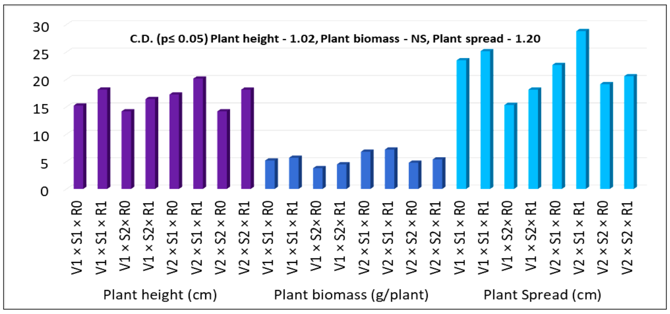

Fig. 2. Effects of second-order interaction of treatments on above-ground plant growth of strawberry.

Plant relative growth rate (RGR)

Different treatments also influenced plant relative growth rate (RGR) significantly (p≤0.05) where V2 exhibited higher RGR during all the growth period *viz.*, 0-15 days (0.50 g/g/week), 15-30 days (0.59 g/g/week) and 30-45 days (0.40 g/g/week) as compared to a lower RGR of 0.41, 0.49 and 0.27 g/g/week V1 during the respective growing periods. Likewise, the hydroponic (S2) growing system exhibited greater RGR during 0-15 (0.50 g/g/week), 15-30 (0.59 g/g/week) and 30-45 days (0.38 g/g/week) compared to a lower RGR during respective periods (0.40, 0.48 and 0.29 g/g/week) under the traditional system (S1) respectively. Removal of runners (R1) resulted in an improved plant RGR (0.47, 0.56 and 0.36 g/g/week) compared to a lower RGR (0.43, 0.52 and 0.31 g/g/week) with no runner removal (R0) during respective growing periods (Fig. 3).

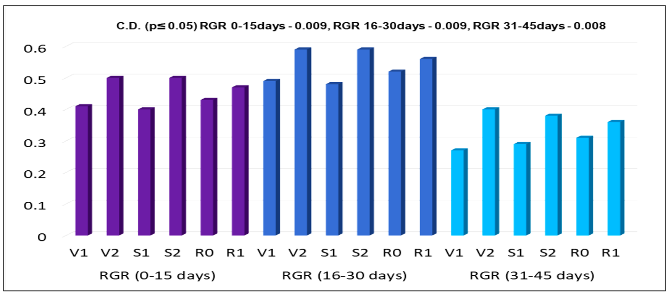

Fig. 3. Individual effects of variety, growing system and runner removal on shoot relative growth rate (RGR) (g/g/week) during different phases of growth in strawberry.

The first-order interactions (Table 1) of V × S reflect that V2 × S2 resulted in maximum RGR of 0.55, 0.65 and 0.45 g/g/week during 0-15, 15-30 and 30-45 days respectively followed by V1 × S1 with RGR values of 0.45, 0.54 and 0.35 g/g/week against the minimum RGR values of 0.36, 0.44 and 0.24 g/g/week during the respective days of measurements. However, the interaction of V × R as well as S × R could not exert any significant difference in RGR throughout growing periods.

The second-order interaction of the treatments (Fig. 4) further revealed that V2 × S1 × R1 resulted in the highest RGR of 0.58, 0.68 and 0.48 g/g/week during the 3 growing periods respectively followed by V2 × S2 × R0, whereas, the minimum values of RGR (0.35, 0.42 and 0.23 g/g/week) during respective periods of plant growth were recorded with V1 × S1 × R0.

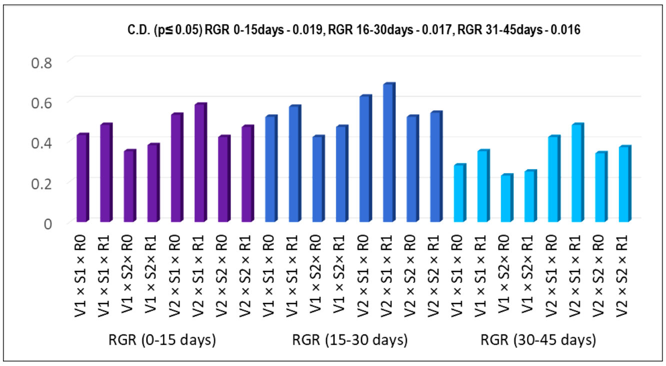

Fig. 4. Effects of Second-order interaction of treatments on shoot relative growth rate (RGR) (g/g/week) during different phases of growth in strawberry.

Root growth

Like above-ground plant growth, variety, growing system and runner removal (Fig. 5) also influenced root growth (p≤0.05) and V1 showed lesser root volume (3.91 cc), length (11.78 cm) and dry weight (1.55 g/plant) compared to V2 with root volume, length and dry weight of 4.35 cc, 13.76 cm and 2.78 g/plant respectively. Hydroponics system (S2) also resulted in higher root volume (4.66 cc) length (13.74 cm) and dry weight (2.48 g/plant) compared to a lower root volume (3.60 cc), length (11.80 cm) and dry weight (1.85 g/plant) obtained in traditional system (S1). Runner removal (R1) again exerted a positive effect on root growth by producing higher root volume (4.35 cc), length (13.28 cm) and dry weight (2.24 g/plant) in comparison to the plants with no runner removal (R0).

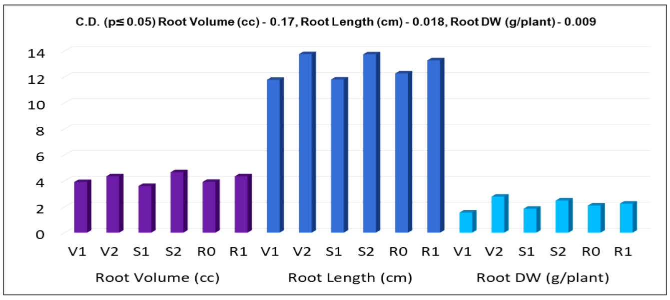

Fig. 5. Individual effects of variety, growing system and runner removal on root growth of strawberry.

Looking into the data on 2-way interaction (Table 2) with V × S, it can be stated that V2 × S2 resulted in the highest

Table 2. Effects of first-order interaction of treatments on root growth attributes of strawberry

Treatment	Root Volume (cc)	Root Length (cm)	Root DW (g/plant)
V1 × S1	3.38	10.89	1.45
V1 × S2	4.45	12.68	1.65
V2 × S1	3.83	12.72	2.26
V2 × S2	4.88	14.80	3.31
CD (p≤ 0.05)	**0.09**	**0.025**	**0.013**
V1 × R0	3.70	11.33	1.52
V1 × R1	4.13	12.24	1.57
V2 × R0	4.15	13.21	2.66
V2 × R1	4.56	14.31	2.90
CD (p≤ 0.05)	**0.08**	**0.025**	**0.013**
S1 × R0	3.40	11.35	1.80
S1 × R1	3.81	12.25	1.90
S2 × R0	4.45	13.19	2.38
S2 × R1	4.88	14.30	2.57
CD (p≤ 0.05)	**0.19**	**0.025**	**0.013**

root volume (4.88 cc), length (14.80) and dry weight (3.31 g/plant) followed by V1 × S2 against the minimum root volume (3.38 cc), length (10.89) and dry weight (1.45 g/plant) under V1 × S1. The combined effect of V × R revealed that V2 × R1 gave rise to the maximum root volume, length and dry weight of 4.56 cc, 14.31 cm and 2.90 g/plant followed by V2 × R0 against the minimum root volume (3.70 cc), length (11.33 cm) and dry weight (1.52 g/plant) recorded with V1 × R0. Among the different interactions of S × R the maximum root volume (4.88 cc), length (14.30 cm) and dry weight (2.57 g/plant) were recorded with S1 × R1 followed by S1 × R0 against the most inferior root volume (3.40 cc), length (11.35 cm) and dry weight (1.80) in S1 × R0.

Root volume, length and dry weight also varied significantly (p≤0.05) under second-order interaction (Fig. 6) wherein V2 × S1 × R1 acquired the highest root volume (5.06 cc), length (15.46 cm) and dry weight (3.47 g/plant) and wassignificantly followed by V2 × S1 × R0 compared to the least root volume (3.20 cc), length (10.44 cm) and dry weight (1.43 g/plant) recorded with V1 × S2 × R0.

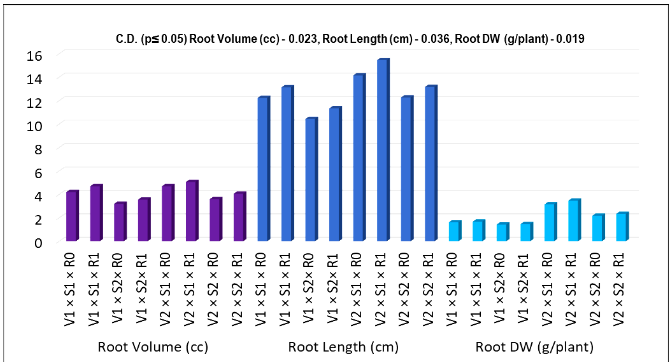

Fig. 6. Effects of second-order interaction of treatments on root growth in strawberry.

Runner growth

Information effect of variety and growing conditions on runner growth provided in Table 3 depicts that variety V1 produced more number (7.54/plant) as well as total length (82.76 cm) of runners compared to variety V2. However, a higher fresh (5.33 g/plant) and dry (0.36 g/plant) weight of runners was recorded with V2 compared to smaller fresh (4.43 g/plant) and dry (0.29 g/plant) weight with V1. V2 also recorded a higher number of propagules (5.54/plant) compared to V1 (4.54/plant). Talking about growing systems, S2 produced a greater number (6.92/plant), total length (68.81 cm), fresh weight (5.87 g/plant) and dry weight (0.39 g/plant) of runners along with the higher number of propagules (6.09/plant) compared to smaller values of these attributes with S1.

Table 3. Effects of first-order interaction of treatments on yield attributing characters of strawberry

Treatment	No. of fruits/ plant	Fruit length (cm)	Fruit breadth(cm)	Fruit Weight (g/fruit)
V1 × S1	17.81	2.64	3.11	11.71
V1 × S2	21.94	2.68	3.07	11.23
V2 × S1	14.08	2.44	2.20	11.30
V2 × S2	14.83	3.09	2.36	12.28
CD (p≤ 0.05)	**1.34**	**0.067**	**0.016**	**0.016**
V1 × R0	19.99	2.47	2.90	10.64
V1 × R1	19.76	2.84	3.29	12.30
V2 × R0	14.33	2.59	2.22	10.74
V2 × R1	14.58	2.94	2.34	12.84
CD (p≤ 0.05)	**1.21**	**0.057**	**0.016**	**0.016**
S1 × R0	16.98	2.33	2.57	10.67
S1 × R1	14.91	2.75	2.74	12.34
S2 × R0	17.34	2.74	2.55	10.72
S2 × R1	19.43	3.03	2.88	12.80
CD (p≤ 0.05)	**1.34**	**0.067**	**0.016**	**0.016**

A perusal of the data with respect to the interaction of treatments (V × S) revealed that V1 × S2 recorded the highest number (7.92/plant) as well as total length (85.32 cm) of runners followed by V1 × S1 against the minimum number (4.13/plant) and total length (47.10 cm) of runners recorded with V2 × S1. However, the highest fresh (6.13 g/plant) and dry (0.45 g/plant) weight alongwith the maximum number of propagules (6.93/plant) was recorded with V2 × S2 followed byV1 × S2 against the minimum values of runner's fresh (3.24 g/plant) and dry (0.24 g/plant) weight along with the number of propagules (3.83/plant) recorded with V1 × S1.

Fruit growth and yield

The information with regard to the main effects of treatments (Fig. 7) indicates that V1 exhibited a higher number of fruits (19.88/plant) and fruit breadth (3.09 cm) while V2 exhibited a lesser number of fruits (14.46/plant) with more fruit length (2.77 cm) and individual fruit weight (11.79 g/plant) V1. A comparison of growing systems showed that S2 showed a higher number of fruits (18.38/plant) fruit length (2.89 cm), fruit breadth (2.72 cm) and fruit weight (11.76 g/fruit) as compared to S1. Similarly, R1 produced a higher number of fruits (17.17/plant) with larger length (2.89 cm) and breadth (2.81 cm) coupled with higher fruit

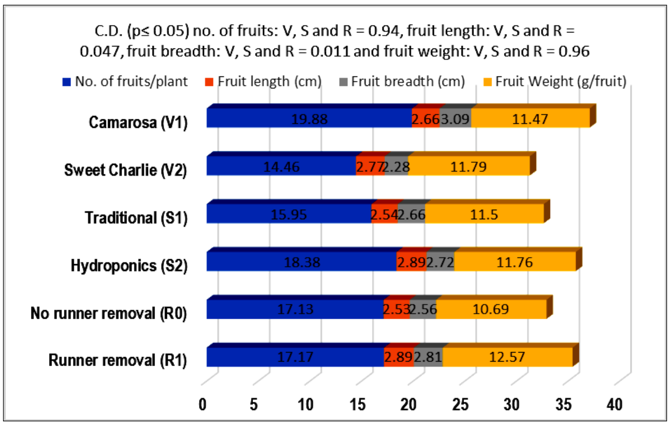

Fig. 7. Individual effects of variety, growing system and runner removal on yield attributing characters of strawberry.

weight (12.57 g/fruit) compared to significantly lower values of these attributes under R0.

A perusal of the data (Table 3) regarding V × S among the first-order interaction showed that V2 × S2 resulted in the highest fruit length (3.09 cm) and fruit weight (12.28 g/plant) with greater number of fruits (21.94/plant). Among V × R, V2 × R1 produced the highest fruit length (2.94 cm) and fruit weight (12.84 g/fruit) while V1 × R1 yielded the maximum number of fruits (19.76/plant) with the highest fruit breadth (3.29 cm). Considering the data pertaining to the interaction of S × R, it can be stated that S2 × R1 resulted in the maximum number of fruits (19.43/plant), fruit length (3.03 cm), breadth (2.88 cm) and fruit weight (12.80 g/fruit)compared to other interactions in the set.

The second order interaction (Fig. 8) of all the treatment factors (V × S × R) indicated that V2 × S2 ×R1 registered the maximum number of fruit (23.32/plant), fruit length (3.23 cm) as well as individual fruit weight (13.25 g/fruit). However, V1 × S1 × R1 produced maximum fruit breadth (3.31 cm). while as the lowest fruit breadth (2.18 cm) was noted with V2 × S1 × R0.

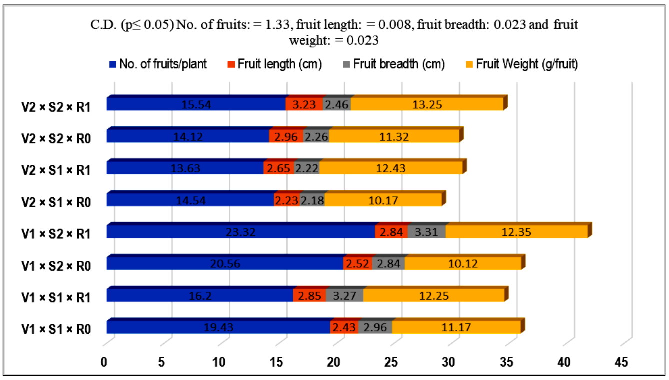

Fig. 8. Effects of Second-order interaction of treatments on yield attributing characters in strawberry.

The information with regard to the main effects of treatment on the fruit yield of strawberries (Fig. 9) clarified that V1 exhibited a higher fruit yield (227.88 g/plant) compared to V2. Also, S1 produced a lesser fruit yield (183.83 g/plant) compared to a higher yield (215.44 g/plant) in the S2 system of cultivation. Similarly, runner removal (R1) recorded a higher fruit yield (201.57 g/plat) compared with a lesser yield of fruits (197.0 g/plant) recorded under R0. The two-way interaction of the data

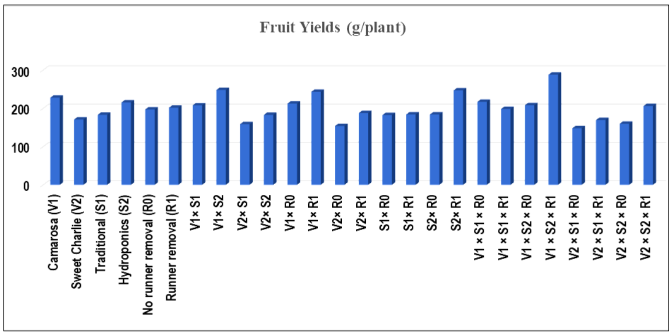

Fig. 9. Effects of variety, growing system and runner removal on fruit yield of strawberry.

further verified the results of individual treatment effects. The highest yield record was made with the interaction V1 × S2 × R1 gave a fruit yield of 288.00 g/plant against the minimum yield of (147.87) under V2 × S1 × R0.

Discussion

Plant height is regarded as an index of crop management but this is not sufficient to quantify strawberry vigour as it is only an auxiliary indicator. Plant spread indicates the leafiness of the plants that determine the amount of light interception to be used for photosynthesis. Plant dry weight provides a precise measurement of biomass, eliminating fluctuations caused by water content and is directly related to photosynthetic productivity. The difference in plant growth between the varieties may be attributed to the differences in one or more DNA sequences of their genetic makeup (19). The improved growth of plants under a hydroponic system may be attributed to the fast uptake of water and minerals due to the steeper gradient of water potential between thenutrient medium and root cell sap. Increased water absorption maintains the cell turgidity that helps in cell enlargement and cell division which ultimatelyincreases the growth of plants. Higher vegetative growth of strawberries under hydroponics has also been reported in earlier research (20) that has been reported to improve WUE (21). The reason for enhanced plant growth due to runner removal may be attributed to the alteration of the source-sink ratio as the growth of runners requires additional energy from the plant (8) that may be diverted to the plant for their own growth. The results are also in conformitywith those of earlier workers (14, 22, 23).

The RGR of the present study through the growing period (Fig. 10) clearly indicates that the RGR was slower

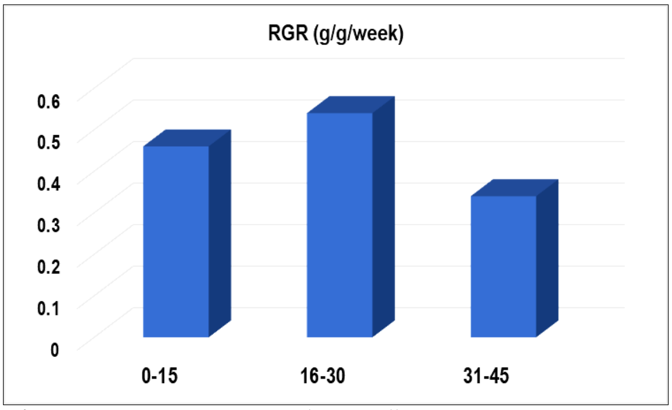

Fig. 10. Relative growth rates, RGR (g/g/week)) of the strawberry plant during different growth periods.

during the initial periods (0-15 days) and increased during 16 – 30 days of the growing period and then again declined during the 31 – 45 days of plant growth and even gone behind the plant RGR observed during initial periods(0 – 15 days) of plant growth.

The growth analysis in terms of RGR proved to be a valuable tool for investigating differences in plant growth characteristics. It is the rate of accumulation of new dry mass per unit of existing dry mass. The faster an individual accumulates biomass, the more carbon is available to increase the growth of roots and shoots for greater access to light and soil nutrients, which in turn enables greater biomass accumulation (24). The present study also reveals that variety, growing system and runner removal individually or in their possible combinations significantly influenced the RGR of strawberries. An increased RGR of hydroponically growing plants has also been reported by earlier researchers (25, 26). The increased RGR under the hydroponic system of cultivation may be attributed to enhanced nutrient and water uptake (27, 28).

Relatively a lesser RGR during the initial phase of plant growth might be due to the less availability of plant surfaces to make food i.e., leaves as source. However, due to the progressive increase in photosynthetic surface area (source leaves), there was availability of more food that resulted in greater value of RGR during the mid-phase of plant growth. However, a sharp decline of RGR during the last phaseof plant growth may be attributed to the diversion of assimilates towards an additionally developed reproductive sink. Earlier studies also reported that the relative growth rate (RGR) during the vegetative stage was 300 mg g^{-1} d^{-1} and dropped at the initiation of flowering buds to 60 mg g^{-1} d^{-1} (29).

Roots, also called as the “hidden half” of plants (30) are meant primarily for resource acquisition, although other abilities such as nutrient storage and plant anchorage are also important (31). For healthy growth, plants must absorb all essential mineral elements via the roots (32). Therefore, an extensive root system is critical for improved biomass production, yield and yield stability. Studies (33) established a close relationship of root dry weight with plant height and aboveground plant dry weight. In hydroponics, the nutrient solution can either be saturated with air prior to its use or changed frequently, or air can be continuously supplied in solution throughout plant life (34-36). The performance of roots grown in different types of soilless growing systems markedly improved over traditional soil growing systems which can be attributed to the air and water balance in the root environment under soilless cultivated plants (37). It has also been reported that hydroponically grown seedlings of *Gledistsia tricanthos* L. var. *inermis* exhibited longer roots in comparison to soil-grown seedlings (38).

The differences in runner growth due to variety may be attributed to their genetic makeup. However, increased runner growth under the hydroponic cultivation system might be the result of amplified water and nutrients that caused cellular elongation and cell division finally resulting in improved runner growth.

Different strawberry genotypes or varieties possess unique genetic traits that influence their growth, development and yield potential. The increased fruit numbers and individual fruit weight under the hydroponic system of cultivation can be attributed to improved plant growth due to the fast uptake of water and minerals due to the steeper gradient of water potential between thenutrient medium and root cell sap. In strawberries, runners are known as strong sinks for leaf assimilates, water and nutrients in competition with developing flowers and fruits (39, 40). Runner removal possibly saves the energy utilized for its growth that might have been utilized for better plant growth and reproduction and resulted in higher yield through increased number of fruits and individual fruit weight. Our results regarding the higher number of fruits in Camarosa are in agreement with earlier reports (41). Relatively, a higher fruit length of the Sweet Charlie variety has also been reported in other studies (42). Our findings regarding the 2 growing systems are also consistence with earlier researchers (43, 44). Other workers also reported that runner removal in strawberries increased total and marketable yield and the number and size of fruits (23).

Conclusion

Growing of strawberry varieties under the NFT system of hydroponics with complete runner removal at regular intervals resulted in significant improvement in plant growth and fruit yield of strawberries. However, two strawberry cultivars viz., Camarosa and Sweet Charlie responded differently under the hydroponic system of cultivation. Camarosa, despite lower plant growth, resulted in a higher number of fruits and improved yield. As such cultivation of Camarosa strawberries under the NFT system of hydroponics along with regular runner removal may be recommended to obtain enhanced fruit yield of strawberries.

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Authors’ contributions

SM conducted the trial of the experiment and recorded various observations on plant growth, quality analysis and yield. FAK conceived the idea and chalked out the detailed layout plan of the work. GC helped in the development of the technical programme and discussion part of the article. SAB guided the for-laboratory analysis of different physiological and biochemical attributes. SN helped in the conduct of the experiment and draft of the article. SAM made the statistical analysis of the data. AK provided the propagation materials (propagules) and helped in the growing of strawberries in the field. SG took care of disease and pest issues of the crop. FK and MA were actively involved in the preparation of diagrams and a survey of literature. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Anonymous. Release of final estimates of 2019-20 and first advanceestimates of 2020-21 of area and production of horticultural crops, 2020. Ministry of Agriculture and Farmers Welfare. 2020. https://pib.gov.in/Pressrelease share.aspx?PRID=1703196
2. Gashgari R, Alharbi K, Mughrbil K, Jan A, Glolam A. Comparison between growing plants in hydroponic system and soil-based system. Proceedings of the 4th World Congress on Mechanical, Chemical and Material Engineering (MCM'18), 2018; Madrid, Spain-August 16-18, 2018 Paper No. ICMIE131. https://doi.org/10.11159/icmie18.131
3. Rajaseger G, Chan KL, Yee TK, Ramasamy S, Khin MC, Amaladoss A, et al. Hydroponics: current trends in sustainable crop production. Bioinformation. 2023;19(9): 925-38. https://doi.org/10.6026/97320630019925
4. Beibel JP. Hydroponics - The science of growing crops without soil. Florida Department of Agriculture. Bulletin. 1960; 180p.
5. William GF. Hydroponics - crop production in liquid culture media. Science. 1937;85(2198):177-78. https://doi.org/10.1126/science.85.2198.177
6. Debangshi U. Hydroponics – an overview. Chronicle of Bioresource Management. 2021;5(3):110-14. https://ojs.pphouse.org/index.php/CBM/article/view/3917
7. Khan FA, Narayan S, Khan, FU, Dar MA, Amir M, Moinuddin, Astha. Hydroponic vegetables: A sustainable food production system and profitable venture under climate change. Indian Horticulture. 2023a;68(2):82-86. https://epubs.icar.org.in/index.php/IndHort/article/view/135859
8. Khan FA, Saima Fayaz, Dar ZM, Khan FU, Mohammad Amir, Astha, Moinuddin. Response of straw berry crop to runner removal: A review. The Pharma Innovation Journal. 2023b;12 (3):5581-85. https://www.thepharmajournal.com/archives/?year=2023&vol=12&issue=3&ArticleId=19561
9. Velazquez-Gonzalez RS, Garcia-Garcia AL, Ventura-Zapata E, Barceinas-Sanchez JDO, Sosa-Savedra JC. A Review on hydroponics and the technologies associated for medium- and small-scale operations. Agriculture. 2022;12:646. https://doi.org/10.3390/agriculture12050646
10. Resh HM. Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. St. Bárbara, EUA. 2022. https://doi.org/10.1201/9781003133254
11. Treftz C, Zhang F, Omaye ST. Comparison between hydroponic and soil-grown strawberries: sensory attributes and correlations with nutrient content. Food and Nutrition Sciences. 2015;6 (15):1371. https://doi.org/10.4236/fns.2015.615143
12. Barman NC, Hasan MM, Islam MR, Banu NA. A review on present status and future prospective of hydroponics technique. Plant Environment Development. 2016;5(2):1-7. https://www.scribd.com/document/522999002/A-Review-on-Present-Status-and-Future-Prospective
13. Kamepalli H. Hydroponics: Indian outlook. The Times of India. June 8, 2023. https://timesofindia.indiatimes.com/blogs/voices/hydroponics-indian-outlook/
14. Hughes BR, Zandstra J, Taghavi T, Dale A. Effects of runner removal on productivity and plant growth of two day-neutral strawberry cultivars in Ontario, Canada. Acta Horticulturae. 2017;1156:327-32. https://doi.org/10.17660/ActaHortic.2017.1156.50
15. Rahman MM, Rahman MM, Hossain MM, Khaliq QA, Moniruzzaman M. Effect of planting time and genotypes growth, yield and quality of strawberry (Fragaria × ananassa Duch.). Scientia Horticulturae. 2014;167(6):56-62. https://doi.org/10.1016/j.scienta.2013.12.027
16. Hoagland DR, Snyder WC. Nutrition of strawberry plant under controlled conditions. (a) Effects of deficiencies of boron and certain other elements, (b) susceptibility to injury from sodium salts. Proceedings of the American Society for Horticultural Science. 1933;30:288-94. https://www.cabidigitallibrary.org/doi/full/10.5555/19351100824
17. Fisher RA. Some remarks on the methods formulated in a recent article on the quantitative analysis of plant growth. Annals of Applied Biology. 1921;7(4):367-72. https://doi.org/10.1111/j.1744-7348.1921.tb05524.x
18. Rao MLN, Venkateswarlu B, Murty AVSN. Influence of population pressure on drought sustenance and root characteristics of dryland rice. Indian Journal of Plant Physiology. 1992;35(1):38-43.
19. Swarup S, Cargill EJ, Crosby K, Flagel L, Kniskern J, Glenn KC. Genetic diversity is indispensable for plant breeding to improve crops. Crop Science. 2020;61(2):839-52. https://doi.org/10.1002/csc2.20377
20. Vikas KA, Kumar A, Singh A, Kumar P, Rafie J, Verma P, Kumar A. Influence of different nutrient concentration on strawberry under hydroponic cultivation system. International Journal of Current Microbiology and Applied Sciences. 2017;6:2999-3006. https://doi.org/10.20546/ijcmas
21. Verdoliva SG, Gwyn-Jones D, Detheridge A, Robson P. Controlled comparisons between soil and hydroponic systems reveal increased water use efficiency and higher lycopene and β-carotene contents in hydroponically grown tomatoes. Scientia Horticulturae. 2021;15:279. https://doi.org/10.1016/j.scienta.2021.109896
22. Lyu CB, Yang WJ, Li KT. Partial defoliation and runner removal affect runnering, fruiting, leaf photosynthesis and root growth in 'Toyonoka'strawberries for subtropical winter production. Horticulture, Environment and Biotechnology. 2014;55(5):372-79. https://doi.org/10.1007/s13580-014-0001-1
23. Sonsteby A, Woznicki TL, Heide OM. Effects of runner removal and partial defoliation on the growth and yield performance of 'Favori'everbearing strawberry plants. Horticulturae. 2021;7(8):215. https://doi.org/10.3390/horticulturae7080215
24. Rivero R, Sønsteby A, Heide OM, Solhaug KA, Remberg S.F. Growth analysis of the everbearing strawberry 'Delizzimo'under controlled temperature and photoperiod conditions. CABI Agriculture and Bioscience. 2022;3(1):43. https://doi.org/10.1186/s43170-022-00110-w
25. Huber J, Zheng Y, Dixon M. Hydroponic cucumber production using a new recyclable growth substrate and irrigation system. Acta Horticulturae. 2009;843:303-10. https://doi.org/10.17660/ActaHortic.2009.843.40
26. Nagel KA, Kastenholz B, Gilmer F, Schurr U, Walter A. Novel detection system for plant protein production of pharmaceuticals and impact on conformational diseases. Protein and Peptide Letters.2010;17:723-31. https://doi.org/10.2174/092986610791190282

27. Bell LW. Relative growth rate, resource allocation and root morphology in the perennial legumes, *Medicago sativa*, *Dorycnium rectum* and *D. hirsutum* grown under controlled conditions. Plant and Soil. 2005;270:199-211. https://doi.org/10.1007/s11104-004-1495-6

28. Peng Y, Niklas KJ, Sun S. The relationship between relative growth rate and whole-plant C: N: P stoichiometry in plant seedlings grown under nutrient-enriched conditions. Journal of Plant Ecology. 2011;4(3):143-56. https://doi.org/10.1093/jpe/rtq026

29. Koelewijn HP. Rapid change in relative growth rate between the vegetative and reproductive stage of the life cycle in *Plantago coronopus*. New Phytologist. 2004;163(1):67-76. https://doi.org/10.1111/j.1469-8137.2004.01078.x

30. Eshel A, Beeckman T. Eds. Plant roots: the hidden half. CRC Press. 2013; https://doi.org/10.1201/b14550

31. Lynch PT, Benson EE, Keith H. Climate change: the role of *ex situ* and cryo-conservation in the future security of economically important, vegetatively propagated plants. The Journal of Horticultural Science and Biotechnology. 2007;82(2):157-60. https://doi.org/10.1080/14620316.2007.11512213

32. White PJ, Brown P. Plant nutrition for sustainable development and global health. Annals of Botany. 2010;105(7):1073-80. https://doi.org/10.1093/aob/mcq085

33. Chen X, Zhu Y, Ding Y, Pan R, Shen W, Yu X, Xiong F. The relationship between characteristics of root morphology and grain filling in wheat under drought stress. Peer J. 2021;9:12015. https://doi.org/10.7717/peerj.12015

34. Santos J D, Da Silva ALL, Costa JL, Scheidt GN, Novak AC, Sydney EB, Soccol CR. Development of a vinasse nutritive solution for hydroponics. J Environ Manage. 2013;114:8-12. https://doi.org/10.1016/j.jenvman.2012.10.045

35. Shalini K, Pratibha P, Ranjeet Y, Santosh K. Hydroponic technique: a soilless cultivation in agriculture. Journal of Pharmacognosy and Phytochemistry. 2018;SP1:1886-91. https://www.phytojournal.com/archives/2018/vol7issue1S/PartAB/SP-7-1-588.pdf

36. Sankhalkar S, Komarpant R, Dessai TR, Simoes J, Sharma S. Effects of soil and soil-less culture on morphology, physiology and biochemical studies of vegetable plants. Current Agriculture Research. 2019;7(2): 222-51. http://dx.doi.org/10.12944/CARJ.7.2.06

37. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation. 2018;17(4):364-71. https://doi.org/10.5958/2455-7145.2018.00056.5

38. Sardare MD, Admane SV. A review on plant without soil-hydroponics. International Journal of Research in Engineering and Technology. 2013;2(3):299-304. https://doi.org/10.15623/IJRET.2013.0203013

39. Albregts EE, Howard CM. Effects of runner removal on strawberry fruiting response. Hort Science. 1986;21:97-98. https://doi.org/10.21273/hortsci.21.1.97

40. Handley DT, Dill JF, Moran RE. Prohexadione-calcium applications to suppress runner growth in strawberry grown in a plasticulture system. Acta Horticulturae. 2009;842:801-04. https://doi.org/10.17660/ActaHortic.2009.842.176

41. Jan S, Baba JA, Sharma MK, Qurat S, Wani FT, Nisar S, et al. Evaluation of different strawberry cultivars for growth, yield and quality characters under temperate conditions of north western Himalayas. International Journal of Current Microbial and Applied Sciences. 2021;10(3):837-44. https://doi.org/10.20546/ijcmas.2021.1003.106

42. Das AK, Singh KP, Prasad B, Ravindra K. Evaluation of cultivars of strawberry, a temperate fruit for its adaptability as well as productivity in sub-tropical agro-climatic condition of Supaul district in Bihar. Asian Journal of Horticulture. 2015;10(2):278-81. https://doi.org/10.15740/HAS/TAJH/10.2/278-281

43. Bakshi P, Bhat DJ, Wali VK, Sharma A, Iqbal M. Growth, yield and quality of strawberry (Fragaria x ananassa Duch.) cv. Chandler as influenced by various mulching materials. African Journal of Agricultural Research. 2014;9(7):701-06. https://doi.org/10.5897/AJAR2013.7983

44. Maher MM, Shylla B, Sharma DD, Sharma U. Influence of different soilless substrates and jeevamrit on flowering and fruiting behavior of strawberry (Frageris X ananassa Dutch.) cv. Chandler. Journal of Pharamcognosy and Phytochemistry. 2020;9(4):428-32. https://doi.org/10.22271/phyto.2020.v9.i4f.11723