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EVALUATION OF THE INTEGRATED EFFECTS OF SOIL MANAGEMENT AND FERTILIZATION STRATEGIES ON THE GROWTH, YIELD AND QUALITY OF SWEET PEPPER (*CAPSICUM ANNUUM* L.) CULTIVATED IN POLYETHYLENE GREENHOUSES

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Abstract

This study investigates the impact of various soil management practices and fertilization treatments on the growth, yield and quality of `DarianaBac`sweet pepper (Capsicum annuum L.) cultivated in polyethylene greenhouses. Experimental variants were defined by two distinct soil preparation methods: plowed soil and rotary-tilled soil, coupled with five different fertilization treatments, including Albit + Turboroot, Biochar + Woodvinegar + Cropmax, Nutriplant + Resid, Orgevit + Kerafol and untreated controls. Comprehensive assessments were conducted across several key parameters: plant biometrics (plant height, number of branches, stem collar diameter, flower count per plant), physiological and stress-related responses (anthocyanin and chlorophyll content), productive parameters (fruit count per plant, average fruit weight, yield per plant), fruit morphology (fruit width, length, and form index) and yield quality indicators (carotenoid and lycopene content, total soluble solids, and dry matter content of fruits). Statistical analysis revealed significant differences in plant development and yield outcomes influenced by both soil treatment and fertilization regime.

Key words*: ploughing tillage, rototiller, soil enrichment practices, crop management, controlled environment.*

INTRODUCTION

The sweet pepper (*Capsicum annuum* L. ssp. *annuum*), a thermophilic species within the Solanaceae family, holds global prominence for its high productivity, pest and disease resilience and versatility in fresh consumption, culinary applications and industrial processing (Brezeanu et al., 2022; Bălăiță et al., 2024). Renowned for its abundant bioactive compounds, including ascorbic acid, carotenoids, tocopherols and phenolic compounds, this crop provides potent antioxidative and health-promoting benefits, mitigating oxidative stress and reducing the risk of chronic diseases such as cardiovascular disorders and cancer (Brezeanu et al., 2022; Stoleru et al., 2023). The compositional quality and phytochemical richness of sweet peppers are profoundly influenced by genetic, environmental and agronomic factors, with sustainable cultivation practices proven to enhance nutrient content while minimizing ecological impact (Stoleru et al., 2023). Contemporary research prioritizes integrating genotype optimization with eco-conscious agricultural practices to elevate the nutritional, economic and environmental value of sweet peppers in a sustainable food system (Brezeanu et al., 2022; Stoleru et al., 2023; Elhawary et al., 2024). In controlled environments such as polyethylene greenhouses, these variables acquire heightened importance, given the need to balance resource efficiency, environmental sustainability and economic viability (Maraveas, 2019).

To meet the growing demand for premium-quality produce while ensuring sustainable agricultural practices, an integrated approach that optimizes soil management and fertilization strategies is essential (Batabyal, 2017). These two critical factors directly influence plant growth, resource use efficiency and the nutritional and phytochemical profiles of the harvested produce (Cabrera-De la Fuente et al., 2018; Heimler et al., 2017), particularly in controlled environments such as polyethylene greenhouses (Ahmed et al., 2024; Zhao et al., 2024).

Soil management practices, such as plowing and rototilling, are fundamental to creating a conducive growth medium for crops (Mefferd, 2019). These practices influence soil aeration, water infiltration, root penetration and nutrient availability, which are vital for enhancing plant vigor and productivity (Mitchell et al., 2019). Plowing ensures deeper soil turnover, promoting nutrient redistribution (Jin et al., 2020), while rototilling focuses on surface soil refinement and microbial activity enhancement (Torotwa et al., 2023). The choice of soil management practice can significantly alter the soil's physical and biochemical properties (Kobierski et al., 2020), altering plant performance and the uptake of nutrients (Lv et al., 2023).

Similarly, fertilization management practices play an equally pivotal role in determining the physiological and biochemical quality of sweet pepper fruits (EL-Mogy et al., 2024). Fertilization not only supplies essential nutrients for optimal plant growth but also modulates the biosynthesis of bioactive compounds such as carotenoids, ascorbic acid and phenolics, which are key determinants of fruit quality (Muscolo et al., 2020; Stagnari et al., 2022).

This research seeks to unravel the synergistic effects of soil preparation techniques and fertilization regimes on growth, yield and quality attributes of sweet pepper, including the accumulation of health-promoting compounds. By examining the interplay between these two pivotal factors, the study offers critical insights into optimizing production systems in greenhouse environments. The findings are anticipated to contribute to advancing sustainnable horticultural practices that prioritize soil health, efficient resource use and high-quality crop production, addressing both consumer demand and environmental sustainability imperatives.

MATERIALS AND METHODS

Location and Experimental Setup

The experiment was conducted in 2024 at the Vegetable Research and Development Station Bacau, Romania.

The trial was carried out in an Almeria-type polyethylene-covered greenhouse with controlled environmental factors (Figure 1).

Figure 1. Geographical Site and Experimental Design

Crop Description

`Darianabac` cultivar of *Capsicum annuum* L. served as the focal point of this research, an early-maturing, medium-vigor variety with a vegetative period of 120 days until the first harvest. The plant habit is characterized by 50% erect and 50% horizontal growth, while the fruit exhibits a yellow hue with greenish tones at physiological maturity, weighing an average of 80-120 g.

Sowing and Transplanting

Sowing: 2nd decade of February

The seeds were sown in Rekyva Remix 1 horticultural peat, a substrate specially designed for seed germination. The substrate features small and/or medium fractions with the following characteristics: pH 5.5-6.5, electrical conductivity 0.5-1 mS/cm, and a chlorine-free NPK content ≤ 1 kg/m³.

Transplanting: 3rd decade of February

The seedlings were transplanted into 70-cell alveolar trays. The substrate used was Rekyva Remix 2 horticultural peat, designed for seedling cultivation, characterized by medium and/or large fractions with pH 5.5-6.5, electrical conductivity 1-2 mS/cm, and a chlorine-free NPK content ≤ 2 kg/m³.

Experimental Variants

The experimental variants, detailed in Table 1, were implemented using a mirrored design under two distinct soil management systems:

Plowed soil (30 cm depth), with variants labeled as P1R1, P1R2, P1R3, ..., P4R2, etc.

Rototilled soil (incorporated with a rototiller), with variants labeled as RT1R1, RT1R2, RT1R3, ..., RT4R2, etc.

Table 1. Experimental variants. Fertilization regimens: composition and application schedules

Crop/Cultivar	Soil management practice	Fertilization scheme	Application dates and no of treatments
`DarianaBac` sweet pepper	plowed soil	**P1** - Albit (0.01%) + Turboroot (0.5%)	I - 3rd decade of May; II - 2nd decade of June; III - 1st decade of July;
		P2 - Biochar (10 g/plant) + Wood Vinegar (0.5%) + Cropmax (0.25%)	
		P3 - Nutriplant 20:20:20 (0.015%) + Resid (2 g/plant)	
		P4 - Orgevit (10 g/plant) + Kerafol (0.25%)	
		P5 - Control (untreated)	
	rototilled soil	**RT1** - Albit (0.01%) + Turboroot (0.5%)	
		RT2 - Biochar (10 g/plant) + Wood Vinegar (0.5%) + Cropmax (0.25%)	
		RT3 - Nutriplant 20:20:20 (0.015%) + Resid (2 g/plant)	
		RT4 - Orgevit (10 g/plant) + Kerafol (0.25%)	
		RT5 - Control (untreated)	

Figure 2. Aspects regarding the application of fertilizing substances and biostimulatory compounds

Each experimental variant was replicated three times, with each replication including five plants.

Cultivation and Irrigation

Plant spacing: 25 cm between plants within a row and 70 cm between rows, resulting 57.143 plants/ha.

Irrigation: Drip irrigation was employed using drip hoses.

Weed control: Black polyethylene mulch was applied between the rows for optimal weed control.

Vegetative and Generative Development of Sweet Pepper Plants

An extensive array of growth parameters was meticulously monitored to evaluate plant development. These parameters encompassed total plant height, stem collar diameter, number of secondary stems (branches) and flowers. At the conclusion of the growth cycle, comprehensive data on fruit yield were gathered, including metrics such as the number of fruits per plant, average fruit weight, yield per plant, fruit width, fruit height, and the fruit form index (calculated as the ratio of fruit height to width). Measurements were performed through direct counting, with linear dimensions assessed using a precision ruler, diameters measured with a calibrated caliper and weights determined using a high-accuracy electronic balance.

Physiological parameters

The quantification of chlorophyll pigments and anthocyanins was performed using two comparable devices, the CCM 200 plus and ACM 200 plus, both manufactured by OptiSciences. The data were expressed through indices designed to precisely reflect the total concentrations of chlorophyll pigments and anthocyanins, namely the Chlorophyll Concentration Index and the Anthocyanin Content Index.

Quality Assessment

The quality evaluation of sweet peppers fruits influenced by the two experimental factors, encompassed several parameters, including β-carotene and lycopene concentrations, total soluble solids (TSS) and dry matter (DM) content (Figure 3).

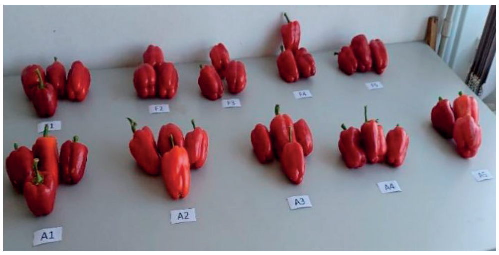

Figure 3. Processing of fruits for laboratory specimen procurement

β-carotene and lycopene quantification – extractions were conducted using petroleum ether as the solvent, with absorbance measured spectrophotometrically at 452 nm for β-carotene and 472 nm for lycopene. The respective concentrations were calculated by multiplying the absorbance readings by standardized conversion factors—19.96 for β-carotene and 14.495 for lycopene. The results were then reported in milligrams per 100 grams of fresh weight (mg·100 g^{-1} F.W.), ensuring an accurate representation of pigment concentration.

Total soluble solids (TSS) were quantified using a precision handheld refractometer, and the results were reported in degrees Brix, following the AOAC (2005) method, section 932:12.

Dry matter (DM) was determined by drying fresh, uniform samples in a forced-air oven (Biobase) maintained at a constant temperature of 103 ± 2°C for 24 hours, until achieving a stable weight. This procedure adhered strictly to the AOAC (2000) protocol, with the final results expressed as a percentage.

Statistical analysis

The analytical data obtained from the study were subjected to statistical evaluation utilizing IBM SPSS Statistics software, version 26.0. Analysis of variance (ANOVA) was employed to identify differences among group means, with subsequent pairwise comparisons performed using Tukey's post hoc test. Statistical significance was established at a confidence level of $p < 0.5$. Results are presented as mean values accompanied by their corresponding standard deviation.

RESULTS AND DISCUSSIONS

The present study assessed the influence of diverse fertilization treatments and soil management techniques on the growth and productivity of the DarianaBac sweet pepper variety under controlled greenhouse conditions.

Differences in plant height, secondary stems, stem collar diameter, flower production and fruit set 30 days after transplanting were evaluated (Table 2). While statistically significant differences (Tukey test, $p<0.05$) were identified only for flower production, observed variations in the other parameters did not reach significance, as indicated by shared letter groupings in the analysis. These findings underscore the specific sensitivity of flower production to the interplay between nutrient application and soil preparation, while other growth parameters appeared more resilient to these treatments.

Rototilled soils consistently promoted greater plant height compared to plowed soils, with the highest value recorded in rototilled soil treated with Albit and Turboroot (RT1 - 52.77 ± 8.38 cm) versus plowed soil (P1-P5, 41.77-49.00 cm). Although differences within soil management types were not statistically significant, the findings suggest that rototilling enhances root expansion and nutrient availability. Environmental factors, such as light intensity and temperature, appeared to have a more pronounced influence on plant height than soil or fertilization practices. Secondary stem production also favored rototilled soils, with RT5 (9.44 ± 1.24) and RT1 (9.11 ± 0.93) achieving the highest values. Orgevit and Kerafol treatments further supported vegetative growth, highlighting the combined role of soil structure and specific fertilizers in promoting branching (Fan et al., 2021; Bodner et al., 2021). Stem collar diameter remained consistent across treatments, suggesting structural growth is less sensitive to soil preparation and fertilization (Wolf, 2022). However, flower production showed a marked response, with rototilled soil and Nutriplant plus Resid (RT3 - 51.33 ± 7.28 flowers) achieving the highest results. These findings emphasize the role of enhanced soil aeration and targeted fertilization in optimizing flowering potential (Cho et al., 2017; Welch, 2024). Fruit set 30 days post-transplantation was highest in P4 and RT4 (Orgevit + Kerafol), yielding 3.00 ± 1.30 and 2.78 ± 2.05 fruits, respectively, compared to controls (RT5 - 2.11 ± 1.83; P5 - 1.63 ± 1.22). Fertilization treatments significantly improved fruiting, underscoring the synergy between soil management and balanced nutrient application in enhancing reproductive success (Morugán-Coronado et al., 2020; Liu et al., 2024; Brezeanu et al., 2022).

Overall, the results confirm that combining rototilling with specific fertilization strategies, such as biochar, wood vinegar, Cropmax and Orgevit, significantly improves key growth parameters and productivity.

Table 2. Morphological and reproductive characteristics of `Darianabac` sweet pepper plants

Variant	Plant height (cm)	No of secondary stems	Stem collar Ø (mm)	No of flowers/plant	No of fruits/plant (30 days after transplanting)
P1	44.20±7.98ns	7.10±1.45ns	9.39±1.32ns	32.20±9.05b	1.63±1.22ns
P2	41.77±5.78ns	7.23±1.56ns	10.29±1.25ns	32.80±5.87b	1.20±1.2ns
P3	49.00±4.41ns	7.20±1.39ns	9.82±0.93ns	44.53±6.19ab	1.77±1.56ns
P4	47.67±4.30ns	8.00±2.06ns	8.97±1.30ns	35.43±8.05ab	3.00±1.3ns
P5	47.77±6.57ns	7.43±2.01ns	9.19±1.45ns	38.53±4.8ab	1.80±1.09ns
RT1	52.77±8.38ns	9.11±0.93ns	9.99±0.97ns	45.44±10.54ab	1.11±1.27ns
RT2	49.57±4.64ns	8.22±1.86ns	10.13±1.02ns	50.33±7.75a	2.44±1.42ns
RT3	49.43±3.43ns	7.89±1.05ns	9.89±0.90ns	51.33±7.28a	2.56±1.74ns
RT4	47.43±5.08ns	8.67±2.00ns	10.08±0.85ns	50.56±8.68a	2.78±2.05ns
RT5	51.33±4.72ns	9.44±1.24ns	10.23±0.83ns	49.11±14.17ab	2.11±1.83ns

The presented values represent the arithmetic mean accompanied by the standard deviation. Lowercase letters indicate the outcomes of Tukey's post-hoc analysis at a significance threshold of $p < 0.05$, where "a" designates the highest recorded value and "ns" - non-significant differences. P1 plowed soil * Albit + Turboroot; P2 - plowed soil * Biochar + Wood Vinegar + Cropmax; P3 - plowed soil * Nutriplant 20:20:20 + Resid; P4 - plowed soil * Orgevit + Kerafol; P5 - plowed soil * unfertilized (Control); RT1 – rototilled soil * Albit + Turboroot; RT2 - rototilled soil * Biochar + Wood Vinegar + Cropmax; RT3 - rototilled soil * Nutriplant 20:20:20 + Resid; RT4 - rototilled soil * Orgevit + Kerafol; RT5 - rototilled soil * unfertilized (Control)

The study also highlighted the pivotal role of soil management and fertilization in modulating physiological parameters of sweet pepper (Figure 4).

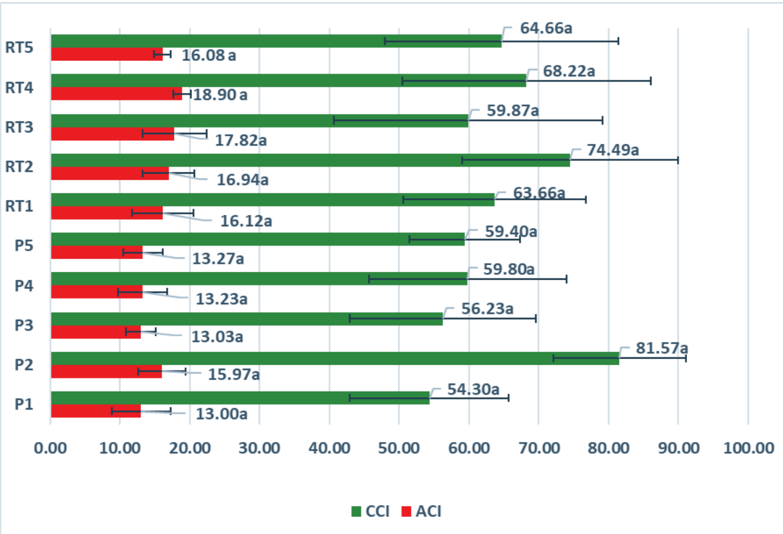

Figure 4. Concentration of anthocyanin and chlorophyll content of `Darianabac` sweet pepper leaves
Note: Same letters show no significant difference between items according to Tukey's post-hoc test; $p \leq 0.05$

The highest Chlorophyll Content Index (CCI) was recorded in plowed soil amended with biochar, wood vinegar and Cropmax (P2 - 81.57), significantly outperforming other plowed soil variants. In rototilled soil, the same fertilization scheme (RT2 - 74.49) produced the highest CCI, comparable to P2, while Orgevit and Kerafol (RT4 - 68.22) also performed well. Controls (P5 - 59.40; RT5 - 64.66) showed moderate values, demonstrating the superiority of enriched treatments in enhancing photosynthesis (Hur et al., 2024).

Anthocyanin Content Index (ACI) was highest in rototilled soil with Orgevit and Kerafol (RT4

- 18.90) and Nutriplant with Resid (RT3 - 17.82), with comparable values across most treatments, including controls (P5 - 13.27). This consistency suggests anthocyanin synthesis depends more on environmental factors than fertilization (Kutman, 2023; Kaur et al., 2023; Yan et al., 2022).

Rototilling enhanced nutrient integration, especially for biochar and wood vinegar, through improved soil aeration and microbial activity (Wang et al., 2022). However, ACI appeared largely independent of nutrient inputs, aligning with its reliance on stress-induced pathways (Araguirang & Richter, 2022; Li & Ahammed, 2023).

Thus, biochar, wood vinegar and Cropmax significantly improved chlorophyll synthesis, while anthocyanin accumulation was less responsive to fertilization. These findings highlight the interplay of soil preparation and nutrient management in optimizing physiological performance in protected cultivation systems.

The significant effects of soil preparation and fertilization on key yield parameters of sweet pepper (DarianaBac variety), including average fruit weight, fruit count per plant and total yield per plant are highlighted in Table 3.

Average fruit weight was highest in rototilled soil fertilized with biochar, wood vinegar and Cropmax (RT2, 97.33 g ± 11.88), outperforming other treatments, including P2 (95.50 g ± 22.28) and P3 (94.43 g ± 18.74). The lowest value was recorded in RT4 (79.53 g ± 14.02), treated with Orgevit and Kerafol, suggesting suboptimal interactions between this fertilization and rototilled soil. The results highlight biochar's potential to enhance soil structure and nutrient retention, while wood vinegar's organic acids further augment nutrient availability, aligning with findings by Lei et al. (2024) and Simiele et al. (2022).

Fruit count per plant (60 days post-transplant) was highest in RT2 (22.33 ± 7.57), followed by RT1 (21.33 ± 7.57) and RT4 (20.67±1.53), significantly exceeding plowed soil variants such as P1 (13.00 fruits) and P5 (9.67 fruits). Rototilled soil likely supports superior nutrient and water uptake, driving higher reproductive output.

The highest total yield per plant was observed in RT2 (2160.17 g ± 319.09), followed by RT1 (1838.63 g ± 506.8), both of which significantly outperformed plowed soil variants, such as P5 (783.39 g ± 256.75). These results underscore the pivotal role of rototilling in enhancing yield potential and optimizing large-scale production (Shah & Wu, 2019). Also, humic substances, an integral part of the treatments in P2 and RT2 variants, are recognized as the most vital constituents of soil, playing a pivotal role in its productivity (Raducanu et al., 2016). The significant differences between rototilled and plowed soil variants emphasize the crucial impact of soil preparation, while the lower yields observed in the untreated control (P5) underscore the importance of implementing targeted fertilization strategies to optimize crop production.

Table 3. Fruit yield and productivity parameters of `Darianabac` sweet pepper plants

Variant	Average fruit weight (g)	No of fruits/plant (60 days after transplanting)	Total yield/plant (g)
P1	87.10±21.07ns	13.00±4.00abc	1129.94±477.42ab
P2	95.50±22.28ns	11.33±2.89abc	1085.40±237.01ab
P3	94.43±18.74ns	11.00±3.61bc	1042.98±530.51b
P4	93.73±7.49ns	11.67±3.79abc	1111.32±329.7ab
P5	81.67±15.15ns	9.67±4.51c	783.39±256.75b
RT1	85.17±19.41ns	21.33±5.77ab	1838.63±506.8ab
RT2	97.33±11.88ns	22.33±7.57a	2160.17±319.09a
RT3	81.17±10.02ns	19.33±9.02abc	1574.11±408.33ab
RT4	79.53±14.02ns	20.67±1.53abc	1632.49±318.51ab
RT5	82.77±21.16ns	18.37±2.89abc	1517.87±253.98ab

The presented values represent the arithmetic mean accompanied by the standard deviation. Lowercase letters indicate the outcomes of Tukey's post-hoc analysis at a significance threshold of $p < 0.05$, where "a" designates the highest recorded value and "ns" - non-significant differences. P1 plowed soil * Albit + Turboroot; P2 - plowed soil * Biochar + Wood Vinegar + Cropmax; P3 - plowed soil * Nutriplant 20:20:20 + Resid; P4 - plowed soil * Orgevit + Kerafol; P5 - plowed soil * unfertilized (Control); RT1 – rototilled soil * Albit + Turboroot; RT2 - rototilled soil * Biochar + Wood Vinegar + Cropmax; RT3 - rototilled soil * Nutriplant 20:20:20 + Resid; RT4 - rototilled soil * Orgevit + Kerafol; RT5 - rototilled soil * unfertilized (Control)

The data also revealed notable variations in fruit dimensions across the different treatments (Table 4). For fruit width, plowed soil treatments, particularly P3 (66.00 mm ± 12.27), exhibited the widest fruits, followed by P2 (64.53 mm ± 5.71), P4 (64.10±4.07) and RT2 (63.23 mm ± 2.46). These results suggest that certain plowed soil treatments may be more conducive to fruit width development. In contrast, RT1 had the smallest fruit width, averaging 58.53 mm ± 7.36, which could indicate a potential limitation in nutrient availability or soil structure in this treatment. Regarding fruit length, the largest fruits were observed in P5 (80.90 mm ± 12.96), followed by RT1 (78.80 mm ± 10.47). Notably, biochar + wood vinegar + Cropmax and, respectively, Nutriplant + Resid fertilization schemes showed lower average fruit lengths in both plowed and rototilled soils. These variations highlight the differing impacts of soil preparation methods on fruit length, where plowing may promote longer fruit development. Overall, the results underscore the complex interactions between soil preparation, fertilization strategies and fruit development, with plowed treatments often outperforming rototilled ones in certain parameters.

Table 4. Morphological characteristics and fruit form indices

Variant	Fruit width (mm)	Fruit length (mm)	Fruit form index (W/L)	Fruit form index (L/W)
P1	62.97±3.28ns	72.53±14.36ns	0.88±0.10ns	1.15±0.14ns
P2	64.53±5.71ns	74.67±7.54ns	0.87±0.10ns	1.16±0.14ns
P3	66.00±12.27ns	73.10±4.67ns	0.91±0.12ns	1.12±0.15ns
P4	64.10±4.07ns	77.77±12.52ns	0.83±0.03ns	1.21±0.04ns
P5	60.33±23.75ns	80.90±12.96ns	0.75±0.24ns	1.44±0.53ns
RT1	58.53±7.36ns	78.80±10.47ns	0.74±0.06ns	1.35±0.10ns
RT2	63.23±2.46ns	73.87±6.99ns	0.86±0.07ns	1.17±0.10ns
RT3	62.03±5.22ns	72.27±8.88ns	0.86±0.05ns	1.17±0.07ns
RT4	61.27±7.30ns	69.00±24.07ns	0.90±0.14ns	1.13±0.19ns
RT5	61.40±8.91ns	75.67±15.46ns	0.84±0.24ns	1.26±0.40ns

The presented values represent the arithmetic mean accompanied by the standard deviation. Lowercase letters indicate the outcomes of Tukey's post-hoc analysis at a significance threshold of $p < 0.05$, where "ns" - non-significant differences. P1 plowed soil * Albit + Turboroot; P2 - plowed soil * Biochar + Wood Vinegar + Cropmax; P3 - plowed soil * Nutriplant 20:20:20 + Resid; P4 - plowed soil * Orgevit + Kerafol; P5 - plowed soil * unfertilized (Control); RT1 – rototilled soil * Albit + Turboroot; RT2 - rototilled soil * Biochar + Wood Vinegar + Cropmax; RT3 - rototilled soil * Nutriplant 20:20:20 + Resid; RT4 - rototilled soil * Orgevit + Kerafol; RT5 - rototilled soil * unfertilized (Control)

On the nutritional quality of sweet pepper, specifically lycopene, β-carotene, soluble solids and dry matter content, the analysis of soil management and fertilization practices revealed significant variations, highlighting the complex interactions between these factors (Table 5).

Lycopene content was highest in RT4 (6.71 mg/100 g ± 0.12), significantly surpassing other treatments, likely due to the synergistic effect of Orgevit and Kerafol. RT5 also exhibited elevated lycopene levels (6.26 mg/100g ± 0.02), suggesting the positive influence of rototilled soil with control fertilization. Conversely, plowed treatments, particularly P3 (4.23 mg/100 g ± 0.09) and P2 (4.80 mg/100 g ± 0.06), demonstrated lower lycopene levels, likely reflecting suboptimal conditions for carotenoid biosynthesis.

For β-carotene, RT4 again showed higher concentration (15.98 mg/100 g ± 0.25), but the highest one was observed in P1 (18.36 ± 0.18), indicating that nutrient optimization in these treatments enhances β-carotene production. Plowed soil variants, such as P2 (10.49 mg/ 100 g ± 0.13) and P4 (10.41±0.21), had significantly lower β-carotene levels, emphasizing the role of nutrient bioavailability in carotenoid biosynthesis (Khaliq et al., 2023).

Soluble solids content, indicative of fruit sweetness, was highest in RT5 (9.30 °Brix ± 0.26), suggesting that rototilling with the control treatment promotes sugar accumulation. P2 (6.90 °Brix ± 0.26) exhibited the lowest soluble solids content, possibly due to imbalances in nutrient uptake.

For dry matter content, both P1 (11.01% ± 0.20) and RT5 (11.44% ± 0.03) showed higher values, reflecting enhanced biomass accumulation due to improved photosynthetic activity. Conversly, P5 (7.97% ± 0.22), the untreated control in plowed soil, had the lowest dry matter content, emphasizing the necessity of fertilization in improving plant biomass (Condon, 2020).

Table 5. Nutritional and biochemical composition of `Darianabac` sweet pepper fruits

Variant	Lycopene (mg·100 g^{-1} F.W)	β-carotene (mg·100 g^{-1} F.W.)	Soluble solids (°Brix)	Dry matter (%)
P1	5.10±0.10de	18.36±0.18a	8.67±0.25ab	11.01±0.20a
P2	4.80±0.06e	10.49±0.13e	6.90±0.26b	8.41±0.04de
P3	4.23±0.09f	14.14±0.08d	7.30±0.26ab	9.79±0.15b
P4	6.43±0.09ab	10.41±0.21e	8.53±0.32ab	9.01±0.04cd
P5	5.85±0.28c	17.23±0.56b	8.07±1.77ab	7.97±0.22e
RT1	5.36±0.14d	10.54±0.23e	8.50±0.20ab	8.83±0.29cd
RT2	5.89±0.08c	14.46±0.05d	7.80±0.40ab	8.67±0.23cd
RT3	5.15±0.07de	11.11±0.43e	7.93±1.59ab	8.88±0.19cd
RT4	6.71±0.12a	15.98±0.25c	8.57±0.29ab	9.13±0.41c
RT5	6.26±0.02b	15.18±0.08cd	9.30±0.26a	11.44±0.03a

The presented values represent the arithmetic mean accompanied by the standard deviation. Lowercase letters indicate the outcomes of Tukey's post-hoc analysis at a significance threshold of $p < 0.05$, where "a" designates the highest recorded value. P1 plowed soil * Albit + Turboroot; P2 - plowed soil * Biochar + Wood Vinegar + Cropmax; P3 - plowed soil * Nutriplant 20:20:20 + Resid; P4 - plowed soil * Orgevit + Kerafol; P5 - plowed soil * unfertilized (Control); RT1 – rototilled soil * Albit + Turboroot; RT2 - rototilled soil * Biochar + Wood Vinegar + Cropmax; RT3 - rototilled soil * Nutriplant 20:20:20 + Resid; RT4 - rototilled soil * Orgevit + Kerafol; RT5 - rototilled soil * unfertilized (Control)

CONCLUSIONS

The results demonstrate that both soil preparation and fertilization treatments significantly affect the growth and productivity of sweet pepper. The highest yields, largest fruit sizes and most favorable fruit production were consistently observed in rototilled soil treatments with biochar, wood vinegar and Cropmax. These findings emphasize the importance of integrated soil management and nutrient application for optimizing crop productivity, particularly in greenhouse environments. While certain fertilization treatments in plowed soils yielded positive results, rototilled soil consistently provided the most advantageous conditions for growth and fruit production.

Both soil management practices combined with targeted fertilization, significantly enhance the nutritional quality and biomass of sweet pepper, underscoring the critical role of optimized nutrient availability in promoting carotenoid biosynthesis, sugar accumulation and overall plant vigor.

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