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Assessment of some morphological and physiological parameters in lettuce (*Lactuca sativa* L.) cultivated in hydroponic system

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Abstract: Lettuce is a valuable leaf vegetable for a well-balanced diet, since it is rich in nutrient elements, has low calories and provides dietary antioxidants. Compared to soil-based cultivation, the hydroponic system is an alternative associated with a shortening of growing cycles and a reduction of wasted water amount. The aim of this study was to analyze the growth of lettuce plants under hydroponic and soil cultivation systems, during three phenological growth stages (45; 47 and 49) according to BBCH scale. During the study different morphological and physiological parameters were evaluated: Plant height (PH); Stem diameter (SD); Fresh mass (FM); Dry mass (DM); Leaf area (LA); Chlorophyll content (CC); Transpiration rate (TR). The research was carried out using a complete randomized design with a 2 × 3 factorial arrangement of cultivation system and growth stages. Plants grown in hydroponic system presented higher values of most parameters, except for DM and TR. The cultivation system had the highest effect on PH, SD and LA. The highest variation between growth stages were observed for PH, LA and CC. Finally, we can conclude that lettuce plants cultivated under hydroponic system, presented better growth parameters associated with higher head weight and yield.
Keywords: lettuce, hydroponic, morphological, physiological parameters

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Introduction

Lettuce is one of the most important leafy vegetables worldwide, as it is considered a rich source of vitamins (A, C, E, K), polyphenols, and antioxidant compounds (Senizza et al., 2020), is typically low in calories and packed with fiber (Llorach et al., 2008). Lettuce production during late spring and summer often negatively affects yield and quality of heads. As such, adverse temperatures and long days largely limit warm season production of lettuce. Exposure of lettuce to 13 h of daylight and temperatures above 24 °C caused a premature inflorescence initiation, otherwise known as bolting (Sublett et al., 2018).

Hydroponics is an alternative to conventional soil-based cultivation: both growing environment and inputs of water and nutrients may be controlled; less work is required; growing cycles are shorter; and there is less wasted water (Paulus et al., 2012; de Souza et al., 2019). For short-term crops like lettuce, utilizing Nutrient Film Technique (NFT), which belongs to closed hydroponic systems category, is a frequent choice. However, this system requires repeated monitoring of the flow of the solution (Kaiser & Ernst, 2012). Hydroponics with recirculation (closed system) is the most technically, economically and environmentally efficient system by its

Table 1: Mean of plant height and stem diameter for lettuce under two cultivation systems during three phenophases

Plant height (mm)				
Cultivation System (CS)	Phenophase (P) BBCH45	BBCH47	BBCH49	Cultivation system mean
Soil	z 62.8±6.0 b	y 120.0±9.9 b	x 197.2±7.0 b	126.7±11.6 B
Hydroponic	z 90.6±4.4 a	y 173.3±10.7 a	x 263.2±12.7 a	175.7±14.9 A
Phenophase mean	76.7±4.9 Z	146.7±9.6 Y	230.2±10.7 X	151.2±3.1
CS − $LSD_{5\%}$ = 14.7 mm (A,B); P- $LSD_{5\%}$ = 17.9 mm; CS × P-$LSD_{5\%}$ = 25.4 mm				
Stem diameter (mm)				
Cultivation System (CS)	Phenophase (P) BBCH45	BBCH47	BBCH49	Cultivation system mean
Soil	y 10.6±0.4 b	xy 11.9±0.3 b	x 12.9±0.4 b	11.2±0.2 B
Hydroponic	y 14.7±0.7 a	y 15.8±0.8 a	x 18.2±1.5 a	16.2±0.7 A
Phenophase mean	12.7±0.6 Y	13.8±0.7 XY	15.6±0.9 X	13.3±0.1
CS − $LSD_{5\%}$ = 1.2 mm (A,B); P- $LSD_{5\%}$ = 1.5 mm (X,Y); CS × P-$LSD_{5\%}$ = 2.1 mm				

(a, b, for vertical comparisons; x, y, z, for horizontal comparisons). Data represents mean ± SE. Different letters indicate significant differences ($p < 0.05$)

considerable savings in water and fertilizers, and minimal discharge of residual fertilizer solution into the environment (Lazo & Gonzabay, 2020). In hydroponic system, soil preparation and weed control are not require), avoids the need for crop rotation, and reduces pesticide application (Palermo, Paradiso, Pascale, & Fogliano, 2011). Harvesting can be carried out in a complex or simple infrastructure in small spaces and with low costs of production variables, but with a high initial investment. One disadvantage is the easy proliferation of root diseases in a soilless system with recirculation of nutrient solution (Resh, 2013). However, hydroponic systems are particularly sensitive to water pollution due to the lack of any buffer capacity as it is given in soil. Via direct root contact, pollutants may be taken up as shown in numerous studies (Carvalho et al., 2014; Herklotz et al., 2010).

The intensity of light has a major influence on the yield and quality of lettuce. As such, the highest plant biomass was recorded high light intensity treatment, whereas under low light intensity non-marketable and vortex-like plants were produced (Voutsinos et al., 2021). Also, the mineral contents of plants are affected by the amount of received light. Light quality is an important factor in the effective regulation of the growth and quality of lettuce (Li et al., 2021). The combination of red and blue light serves as a highly efficient light source for promoting lettuce growth (Amoozgar et al., 2017; Chen et al., 2016).

Hydroponic production of lettuce uses land and water more efficiently than conventional farming and could become a strategy for sustainably feeding the world's growing population, if the high energy consumption can be overcome through improved efficiency and/or cost-effective of the system (Barbosa et al., 2015). The aim of this study was to an-

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Table 2: Mean of plant height and stem diameter for lettuce under two cultivation systems during three phenophases

Cultivation System (CS)	Fresh mass (g) Phenophase (P) BBCH45	BBCH47	BBCH49	Cultivation system mean
Soil	y 196.0±10.1 a	y 249.1±15.6 b	x 317.2±17.2 a	254.1±12.7 B
Hydroponic	y 227.4±12.3 a	x 311.9±20.8 a	x 361.9±23.5 a	300.4±18.2 A
Phenophase mean	211.6±8.6 Y	280.5±15.8 X	339.6±20.5 X	277.2±3.6
CS − $LSD_{5\%}$ = 34.8 g (A,B); P- $LSD_{5\%}$ = 42.6 g (X,Y,Z); CS × P-$LSD_{5\%}$ = 60.2 g				
Cultivation System (CS)	Dry mass (g) Phenophase (P) BBCH45	BBCH47	BBCH49	Cultivation system mean
Soil	y 9.27±0.48 a	xy 11.94±1.39a	x 13.92±1.75 a	11.71±0.82 A
Hydroponic	y 8.67±0.44 a	xy 10.57±0.68a	x 12.82±0.71 a	10.69±0.48 A
Phenophase mean	8.99±0.32 Z	11.20±0.77 Y	13.41±0.93 X	11.20±0.15
CS − $LSD_{5\%}$ = 1.75 g (A,B); P- $LSD_{5\%}$ = 2.14 g (X,Y,Z); CS × P-$LSD_{5\%}$ = 3.03 g				

(a, b, for vertical comparisons; x, y, z, for horizontal comparisons). Data represents mean ± SE. Different letters indicate significant differences ($p < 0.05$)

alyze the growth of lettuce plants (cv. Regina di Maggio) under hydroponic and soil cultivation systems, during three phenological growth stages (45; 47 and 49) according to BBCH scale.

Materials and Methods

The research was carried out using a complete randomized design with a 2 × 3 factorial arrangement of cultivation system (CS) and phenophases (P). Three weeks old seedlings of lettuce plants (cv. Regina di Maggio) were cultivated in pots with soil (1peat:1sand: 1compost) and in hydroponic system using Hoagland nutrient solution. In the greenhouse the temperature ranges between 15-25 °C associated with 60-70% humidity. The light in the greenhouse was based on natural solar radiation.

For each phenophase five plants from different CS were used for analysis and measurements. During the study different morphological and physiological parameters were evaluated: Plant height (PH); Stem diameter (SD); Fresh mass (FM); Dry mass (DM); Leaf area (LA); Chlorophyll content (CC); Transpiration rate (TR). The size of plants was estimated using a digital caliper, and the mass of heads was evaluated with a precision scale. Leaf area was determinate using leaf area meter AM350 and was expressed in cm^2. The chlorophyll content was estimated by means of chlorophyll meter Minolta in SPAD units.

The data for all analyses and determination were statistically processed using ANOVA, and the means were compared using the least significant difference test (Ciulca, 2006). The significance of differences was marked with letters, being considered as significant ($p < 0.05$), the differences between means with different letters.

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Table 3: Mean of plant height and stem diameter for lettuce under two cultivation systems during three phenophases

Cultivation System (CS)	Phenophase (P) BBCH45	BBCH47	BBCH49	Cultivation system mean
Leaf area (cm^2)				
Soil	z 38.47±2.48 a	y 46.03±4.04 b	x 93.78±5.32 b	59.43±5.32 B
Hydroponic	z 46.54±4.41 a	y 62.20±7.35 a	x 120.45±7.50 a	76.40±7.22 A
Phenophase mean	42.50±2.64 Z	54.11±4.52 Y	107.12±5.51 X	67.91±1.45
CS – $LSD_{5\%}$ = 9.02 cm^2 (A,B); P – $LSD_{5\%}$ = 11.02 cm^2 (X,Y,Z); CS × P – $LSD_{5\%}$ = 15.59 cm^2				
Chlorophyll content (SPAD)				
Soil	z 5.16±0.16 a	y 8.17±0.71 b	x 11.34±0.46 b	8.22±0.57 B
Hydroponic	z 7.09±0.36 a	y 10.78±1.94 a	x 13.47±0.38 a	10.44±0.82 A
Phenophase mean	6.12±0.30 Z	9.47±1.05 Y	12.41±0.39 X	9.33±0.16
CS – $LSD_{5\%}$ = 1.20 (A,B); P – $LSD_{5\%}$ = 1.47 (X,Y,Z); CS × P – $LSD_{5\%}$ = 2.08				
Transpiration rate (mg H_2O h^{-1} cm^{-2})				
Soil	z 1.92±0.09 a	y 2.04±0.07 a	x 2.16±0.08 a	2.04±0.05 A
Hydroponic	z 1.48±0.04 b	y 1.68±0.06 b	x 1.80±0.07 b	1.65±0.04 B
Phenophase mean	1.70±0.07 Z	1.86±0.06 Y	1.98±0.07 X	1.85±0.01
CS – $LSD_{5\%}$ = 0.06 (A,B); P – $LSD_{5\%}$ = 0.07 (X,Y,Z); CS × P – $LSD_{5\%}$ = 0.10				

(a, b, for vertical comparisons; x, y, z, for horizontal comparisons). Data represents mean ± SE. Different letters indicate significant differences ($p < 0.05$)

Results and discussion

The height of plants cultivated in hydroponic system showed significantly higher average values by 38.67%, with increases between 33.47 in BBCH49 and 44.42 in BBCH47. In both cropping systems, a significant increase in plant height of 56.92-91.26% was observed from one phenophase to another (Table 1).

The culture system showed a higher influence on the stem diameter compared to the phenophase or the interaction of the two factors. Thus, in the conditions of hydroponic culture, significantly higher values of this trait were registered by 4.15 mm, on the background of variations from 3.9 mm in BBCH47 to 5.3 mm in BBCH49. Regardless of the culture system, in the first two phenophases the diameter of the stem showed smaller and non-significant variations 0.9-1.3 mm. In the last phenophase the values of this trait were significantly higher by 2.3-3.5 mm compared to the first phenophase.

Under hydroponic system, the plants generally achieved a significantly higher fresh mass by 18.11%. The effect of the culture system on this character was higher in the phenophase BBCH47 where an increase of 25.30% was registered. In BBCH47 and BBCH49, the fresh mass was significantly higher by 32.08-53.51% than in the first phenophase (Table 2). The greater accumulation of biomass observed in plants cultivated on hydroponic system is directly associated

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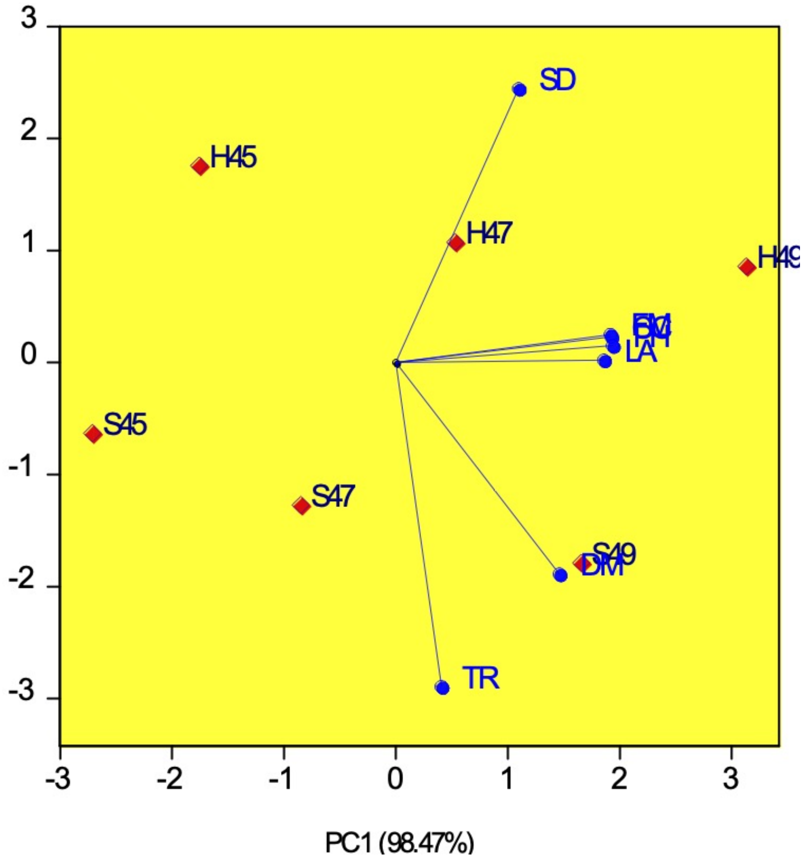

Figure 1: Biplot for morphological and physiological parameters of lettuce under soil and hydroponic systems. S45-Soil BBCH45; S47-Soil BBCH47; S49-Soil BBCH49; H45-Hydroponic BBCH45; H47- Hydroponic BBCH47; H49- Hydroponic BBCH49.

to the availability of nutrients in the nutrient solution, as well as the lower water stress (Rosa et al., 2014).

The culture system showed less influence on dry mass compared to phenophase or the interaction of the two factors. Throughout the study, there are small and insignificant variations of dry mass, against the background of higher values by 0.56-1.73 g in the case of plants grown in soil. Overall, the dry mass of plants recorded significant increases from one phenophase to another, with values ranging from 16.52% between the BBCH47-49 and 24.58% between BBCH45-47.

The leaf area of the plants cultivated in hydroponic system showed significantly higher average values by 28.55%, with increases between 20.98 in BBCH45 and 35.13% in BBCH47. In both culture systems, there is a significant increase in leaf area by 27.32–97.97% from one phenophase to another, more intense in BBCH49 (Table 3).

The phenophase showed a higher influence on the chlorophyll content compared to the culture system or the interaction of the two factors. Thus, under the conditions of hydroponic culture, significantly higher values of this trait were registered by 27%, on the background of variations from 18.78% in BBCH49 to 37.40% in BBCH45. In the last phenophase, the values of this Trait were significantly higher by 31.05% compared to BBCH47. The constant flow of nutrient media to plants in hydroponic systems likely resulted in conditions more favorable than soil cultivation, resulting in plants with significant difference in chlorophyll (Rosa et al., 2014; de Souza et al., 2019).

Under hydroponic conditions, the plants generally achieved a significantly lower transpiration rate by 19%. Regardless of the culture system, a significant intensification of transpiration by 6.45-9.41% from one phenophase to another was observed. In environments with less water availability, there is a decrease in the size of the stomata, so that there is a lower water loss of the plant by transpiration, with the simultaneous increase of its density, contributing to the balance of gas exchange (Batista et al., 2010).
From Figure 1, it can be noticed that plants grown in hydroponic system presented higher values of most parameters, except for dry mass and transpiration rate. Also, based of the position of vectors in the biplot, a strong correlation between leaf area, fresh mass and chlorophyll content was observed.

Conclusion

The cultivation system had the highest effect on plant height, stem diameter and leaf area. The highest variation between phenophases was observed for plant height, leaf area and chlorophyll content. Finally, we can conclude that lettuce plants cultivated under hydroponic system, presented better growth parameters associated with higher head weight and yield. Further studies are needed to analyze the cost-effective and/or efficiency of the two cultivation system of lettuce.

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