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THE INFLUENCE OF FERTILIZERS ON THE DEVELOPMENT OF THE ROOT SYSTEM AND PRODUCTION CAPACITY OF SWEET PEPPER (*CAPSICUM ANNUUM* L.)

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Abstract

The study investigates the impact of different fertilization strategies on the root development and yield capacity of Capsicum annuum *L. Four fertilization variants were tested: V1 - Graundfix®, V2 - Albit®, V3 - Rerum and V4 - Unfertilized (control) on three cultivars in polyethylene greenhouse soil. Parameters assessed included plant height, stem collar diameter, root length, root width and weight, and yield per plant. The application of biofertilizers (V1 and V2) demonstrated a positive impact on the root system activity of the greenhouse culture, when compared to the control and chemical fertilizer treatments. The productivity of the plants was found to be directly proportional to the root parameters.*

Key words: *root system, fertilizer, productivity, sweet pepper.*

INTRODUCTION

Sweet peppers are a popular vegetable consumed worldwide, with a wide range of cultivation regions contributing significantly to the global supply. Both for domestic consumption and for export, Romania produces a significant quantity of sweet peppers.

Crops are predominantly cultivated in open fields; however, there is an emerging trend towards protected crops, such as greenhouse crops, with the objective of extending the growing season and enhancing crop yield and quality.

Research endeavours are currently underway to enhance crop yields, despite the presence of various adverse environmental factors. A multifaceted approach, encompassing physical, chemical, and biological methods, is being employed to address the damage caused by biotic and abiotic stresses on plant life (Radhakrishnan et al., 2017).

The root system of sweet pepper plants is essential for their growth, health and productivity. Understanding the characteristics and functions of the root system can help improve growing practices. Pepper plants, including sweet peppers, have a relatively fibrous root system in the topsoil (0-30 cm), even if the root is initially tap-rooted (Figure 1a, b) (Teliban et al., 2020). The primary root develops from the seed and grows downwards, while secondary and tertiary roots branch out laterally and spread horizontally. (Figure 1)

a b

Figure 1. The root of *Capsicum*
(a - tap root; b - fibrous root)

The root system of pepper plants is usually not very deep compared to other plant species, and adventitious roots develop from the hypocotyl zone. These roots are designed to facilitate efficient uptake of nutrients and water from the soil to support plant growth and fruit production. Some roots can store carbohydrates and other nutrients for use in times of stress or when above-ground growth is limited. Roots interact with soil micro-organisms, including beneficial bacteria and fungi, which can increase nutrient availability and protect against pathogens.

In the contemporary era, agricultural practices are subject to various factors that can impede their efficacy, including but not limited to declining soil fertility, a deficiency of nutrients within the soil, or the presence of pests. In order to address these challenges, modern agriculture relies on the utilization of fertilizers, with the objective of enhancing yield production to meet the escalating demands of a growing population. This approach encompasses the application of both chemical and biological fertilizers, which play a pivotal role in augmenting agricultural productivity and enhancing plant tolerance to diseases and pests. While chemical fertilizers contribute to increased productivity, their prolonged use can result in the alteration of the physico-chemical and biological characteristics of the soil (Pahalvi et al., 2021).

Fertilizers have been shown to enhance plants' capacity to retain moisture and increase root depth. The phosphorus present in fertilizers has been demonstrated to promote accelerated root growth (ALnaass et al., 2021).

Chemical fertilizers have been demonstrated to augment crop yield by supplying essential nutrients; however, they can also lead to significant environmental concerns. Consequently, there has been a growing interest in biofertilizers due to their environmentally friendly and pollution-free characteristics. (Gou et al., 2020).

Biofertilizers are defined as materials containing natural biocompounds, which are constituted of microorganisms that, when applied to seeds, plant surfaces, or soil, promote plant growth and development by increasing the supply or availability of primary nutrients to the host plant (Calara et al., 2020). The utilization of these products has a positive impact on both the environment and the crop by increasing plant productivity (Rati et al., 2015; Raducanu et al., 2016). These biofertilizers may contain micro- or macro-organisms, plant residues, enzymes, or substances that enhance plant growth by fixing atmospheric nitrogen, solubilizing phosphorus, or producing growth-promoting substances. These products are an environmentally friendly alternative to chemical fertilizers and play a key role in sustainable agriculture (Nosheen et al., 2021).

The primary objective of the research endeavour is to observe and document the behaviour of pepper roots under conditions of protected spaces, and subject to the influence of both chemical and biological fertilisers.

MATERIALS AND METHODS

The experiment was conducted at Vegetable Research and Development Station Bacau during the 2024 season. Three cultivars of sweet peppers were utilized: Dariana Bac (C1), Dariochea (C2), and Matiusca (C3). These peppers were obtained from the research station.

In this study, the three sweet pepper cultivars C1, C2 and C3 were cultivated in polyethylene greenhouse soil under three different fertilizations: V1 - Groundfix, V2 - Albit®, V3 - Rerum, and V4 - Unfertilized (control). The objectives of this study were twofold: firstly, to examine the effects of fertilization on root morphological parameters, and secondly, to detect the relationships between root morphological parameters and the three cultivars, in agreement with pepper yield.

Seedlings of sweet pepper were transplanted in the field at age of 55 days in the second week of April in 2024. Sweet pepper seedlings were planted in furrows measuring 70 centimeters in width, situated between rows, with a separation of 25 centimeters on soil that had been mulched.

The fertilization process was executed in two stages, with the initial stage occurring one week after planting and the subsequent stage occurring one month after the first. The experimental design incorporated two organic root fertilizers, Graundfix® and Albit® (V1 and V2 variants, respectively), along with a chemical fertilizer, Rerum, administered through foliar application.

The Graundfix® product has been demonstrated to optimize the availability and mobility of phosphorus and potassium in the soil, thereby enhancing the efficiency of nitrogen fixation. It has been shown to have the capacity to substantially improve crop yield and reduce environmental impact by increasing the nutrient utilization rate of natural fertilizers by a factor of 1.2 to 1.5. Additionally, it facilitates the free flow of silica in plants, stimulates biological processes in the soil, and contributes to soil health, thus preventing soil degradation. The product contains cells of the bacteria *Bacillus subtilis*, *Bacillus megaterium* var. *phosphaticum*, *Enterobacter spp*., *Azotobacter chroococcum*, *Paenibacillus polymyxa*. These bacteria are involved in a number of physiological and molecular mechanisms that enable plants to cope with environmental stressors such as extreme temperatures, water shortage, or exposure to toxic substances.

Albit® is a biostimulator that contains poly-beta-hydroxybutyric acid (a natural biopolymer synthesized from beneficial bacteria such as *Bacillus megaterium* and *Pseudomonas aerofaciens*) and a set of substances including urea, potassium nitrate, magnesium sulfate, potassium phosphate, and conifer extract. The functionality of Albit® is multifaceted, encompassing the stimulation of seed germination, the promotion of robust root development, and the enhancement of nutrient uptake from the soil. It has been observed to stimulate the growth and development of plants, thereby increasing their resilience to extreme temperatures, diseases, and pests. Additionally, Albit® has been demonstrated to improve crop yields, and it is non-toxic and harmless to bees.

Rerum has been demonstrated to exhibit auxin-like characteristics in the context of physiological processes in plants. The product is systemic and is known to enter the absorptive complex of the plant in close temporal proximity to application. It contains the complete range of amino acids that are essential for plant nutrition and is particularly noteworthy in its capacity to enhance the quantity and quality of agricultural production. It has been observed to accelerate the assimilation of inorganic nitrogen, while concurrently enhancing plant resistance mechanisms to diseases and pests. It is an indispensable precursor in auxin synthesis.

Figure 2. Foliar fertilizer application

The plants were individually measured to determine plant root and stem length. The analysis of pepper root morphology was conducted by first severing the roots from the base of the stem, followed by meticulous measurement of their width and length (Figure 3).

Figure 3. Root width measurement

The root morphology parameters, including total plant height (TPH), stem collar diameter (SCD), root length (RL), root width (RW) and root weight (RWE). The mean productivity (PR) was computed for each of the three fertilizers, as well as for the control sample. The results are expressed in tons per hectare (t/ha).

The statistical interpretation was executed with the utilization of SPSS software, version 21. This software facilitated the implementation of analysis of variance (ANOVA) for 95% confidence and the Tukey test to ascertain the significance of observed differences.

RESULTS AND DISCUSSIONS

It has been demonstrated that plants possess the capacity to detect resources present within the soil, in addition to the presence of foreign roots. In response to these stimuli, plants adapt their root development. A study conducted by researchers at Princeton University observed the behaviour of the roots of pepper plants grown singly or in pairs. It was observed that the farther consumes to transport organic molecules. Furthermore, the plant develops a series of vessels capable of transporting water and nutrients to the stem. Consequently, in the presence of competitors, the plant reduces the extent of its root system, but develops an over density of roots close to its stem (Butor, 2021).

A well-developed root system can have the benefit of supporting accelerated plant growth in the early stages of crop growth. It can also facilitate the extraction of water from shallow soil layers, which is otherwise susceptible to loss through evaporation (Kulkarni & Phalke, 2009).

The importance of root system size has long been recognised as being critical in the management of drought conditions (You et al., 2025).

Results of morphological parameters in pepper root according to the fertilizer type used and the yield are shown in figure 4-8.

When monitoring the total plant height (Figure 4), no significant differences are observed between the variants, but a slight increase is observed in the case of Biofertilizer V2 (115.63 cm)

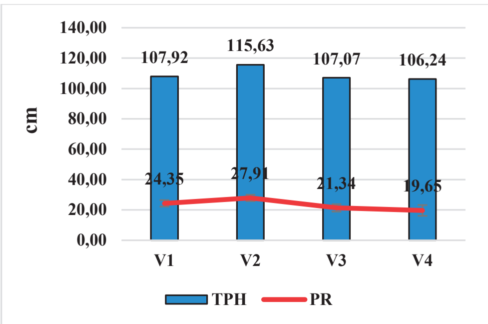

Figure 4. Comparison of Total Plant Height (TPH) and productivity (PR)

Subsequent to the implementation of the fertilizers, a balance was achieved in the diameter of the collar stem (Figure 5). It was observed that all three fertilization variants, in conjunction with the control, exhibited equivalent values.

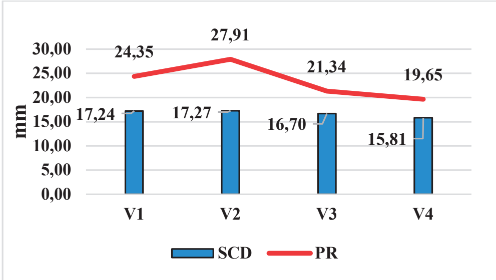

Figure 5. Comparison of Stem Collar Diameter (SCD) and productivity (PR)

Root length is a key indicator of the ability of a plant to take up water from deeper layers of the soil, and it is influenced by an increase in root penetration (Kulkarni & Phalke, 2009).

The fertilization variants V2 (21.27 cm) and V3 (21.17 cm) resulted in an increase in the measured root length, while V1 demonstrated a positive correlation with V4 (Figure 6).

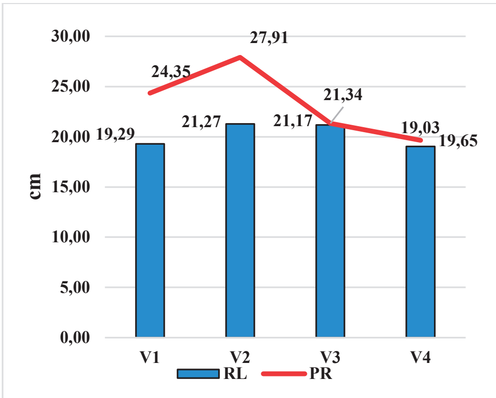

Figure 6. Comparison of Root Length (RL) and productivity (PR)

The impact of the fertilizer was most pronounced in terms of root width in the V2 sample (36.86 cm), followed by the V1 sample, the V3 sample, and finally the V4 sample (Figure 7).

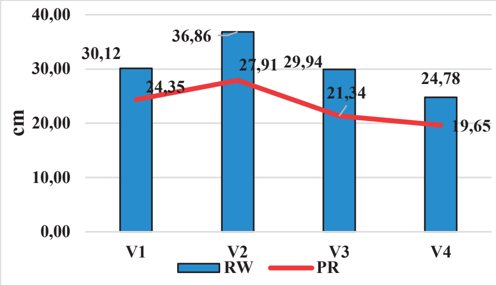

Figure 7. Comparison of Root Width (RW) and productivity (PR)

In the case of root weights, a slight increase was observed for V1 fertilizer, but not an increase in productivity for the same variant (Figure 8).

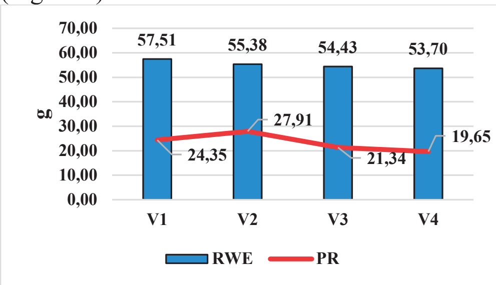

Figure 8. Comparison of Root Weight (RWE) and productivity (PR)

Thus, it is observed that all the three fertilizers used caused an increase in the analysed parameters compared to the control sample.

The observed productivity trajectory was consistent across all five parameters under analysis. The highest values were obtained for V2 fertilizer (27.91 t/ha), followed by V1, and then by V3 and V4.

As illustrated in Figure 9, the analysis encompasses all parameters evaluated for each cultivar. The graph reveals that each cultivar exhibits distinct patterns of root development. Cultivar C1 demonstrates higher values for the parameters of root length (22.04 cm) and root width (31.68 cm). Cultivar C2 exhibits average values for all five parameters, while cultivar C3 shows elevated values for total plant height (146.15 cm), stem collar diameter (18.53 mm) and root weight (66.36 g).

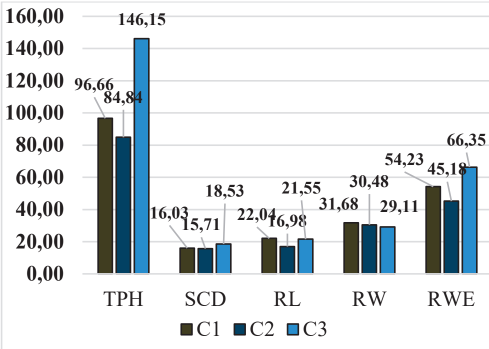

Figure 9. Correlations between cultivar types and analyzed parameters (TPH - total plant height; SCD - steam collar diameter; RL - root length; RW - root width; RWE - root weight)

Table 1. Results of root morphological characteristics and productivity according to cultivar and fertilizer type (2024)

	TPH (cm)	SCD (mm)	RL (cm)	RW (cm)	RWE (g)	PR (T/ha)
C1xV1	85.02±4.68 ab	25.59±3.25 ns	23.54±1.51 a	19.85±2.84 ns	63.05±1.05 ab	28.23±3.46 ns
C1xV2	94.66±0.55 ab	20.92±2.72 ns	25.13±0.36 a	29.46±6.82 ns	46.27±1.02 b	23.41±3.47 ns
C1xV3	82.17±4.62 ab	25.00±5.68 ns	21.40±0.89 ab	19.37±2.33 ns	43.87±2.70 b	24.82±1.77 ns
C1xV4	82.55±9.88 ab	35.27±7.46 ns	22.63±0.67 a	23.39±3.66 ns	84.28±8.50 a	29.03±3.31 ns
C2xV1	77.27±1.28 ab	21.44±3.06 ns	22.61±1.30 a	23.33±5.16 ns	60.24±8.32 ab	24.32±2.10 ns
C2xV2	87.97±7.87 ab	23.84±2.59 ns	21.91±1.91 ab	26.12±5.38 ns	53.53±6.04 ab	29.82±1.85 ns
C2xV3	82.35±0.94 ab	25.61±3.27 ns	24.82±1.87 a	25.87±5.08 ns	66.61±2.87 ab	19.83±2.91 ns
C2xV4	65.00±4.52 b	23.25±5.11 ns	13.45±1.65 b	13.31±0.70 ns	42.67±13.82 b	25.53±5.25 ns
C3xV1	119.56±15.32 a	27.05±3.72 ns	28.13±4.56 a	21.63±3.49 ns	67.92±1.10 ab	29.70±5.14 ns
C3xV2	107.98±17.62ab	24.87±2.72 ns	23.99±1.17 a	20.25±3.35 ns	68.47±7.99 ab	33.38±4.51 ns
C3xV3	104.54±17 ab	25.22±2.56 ns	22.08±0.78 a	19.92±3.68 ns	82.92±7.97 a	30.07±6.20 ns
C3xV4	104.86±15.28ab	30.74±6.14 ns	23.59±0.20 a	22.91±3.71 ns	70.72±5.97 ab	36.73±8.79 ns

*The values represent the mean parameters ± standard error; the lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a, b - represents the highest value; ns - not significant).
C1 - Dariana Bac cultivar; C2 - Dariochea cultivar; C3 - Matiusca cultivar;
V1 - Groundfix fertilizer; V2 - Albit fertilizer; V3 - Rerum fertilizer; V4 - Unfertilizer (control)

As illustrated in Table 1, the impact of cultivar and fertilizer interaction on the parameters under observation is evident. The range of total plant height varies from 119.56 cm for C3 x V1 to 65.00 cm for C2 x V4, while stem collar diameter demonstrates a maximum value of 35.27 mm in C2 x V4 and a minimum value of 20.92 mm in C1 x V2. The average value of root length ranges from 13.45 cm in C2 x V4 to 28.13 cm in C3 x V1. The diameter of the roots ranges from 13.31 cm in C2 x V4 to 29.46 cm in C1 x V2, and the weight of the roots ranges from 42.67 g in C2 x V4 to 84.28 g in C1 x V4. Yield ranges from 19.83 tons per hectare in C2 x V3 to 36.73 tons per hectare in C3 x V4.

CONCLUSIONS

The present study demonstrated that the relationship between pepper crop productivity and root morphology was predominantly influenced by the type of fertilizer utilized, particularly its composition. Higher productivity values were obtained with biofertilizers due to the presence of microorganisms.

Plants have developed adaptive strategies that enable them to activate different signalling and response pathways, thereby facilitating survival and thriving in adverse conditions. A comprehensive understanding of these mechanisms is imperative for the development of innovative technologies that can support sustainable agriculture and ensure global food security.

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