

White-fruited strawberry growth and development under drip irrigation and fertigation

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Abstract. Strawberries, in addition to being a valuable source of nutrition, are also a much-preferred fruit due to their taste, attractive appearance, pleasant aroma, and beautiful colour. White strawberries are even more attractive with their exotic taste and interesting colour. The aim of this paper is to present the effects of the applied regimes of fertilisation and irrigation on the growth parameters of the white strawberry cultivar.

A two-factor experiment was conducted during 2023–2024 in an unheated greenhouse in the Chelopechene experimental field, Sofia, Bulgaria, with the drip-irrigated and fertigated strawberry cultivar *Fragaria x ananassa* ‘Snow White’. The irrigation and fertilisation factors were applied at two rates, where irrigation (IR): I1 – 75% ET_c and I2 – 50% ET_c; fertigation (F): F1 – optimal fertilisation N_{8.09}P_{12.76}K_{15.62} and F2 – suboptimal fertilisation with 75% of F1. Five treatments were tested: control: I0F0 – 100% ET_c, without fertigation; I1F1; I1F2; I2F1; I2F2. I1F1 plants showed the highest values of the studied growth parameters. It was established that plants from the I1F1 treatment (75% IR and 100% F) were the tallest (22.83 cm) and had the largest number of leaves (50.92), number of inflorescences (26.96), number of flowers (89.25), and runners (25.79). The plants from the I1F1 treatment had the highest plant growth index (30.13 cm).

Keywords: white strawberry, growth parameters, plastic tunnel, Bulgaria.

Introduction

Strawberries (*Fragaria × ananassa*) have been a focus of extensive agricultural research (Jo *et al.*, 2021) due to their high demand in fresh markets (Guo *et al.*, 2024) and processed products (Aziz *et al.*, 2019). While traditional strawberry cultivation methods have been effective, challenges such as water scarcity, nutrient management (Pardo-Beainy *et al.*, 2025), and yield optimisation have driven the search for more efficient agricultural practices (Wolcott & Thornsbury, 2025; Udekwe & Seyyedhasani, 2025). In recent years, the integration of drip irrigation and fertigation systems has garnered significant attention as a means to enhance both water and nutrient use efficiency, particularly in high-value crops like strawberries (Lone *et al.*, 2024).

The response of strawberries to drip irrigation and fertigation can be assessed through various vegetative and reproductive growth parameters (Kachwaya *et al.*, 2015). Key indicators include the number of

leaves, which reflects vegetative vigour; the number of inflorescences and flowers, which are directly related to fruiting potential; and the number of runners, which signify the plant’s capacity for vegetative propagation (Ali *et al.*, 2023). Additionally, the plant growth index – a composite measure encompassing parameters such as plant height, leaf area, and canopy spread – provides a holistic view of overall plant development and health. These parameters are essential for evaluating the success of cultivation strategies and predicting yield outcomes (Rahman *et al.*, 2021).

White-fruited strawberries, a cultivar variation with unique colour characteristics, have gained interest due to their distinct flavour profiles and potential for niche market appeal. The ‘Snow White’ cultivar was selected in 2010 from *Fragaria x ananassa* ‘Weisse Ananas’ and *Fragaria chiloensis* f. *Chiloensis* (Olbricht *et al.*, 2013).

‘Snow White’ was selected as the seedling in 2010 from a population of *Fragaria × ananassa* ‘Weisse

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Ananas' × clone numbers which arose from Chilean landraces of *Fragaria chiloensis* f. *chiloensis*. 'Snow White' is officially registered as a white-fruited strawberry variety under the European Plant Breeders' Rights under the registration number 43037 (CPVO, 2026).

The aim of this paper is to present the effects of the applied regimes of fertilisation and irrigation on the growth parameters of the white strawberry cultivar.

Materials and Methods

A two-year-long, two-factor experiment was conducted on drip-irrigated strawberry plants in a tunnel greenhouse in 2023 and 2024 in the Chelopechene experimental field (latitude 42°44'22.8"N, longitude 23°28'3.7"E, and altitude 550 m above sea level) of the Institute of Soil Science, Agrotechnologies and Plant Protection "Nikola Poushkarov" in Sofia, Bulgaria. The Sofia field falls in the temperate continental climate subzone. The greenhouse was unheated with an area of 420 m² (7.9 m × 53 m), and covered with a five-layer UV+EVA+IR+AD+dif 150 µm polyethylene film. The soil could be defined as moderately to strongly water-permeable with an average filtration capacity. The soil was *Chromic Luvisol* with a bulk density of 1.47 g cm⁻³, a field capacity of 22%, and a wilting point of 10% for the 0–50 cm layer. Pre-planting physico-chemical characteristics of the soil (0–20 cm) at the experimental plot were pH 6.5, organic carbon 2.87%, available nitrogen (N) 19.30 mg kg⁻¹, phosphorus (P₂O₅) 4.35 mg kg⁻¹, and potassium (K₂O) 2.79 mg kg⁻¹. To further reduce water losses, mulching with silver-black UV polyethylene mulch with a thickness of 30 µm was applied.

The object of the study was the white strawberry cultivar 'Snow White'. The experimental treatments were arranged according to the split-plot design with three replications. Each plot had a 23.2 m² area and consisted of twin rows of strawberries. Healthy bare-root frigo plants were planted in the scheme of 90 × 30 × 30 cm on 22 March 2023. According to the white strawberry cultivation technology, in each of the experimental plots, the appropriate amount of red fruit plants (*Fragaria* × *ananassa* 'Murano') was provided at a 4:1 ratio to ensure better pollination. The irrigation factor was applied at two rates: I1 – deficit irrigation - 75% ET_c; I2 – deficit irrigation – 50% ET_c. The fertilisation factor was applied at two rates: F1 – optimal fertilisation N_{8.09}P_{12.76}K_{15.62}; F2 – suboptimal fertilisation – 75% (F1) – N_{6.07}P_{9.57}K_{11.94}. Optimal fertilisation per season was developed according to Haifa nutrition recommendations (Haifa Group, 2021) as follows: optimal fertilisation (F1) – first application just before transplanting with NPK 0-52-34 (25 kg ha⁻¹);

second application at establishment with NPK 12-61-0 (45 kg ha⁻¹); third application one week after the second one with NPK 21-21-21 (25 kg ha⁻¹); 4th application at the start of buds swelling, with NPK 11-0-0 +16MgO (10 kg ha⁻¹); 5th application at the first set of flowers at the bottom of the rosette with NPK 12-61-0 (25 kg ha⁻¹); 6th application one week later with NPK 21-21-21 (35 kg ha⁻¹); 7th application in full flowering: (secondary (B) and tertiary (C) flowers open, first petals falling) growth stage with NPK 12-61-0 (25 kg ha⁻¹); 8th application at the receptacle protruding from the sepal whorl growth stage with NPK 15.5-0-0 +26.5CaO (30 kg ha⁻¹); 9th application one week later with NPK 31.5-0-46.2 (80 kg ha⁻¹); 10th application at the first fruit growth stage with NPK 31.5-0-46.2 (80 kg ha⁻¹); 11th application one week later with NPK 21-21-21 (35 kg ha⁻¹); 12th application one week later with NPK 31.5-0-46.2 (80 kg ha⁻¹); 13th application in the main harvest growth stage with NPK 12-61-0 (25 kg ha⁻¹); 14th application in the second harvest growth stage with NPK 0-52-34 (25 kg ha⁻¹); 15th application in senescence, beginning of dormancy – NPK 21-21-21 (40 kg ha⁻¹). Fertilisation of the variants with a suboptimal fertiliser rate (F2) per season was carried out according to the same schedule, using the same types of fertilisers, but with an amount of 75% of the F1 rate.

In total, five treatments were tested: control treatment I0F0: full irrigation (100% ET_c) and without fertigation; I1F1; I1F2; I2F1; I2F2. Irrigation was applied through a drip system, using a Netafim NMC Junior controller for precise irrigation rate application, a Netafim FertiKit Nutrigation system for precise fertigation rate application, pressure-compensated pipelines (Netafim UniRam AS) with an inside diameter of 14.6 mm, a wall thickness of 1.2 mm, built-in troughs, and 20 cm drippers, with a flow rate of 1.6 l h⁻¹.

The microclimate data (air temperature, relative humidity, solar radiation, sunshine duration, and wind speed) in the greenhouse were measured every 30 min. using an automatic meteorological station located in the centre of the experimental area and recorded in a data logger (HOBO USB Micro Data Logger, USA). FAO Penman-Monteith Equation (Allen *et al.*, 2006a) was used for determining the reference evapotranspiration:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)},$$

where: ET₀ is the reference evapotranspiration, mm day⁻¹;

Δ – slope vapour pressure curve (kPa °C⁻¹);

R_n – net radiation at the crop surface (MJ m⁻² day⁻¹);

G – soil heat flux density ($\text{MJ m}^2 \text{day}^{-1}$); γ – psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$);
T – mean daily air temperature at 2 m height ($^\circ\text{C}$);
 u_2 – wind speed at 2 m height (m s^{-1});
 e_s – saturation vapour pressure (kPa);
 e_a – actual vapour pressure (kPa).

Crop evapotranspiration was determined by the formula (Allen *et al.*, 2006a):

$$\text{ET}_c = \text{ET}_o K_c,$$

where: ET_c is crop evapotranspiration under standard conditions (mm day^{-1}),

K_c – crop coefficient;

ET_o – reference evapotranspiration (mm day^{-1}).

Crop coefficient was 0.30, 0.80 and 0.70 respectively in the initial, middle, and end growing stage (Allen *et al.*, 2006b).

Growth parameters were measured by treatments, from tagged 4 consecutive plants per replication of the following indicators: plant spread, number of leaves, inflorescences, flowers, and runners. The plant growth index was determined by the formula:

$$\text{PGI} = \frac{X+Y+h}{3},$$

where: PGI is the plant growth index (cm);

X – plant width (cm);

Y – perpendicular width (cm);

h – plant height (cm).

The obtained data were statistically analysed using ANOVA software STATISTICA 8.0. Fisher LSD test at a significance level ($p < 0.05$) to measure specific differences between pairs of means.

Results and Discussion

Based on collected data on the greenhouse microclimate, the 10-day crop evapotranspiration was determined throughout the 2023 and 2024 growing seasons (Fig. 1). The mean 10-day strawberry

evapotranspiration throughout the 2023 growing season was 16.57 mm, and ranged from 3.90 mm (first decade of April) to 33.02 mm (second decade of July). During the flowering stage (25 April – 24 May), the average 10-day ET_c value was 14.57 mm, and during the harvesting stage (25 May – 14 July) it was 25.58 mm. The mean 10-day strawberry evapotranspiration throughout the 2024 growing season was 17.35 mm, and ranged from 2.60 mm (first decade of November) to 32.22 mm (second decade of July). During the flowering stage (27 March – 02 May), the average 10-day ET_c value was 14.93 mm, and during the harvesting stage it was 22.08 mm (17 April – 17 June). The mean 10-day ET_c increased, synchronised with the intensity of vegetative development of strawberries and with increasing temperature.

Strawberry growth parameters for the 2023 growing season are shown in Fig. 2. Whole growth parameters had statistical significance at $p < 0.05$ among treatments and dates. Plant spread in the NE-SW direction data were arranged in three homogeneous groups. Treatments with an irrigation rate of 100% ET_c and 75% ET_c (I0F0, I1F1, I1F2) were significantly higher compared to treatments with an irrigation rate of 50% ET_c (I2F2 and I2F1). I1F1 treatment (irrigation 75% (ET_c) and fertigation $N_{8.09}P_{12.76}K_{15.62}$) had a mean plant spread in the NE-SW direction of 31.58 cm, 82% more than the I2F2 treatment (irrigation 50% (ET_c) and fertigation $N_{6.07}P_{9.57}K_{11.72}$). Plant spread in the NW-SE direction data were arranged in two homogeneous subsets. In regard to this parameter, the deficit irrigation rate treatments of 50% ET_c (I2F2 and I2F1) were significantly lower compared to the I1F2 treatment. The control treatment (I0F0) had a mean plant spread of 34.75 cm in the NW-SE direction. While this was 25% greater than the I2F2 treatment, the differences were not statistically significant. The tallest plants were the plants in the I1F1 treatment of 22.92 cm, 25% taller than the I2F2 treatment plants and 29% taller than the I2F1 treatment plants. Plant height data were arranged in three homogeneous

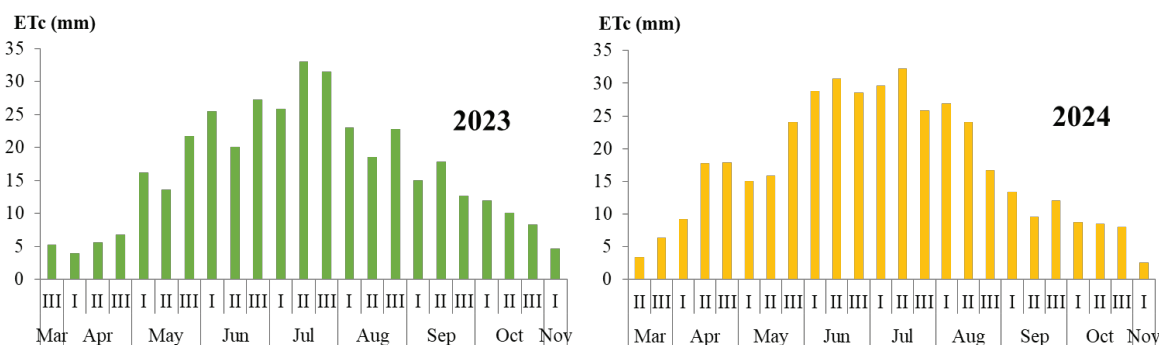


Figure 1. Evapotranspiration of strawberries for a 10-day period in the years 2023 and 2024.

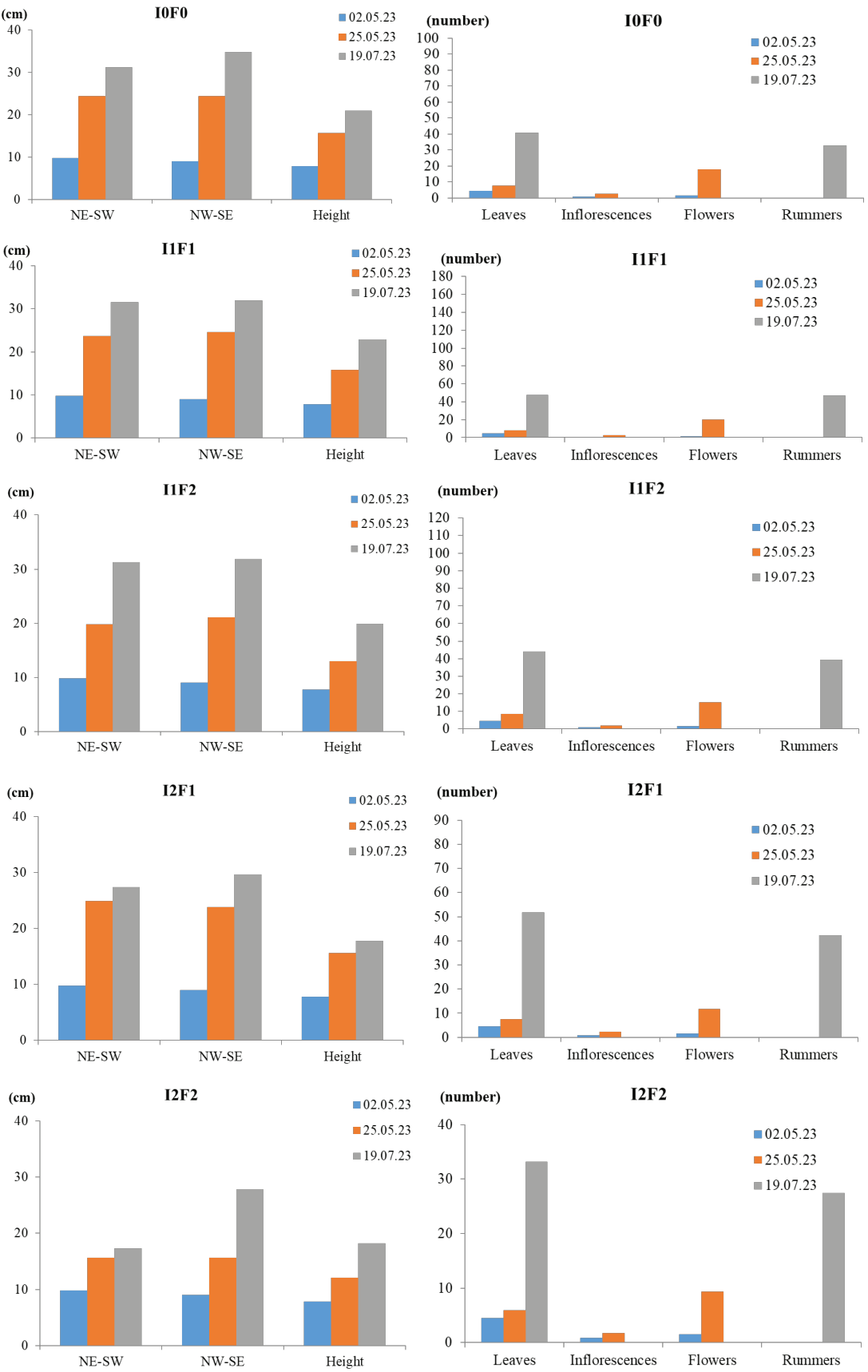


Figure 2. Growth parameters of white strawberry by treatments for the 2023 growing season.

subsets. Plants from the I0F0 treatment (100% (ET_c) irrigation rate, without fertigation) had the highest plant growth index (28.94 cm), 36% higher than the I2F2 treatment (irrigation 50% ET_c and fertigation $N_{6.07}P_{9.57}K_{11.72}$). Plant growth index data were arranged in three homogeneous subsets. The maximum mean number of leaves (51.67) was obtained in the I2F1 treatment (irrigation 50% ET_c and fertigation $N_{8.09}P_{12.76}K_{15.62}$), 55% higher than in the I2F2 treatment (irrigation 50% ET_c and fertigation $N_{6.07}P_{9.57}K_{11.72}$). Data on the mean number of leaves were arranged in three homogeneous subsets. Plants fertigated with a higher fertigation rate had more leaves, but they were significantly smaller. It could be assumed that fertilisation has a stronger influence on the formation of the number of leaves than irrigation. Similar results are reported from Singh *et al.* (2019) for *Fragaria* × *ananassa*, cv. ‘Chandler’ at different irrigation and fertigation levels.

Fig. 3 presents growth parameters of white strawberry by treatments for the 2024 growing season. Whole growth parameters have statistical significance at $p < 0.05$. The results of Duncan’s multiple range test for the significance of differences showed that plant spread in the NE-SW direction data were arranged in three homogeneous groups. There was no significant difference between the control treatment I0F0, I1F2 and I2F1 at a significance level of $p = 0.05$. There

was a statistically significant difference between other pairs. I1F1 treatment (irrigation 75% (ET_c) and fertigation $N_{8.09}P_{12.76}K_{15.62}$) had a mean plant spread in the NE-SW direction of 35.75 cm, 66% more than in the I2F2 treatment (irrigation 50% (ET_c) and fertigation $N_{6.07}P_{9.57}K_{11.72}$). The I1F1 treatment is most effective for increasing the NE-SW growth parameter. Conversely, the I2F2 combination seems to have a suppressive effect or is the least efficient setup. Plant spread in the NW-SE direction data were arranged in four homogeneous groups. Control treatment I0F0 had a mean plant spread in the NW-SE direction of 35.75 cm, 67% more than the I2F2 treatment plants. The tallest plants were the plants in the I1F1 treatment – 22.75 cm, 74% taller than I2F2 treatment plants. The results of Duncan’s multiple range test for the significance of differences show that plant height data had a statistical difference between all pairs. Plants in the I1F1 treatment had the highest plant growth index (31.42 cm), which was 69% higher than in the I2F2 treatment (irrigation 50% ET_c and fertigation $N_{6.07}P_{9.57}K_{11.72}$), arranged in four homogeneous groups. The maximum mean number of leaves (54.08) was obtained in the I1F1 treatment, 68% higher than in the I2F2 treatment. Data were arranged in four homogeneous groups. The maximum mean number of flowers (158.42) was obtained in the I1F1 treatment, 6 times more than in the I2F2

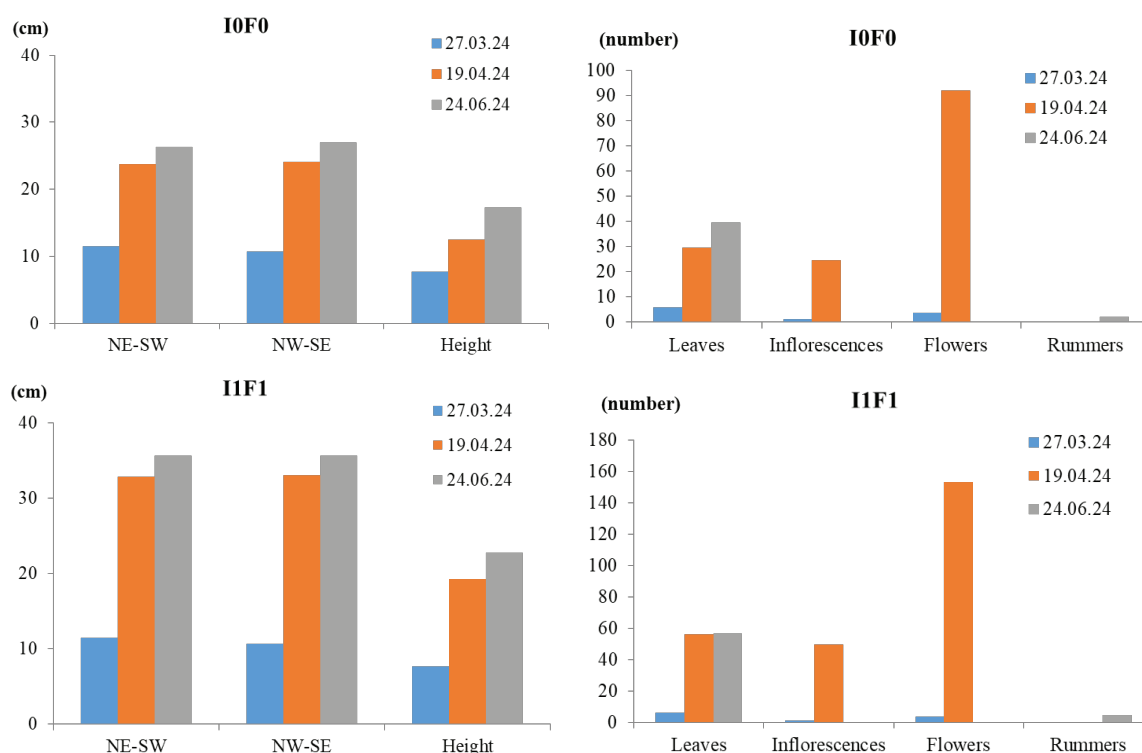


Figure 3. Growth parameters of white strawberry by treatments for the 2024 growing season.

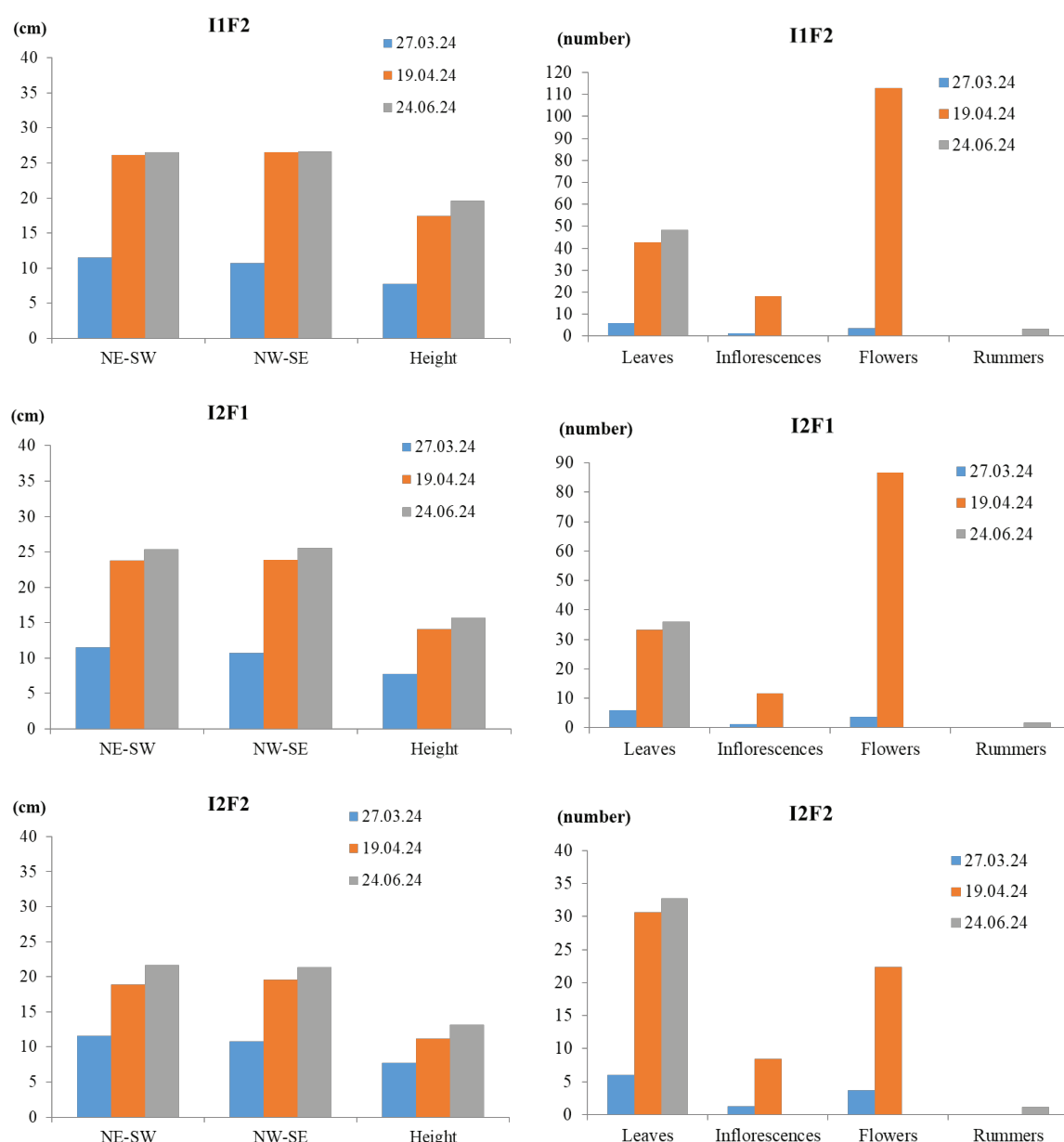


Figure 3. Growth parameters of white strawberry by treatments for the 2024 growing season.

treatment. Data were arranged in four homogeneous groups. The maximum mean number of runners (4.75) was obtained in the I1F1 treatment, which was 6 times more than in the I2F2 treatment. Data were arranged in four homogeneous groups.

The results (Table 1) of two evaluation years showed that all growth parameters have statistical significance among treatments at $p < 0.05$. There was no significant difference between the control treatment I0F0, I1F2 and I2F1 at a significance level of $p = 0.05$ for plant spread in the NE-SW direction. There was a statistically significant difference between other treatments. Plants in the I1F1 treatment (irrigation

75% (ET_c) and fertigation $N_{8.09}P_{12.76}K_{15.62}$) had the highest mean plant spread in the NE-SW direction: 33.67 cm, 73% more than in the I2F2 treatment (irrigation 50% (ET_c) and fertigation $N_{6.07}P_{9.57}K_{11.72}$), which was the lowest. There was no significant difference between the control treatment I0F0, I1F2 and I2F1 at a significance level of $p = 0.05$ for plant spread in the NW-SE direction data. Control treatment I0F0 had a mean plant spread in the NW-SE direction of 29.38 cm, which is 19% more than in the I2F2 treatment. The tallest plants were in the I1F1 treatment (22.83 cm, 47% taller than in the I2F2 treatment, which had the shortest plants). The results

Table 1

Average growth parameters of white strawberry by treatments for the 2023–2024 growing seasons

Treatment	Plant spread			Plant growth index	Leaves (number)	Inflorescences (number)	Flowers (number)	Runners (number)
	NE-SW (cm)	NW-SE (cm)	Height (cm)					
I0F0	28.54 ^a	29.38 ^a	18.54	25.49 ^a	41.54 ^a	13.50 ^a	51.50 ^{ab}	20.67 ^a
I1F1	33.67	33.88	22.83	30.13	50.92	26.96	89.25	25.79 ^c
I1F2	28.50 ^a	30.13 ^a	20.29	26.31 ^a	44.33 ^a	10.92 ^{ab}	65.46 ^b	17.96 ^{ab}
I2F1	26.33 ^a	27.83 ^a	16.79 ^a	23.65	44.33 ^a	7.25 ^b	49.92 ^a	22.00 ^{ac}
I2F2	19.42	24.58	15.67 ^a	19.89	32.75	5.71 ^b	17.92	14.33 ^b
F _{exp.}	40.88	14.29	25.23	34.48	10.83	18.73	25.74	6.24
P _{exp}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0002

Values with the same lowercase letter for the same parameter were not statistically different ($p<0.05$).

of Duncan’s multiple range test for the significance of differences show that plant height data are arranged in four homogeneous groups. Plants from the I1F1 treatment had the highest plant growth index (30.13 cm), which was 51% higher than in the I2F2 treatment (irrigation 50% ETc and fertigation N_{6.07}P_{9.57}K_{11.72}). The maximum mean number of leaves (50.92) was obtained in treatment I1F1, which was 55% higher than the I2F2 treatment. The maximum mean number of flowers (89.25) was obtained in treatment I1F1, which was 398% higher than in the I2F2 treatment. The maximum mean number of runners (25.79) was obtained in the I1F1 treatment, 80% higher than in the I2F2 treatment.

Conclusions

Different levels of irrigation and fertigation affect the growth parameters of the white fruited strawberry ‘Snow White’. It was found that plants in the I1F1 treatment (75% IR and 100% F) had the best plant development among the evaluated treatments, where plants were the tallest (22.83 cm) and had the largest number of leaves (50.92), inflorescences (26.96), flowers (89.25), runners (25.79), and the highest plant growth index (30.13 cm).

Despite their aesthetic appeal, the growth and development of white-fruited strawberries under modern agricultural practices, particularly those involving drip irrigation and fertigation, remain underexplored. Understanding how these practices affect their growth dynamics, fruit yield, and quality is critical for growers aiming to optimise production while meeting market demands.

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