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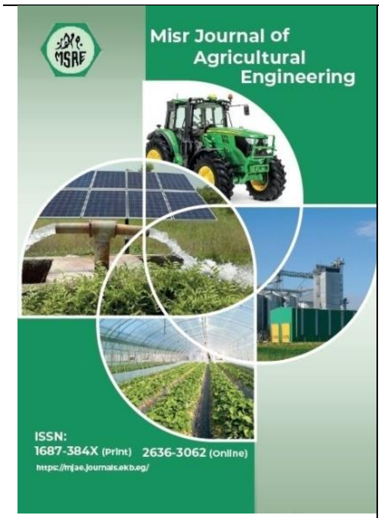
SOME ENGINEERING FACTORS INVOLVED IN IRRIGATION OF PEPPERMINT UNDER HYDROPONIC FARMING SYSTEM

A. Derbala[1], S. Abd Rabo[2], and M. M. Amer[3&*]

[1] Prof. of Ag. Eng., Ag. Eng. Dept., Fac. of Ag., Tanta U., Egypt.
[2] Postgraduate stud., Ag. Eng. Dept., Fac. of Ag., Tanta U., Egypt.
[3] Assoc. Prof. of Ag. Eng., Ag. Eng. Dept., Fac. of Ag., Tanta U., Egypt.

[*] E-mail: mai.amer@agr.tanta.edu.eg - mayieamer@yahoo.com



Keywords:
Hydroponic System; Operating Pressure; Nutrient Solution Temperature; Peppermint, Oxygen; Herb yield, Water Productivity

ABSTRACT

This research was done to gauge and control the hydroponic system's operational characteristics. Four different operating pressure levels of 0.50, 0.75, 1.00, and 1.25 bar and four different nutrient solution temperatures of 16, 22, 28 and 34 ºC were tested, as well as the impacts on oxygen level, herb productivity, water productivity, and power consumption of peppermint seedlings that were. The findings demonstrated that the ideal production circumstances were peppermint age of 45 days, nutrient solution temperature of 28 °C, and operating pressure of 100 kPa. The findings also indicated that there were 102.06 leaves, a plant height of 21.73 cm, a stem diameter of 2.25 mm, and a total leaf weight of 5.7 g/plant. The maximum dissolved oxygen concentration was 6.92 mg/L. The greatest root length recorded for peppermint was 48 cm, operating at 100 kPa and a nutrient solution temperature of 22 °C (1bar). At a root zone temperature of 28°C, peppermint water productivity reached its greatest value of 0.099 kg/m^3 and the maximum amount of essential oil was 2.73%.

INTRODUCTION

The world population is expected to grow to 9.8 billion people by the year 2050, which poses several questions about the security of the world's food supply. At the same time, urbanization, industrialization, and climate change are predicted to cause agricultural land to drop alarmingly and fertile soils to degrade. Additionally, a number of biotic and abiotic stressors interfere with crop yield, which has a significant negative economic impact on traditional agriculture. Therefore, it is essential to develop unique technologies in conjunction with specialized production processes in order to overcome the existing situation and to safeguard the future. This enables more effective management of nutrient availability and plant growth.

Hydroponics allows for the modification of the root environment to enhance one or more aspects of plant production. One of the most significant determining elements of crop output and quality in hydroponic farming systems is the temperature of the nutrient solution **(Al-Rawahy et al., 2024)**. The amount of oxygen absorbed by plants and the oxygen dissolved are directly correlated with the temperature of the nutrient solution. Additionally, it has been noted that the temperature of the nutrient solution affects the crop's differential uptake of water and nutrients **(Suhl et al., 2019)**.

The impact of nutrient solution temperatures on vegetable crops produced in hydroponic systems' oxygen levels, nutrient uptake, growth, and yield has been the subject of numerous studies **(Raviv et al., 2019)**. In Egypt, 68499 feddan of medicinal, aromatic, and cutting flower plants are grown, yielding 56390 Mg annually. On 2492 feddans, peppermint is produced, producing 47659 Mg annually **(El-Marsafawy, *et al* 2021)**.

according to **Jayachandran et al. (2022)** Peppermint oil has good antibacterial capabilities, , and hence protects against diseases and germs that harm food. One of the main issues restricting the development characteristics of hydroponic crops is high nutrient solution temperature stress in the root zone, which is caused by variations in the dissolved oxygen levels in nutrient solution during high-temperature seasons. This suggests that the temperature stress that hydroponically grown crops encounter may be mitigated by simpler and more practical root-zone temperature regulation **(Muthir et al., 2019).**

Hydroponics has been used to cultivate a variety of crops, including lettuce, cucumber, tomatoes, herbs, and different types of flowers **(Majid et al., 2021)**. It offers benefits such as rapid growth, high yield, ease of handling, efficient water use, and decreased fertilizer consumption as compared to a conventional cultivating system **(Magwaza et al., 2020).**

A drip irrigation system's primary advantages are its higher water conservation compared to other systems and its ability to withstand equipment or power failures. This method can be quite successful because of the solution's timely delivery. The water pump transports an inadequate amount of nutritional solutions from the reservoir to the roots of individual plants. It produces a very high-quality crop and is commonly used to grow tomatoes and peppers **(Jayachandran et al., 2022).** The study's main objective was to assess and optimize the hydroponic system's operating parameters by looking at how changing the root zone temperature affected the oxygen level and how operating pressure affected peppermint (Mentha piperita) development.

2. MATERIALS AND METHODS

From May to August 2021, the study took place in Damietta province, Egypt (31º11'10" N, 31º 35'59" E), during a four-month period. Peppermint (Mentha piperita) seedlings that were two weeks old were moved into plastic containers that were filled with a 1:1:1 blend of vermiculite, perlite, and peat moss medium. Table 1 provides the meteorological data for Damietta Station. August saw the highest recorded air temperature of 33.5°C, while May saw the lowest recorded temperature of 15.6°C. According to the National Centers for Environmental Information (2021), the months of May and July and August had the lowest and greatest relative humidity measurements, respectively. In order to keep the peppermint's EC between 2.0 and 2.4 dS/m and pH between 5.5 and 6.0, nutrient solution was supplied to the irrigation water in the main tank.

2.1 Installation of the system and experimental techniques

A method of soilless cultivation is used in the investigation (Drip hydroponic system). Fig. 1 contains a schematic representation of the main parts of the prototype. The drip hydroponic system that was used is depicted in the accompanying diagram.

Table 1: The climatic data collected from Damietta station

Month	Min Temp., (°C)	Max Temp., (°C)	Humidity (%)	Wind (km/day)	Sun, (hours)	Rad., (MJ/m²/day)	ETo (mm/day)
January	7.0	19.5	67	112	6.2	11.4	1.82
February	7.5	20.5	59	121	6.9	14.2	2.43
March	9.3	23.2	61	147	7.8	18.1	3.32
April	12.0	27.1	50	130	8.7	21.6	4.39
May	15.6	33.2	44	130	9.6	24.1	5.64
June	18.6	33.6	54	130	10.8	26.1	5.99
July	20.5	32.6	61	112	10.5	25.5	5.61
August	20.5	33.5	63	112	10.2	24.2	5.38
September	19.0	32.5	60	95	9.4	21.0	4.54
October	17.1	28.7	59	86	8.5	16.9	3.34
November	14.0	25.8	62	95	7.3	13.0	2.47
December	9.2	21.2	63	95	5.9	10.5	1.83
Average	14.2	27.6	59	114	8.5	18.9	3.90

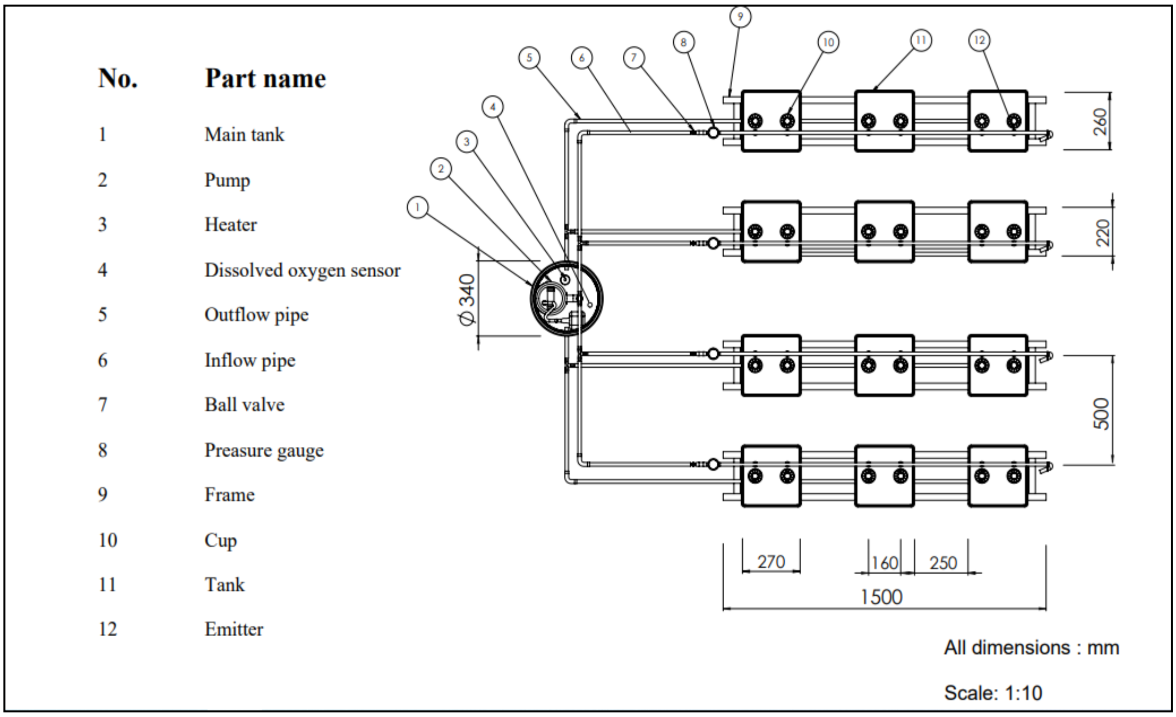


Fig. 1: A Schematic diagram of drip hydroponic farming system

The system was made up of four frames, each of which could hold three tanks and was built to be five times thicker than a human. That is, the frame measured 1.50 m in length, 0.22 m in width, and 0.25 m in height. 50 L of Hoagland nutritional solution is stored in the main tank, which is made of green polyethylene. The additional nutrient solution was sent to the other tanks, each of which has a 15 L capacity and measures 0.34 m in height, 0.24 m in width, and 0.27 m in manhole width. They are connected to emitters by a 16 * 10-3 m inflow pipe. The inflow pipe was equipped with six emitters per line, each of which had a 4 L/h discharge rate at an operating pressure of one bar.

A ball valve controlled a pressure gauge, which in turn controlled the emitter's pressure. Peppermint was grown in hydroponic plastic cups with pots spaced 15 cm apart. The fertilizer solution was kept in a tank as part of the irrigation system. A 0.75 kW submersible pump [Model: QDS - CW/DW, Q = 160 L/min., H = 3 bar, V = 220, n = 2850 rpm] was used to pump the nutritional solution. It was connected to the remainder of the system by 16 * 10-3 m tubing. To irrigate the plant, the nutritious solution was injected into the emitter.

We used a timer [model: YTS-F, 220v/240v/50Hz, 0-3500 W] to adjust the watering intervals. During the herb development period, it was stimulated four times a day for 15 minutes every six hours. The fertilizer solution was moved from additional tanks to the main tank using a 1.6 cm outflow pipe. A submersible stainless-steel heater [Model: RS, P = 500 W, V = 220-240 V, 50 Hz] was used to regulate the temperature. In order to track how temperature affects the amount of dissolved oxygen in the nutritional solution, a heater was placed in the main tank. Polyethylene sheets, which transmit 84% of light, and sun mesh sunscreen for plants (shade mesh), which transmit 70% of light, were used for environmental testing.

2.2 Experimental conditions

The investigations were conducted to ascertain the effects of the following factors on peppermint:

- The treatments included four different nutrient solution temperatures NST1 (16^{o}C) NST2 (22 ^{o}C), NST3 (28 ^{o}C) and NST4 (34 ^{o}C).
- Four various operating pressures (0.50, 0.75, 1.00 and 1.25 bar).

2.3 Measurements

2.3.1 Estimation of dissolved oxygen level (DO) in the nutrient solution

Voltage and dissolved oxygen content are inversely correlated at constant temperature. Valid data can only be acquired after calibrating the voltage corresponding to saturated dissolved oxygen by introducing a 0.5 mol/L NaOH solution to the membrane cap due to minor variations in probe manufacturing. An Arduino was used to capture the data on the change in dissolved oxygen on an hourly basis throughout the day.

2.3.2 Estimation of production

To determine the quantity of essential oil and assess the growth of the crop, a sample of six plants was taken from each treatment.

2.4 Growing parameters

2.4.1 Plant height and root length

Using an electronic digital caliper with a precision of 0.02 mm, the plant's height and root length after harvesting were measured every six days during the experiment.

2.4.2 Number of leaves per plant

Throughout the experiment, the number of leaves on each plant was counted every six days.

2.4.3 Stem diameter (mm)

Following harvesting, the diameter of the stem was measured using a digital electronic caliper that had an accuracy of 0.02 mm.

2.4.4 Total fresh weight of leaves (g/plant)

Fresh leaf weight was measured with an accuracy of 0.01 g after harvest.

2.5 Estimation of essential oil quantity

By the steam distillation method, the essential oils are extracted from leaves. The specimens were studied at the central laboratory, Faculty of Agriculture, Ain Shams University.

2.6 Estimation of water productivity

The following formula, provided by **Bhushan in 2007**, was used to calculate the water productivity (kg/m³).

$$\text{Water productivity (kg/m}^3\text{)} = \frac{Yeild\left(\frac{kg}{ha}\right)}{Crop\ water\ use\ \left(\frac{m^3}{ha}\right)}$$

2.7 Statistical analysis

The programmed R was used for the statistical analysis. The Pearson correlation coefficients (r) which were used for evaluation were calculated and were significant at $p > 0.01$ level. *** ($p=0.01$) marks the significant levels.

3. RESULTS AND DISCUSSION

Implementing a drip hydroponic system will allow the alteration of root zone temperature along with the investigation of how operating pressure affects oxygen levels, herb yield, and water productivity.

3.1 Effect of NST on the nutrient solution content of DO

From the data illustrated in Fig. 2, the NST affected the DO concentration during the day at different dates of measurements.DO concentration had a positive relationship with NST to reach the maximum concentration at 28°C NST then the relation converted to negative with increasing NST over 28°C.

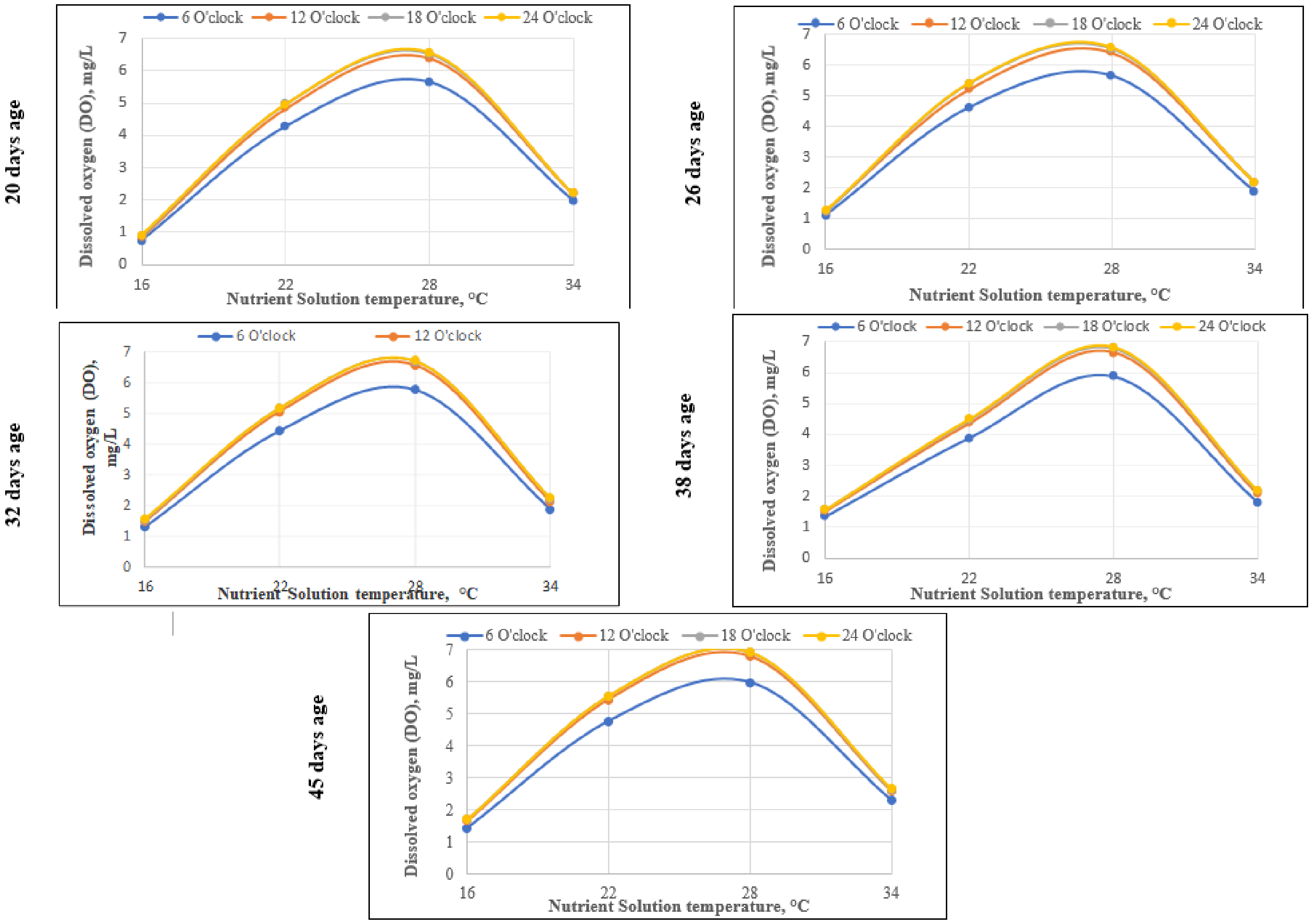


Fig. 2: Effect of root zone temperatures on dissolved oxygen for peppermint at 20,26,32,38, and 45 days after transplanting.

Table 2 shows the relationships and the R^2 values. The relationships were a polynomial equation between the NST and DO concentration with a high correlation coefficient. This high correlation of the DO with the NST affected the growing parameters of the peppermint.

Table 2: The regression analysis and relationships between NST and DO

	Days after cultivation, day	Day time	Dissolved Oxygen Concentration (DO), mg/L	R^2
Nutrient Solution Temperature (NST), °C	20 days	6	$y = -0.05x^2 + 2.5851x - 27.976$	0.9713
		12	$y = -0.0568x^2 + 2.9345x - 31.735$	0.9698
		18	$y = -0.0584x^2 + 3.0118x - 32.531$	0.9705
		24	$y = -0.0582x^2 + 3.0005x - 32.363$	0.9682
	26 days	6	$y = -0.0504x^2 + 2.5787x - 27.353$	0.9801
		12	$y = -0.0571x^2 + 2.921x - 31.036$	0.9797
		18	$y = -0.0593x^2 + 3.0354x - 32.296$	0.9843
		24	$y = -0.0592x^2 + 3.0281x - 32.16$	0.9828
	32 days	6	$y = -0.0492x^2 + 2.5116x - 26.485$	0.9571
		12	$y = -0.056x^2 + 2.8587x - 30.143$	0.9575
		18	$y = -0.0566x^2 + 2.8932x - 30.476$	0.9585
		24	$y = -0.0565x^2 + 2.8845x - 30.336$	0.9568
	38 days	6	$y = -0.0457x^2 + 2.3418x - 24.698$	0.8838
		12	$y = -0.0513x^2 + 2.6315x - 27.763$	0.8791
		18	$y = -0.0521x^2 + 2.6717x - 28.156$	0.8814
		24	$y = -0.0524x^2 + 2.6919x - 28.407$	0.8827
	45 days	6	$y = -0.0485x^2 + 2.4911x - 26.124$	0.9714
		12	$y = -0.0553x^2 + 2.8339x - 29.684$	0.9724
		18	$y = -0.0565x^2 + 2.8918x - 30.267$	0.9721
		24	$y = -0.0563x^2 + 2.8865x - 30.22$	0.9724

3.2 Effect of DO concentration on growing parameters

From Fig. 3 it can be observed that the DO concentration in the nutrient solution had a high significant effect on the tested growth parameters (steam diameter, root length and total fresh weight of leaves) with R^2 values of 0.8009, 0.4038, and 0.5378, respectively.

3.3 Effect of nutrient solution temperature on growing parameters

Fig. 4 shows the correlation matrix between the NST and the growing parameters: steam diameter (SD), root length (RL), and the total leaves fresh weight (TFW). The results revealed a high significant correlation between the NST and SD and RL with a correlation coefficient of 0.667*** and 0.852*** for SD and RL respectively.

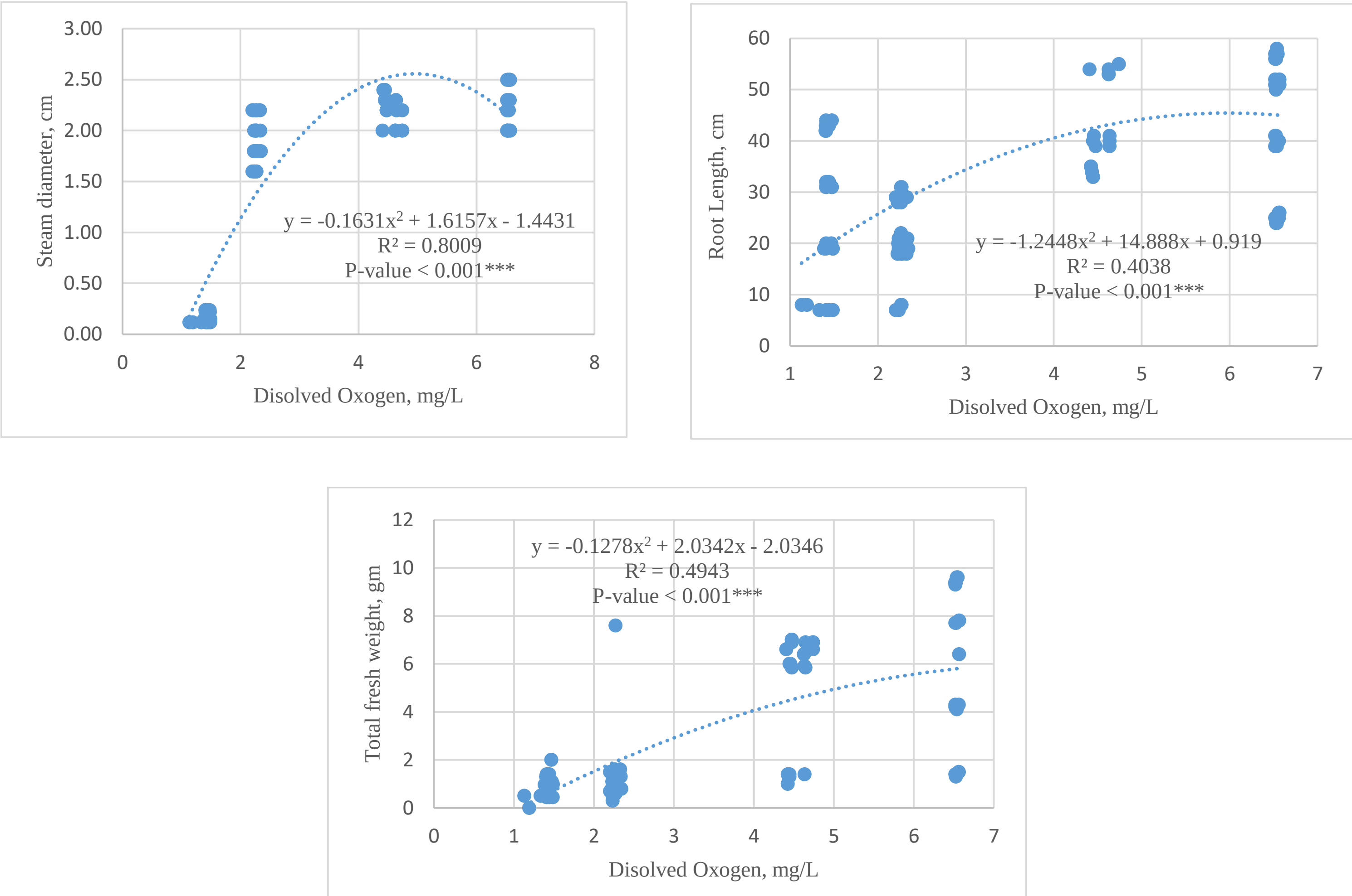


Fig.3: Steam diameter (a), root length (b), total fresh weight (c) of peppermint, as affected by the dissolved oxygen concentration

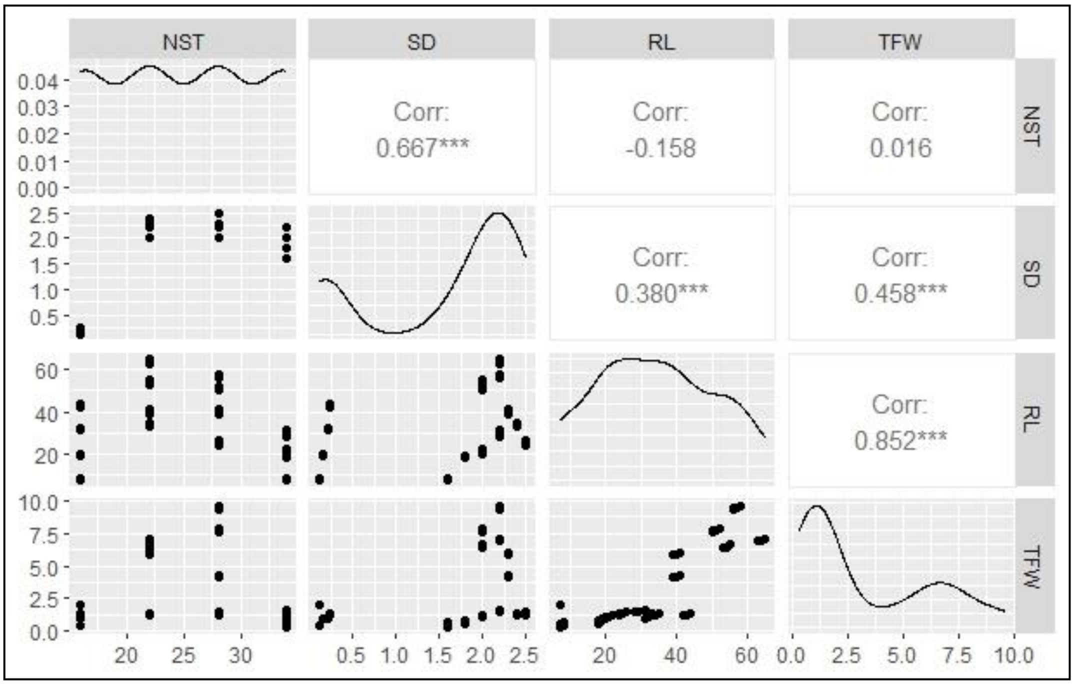


Fig. 4: The matrix of correlation coefficient between the NST and growing parameters

3.4 Effect of operating pressure on the peppermint growth parameters

Fig. 5 illustrates the correlation matrix between the Operating pressure (P) and the plant growth parameters: steam diameter (SD), root length (RL), number of leaves at the end of the experiment (NL5), plant height at the last period of measurements (Ph5) and the total leaves fresh weight (TFW). The results showed a significant correlation between the P and RL, TWF, NL5, and Ph5 with a correlation value of 0.361***, 0.374***, 0.454***, and 0.582***for RL, TWF, NL5, and Ph5, respectively. The results also demonstrated a high round positive correlation between different growth parameters i.e, TWF with RL, the relation had a correlation value of 0.852 and 0.886 for RL with NL5 and RL with Ph5 with high significant level and P-value < 0.001***.

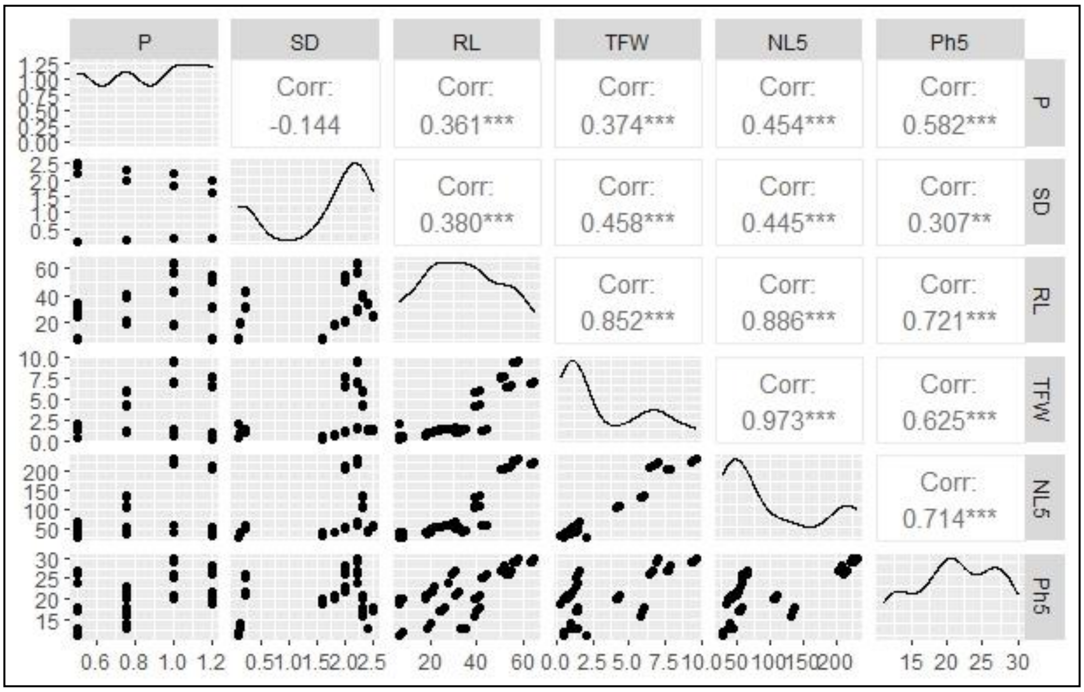


Fig.5: The matrix of correlation coefficient between the Operating pressure and growing parameters

3.5 Estimation of essential oil quantity of peppermint

The samples were examined after each stage of growth in order to extract the peppermint leaves' essential oils. Figures 6 a and 6 b explain the effect of NST and the DO concentration on the essential oil percentage.

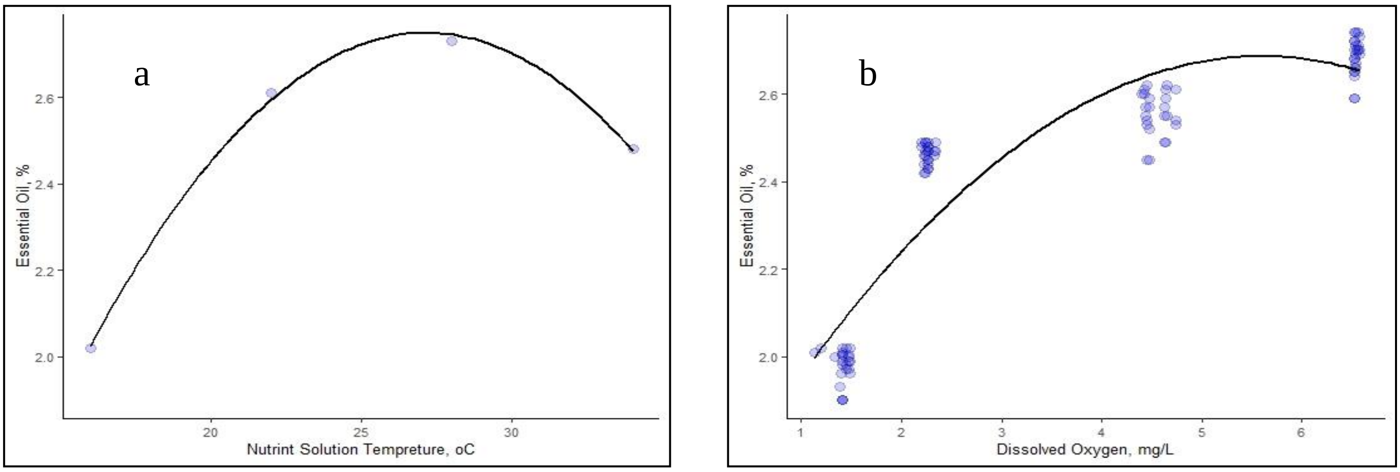


Fig. 6: (a) Nutrient solution temperatures and (b) Dissolved Oxygen effect on the essential oil percentage

The essential oil quantity reached a maximum quantity of 2.73% when the nutrient solution temperature was 28 ºC and a minimum of 16 ºC when the essential oil quantity was measured at 2.02%. The R^2 value was 0.998 for the relationship between NST and the essential Oil percentage with a high significant level and P-value < 0.001**, but R^2 value for the relationship between DO and essential oil was 0.8205 with a significant level at P- value < 0.05*.

4. CONCLUSION

As for peppermint growing details, the performance metrics of the drip hydroponic system mintits highly proficient. For the drip hydroponic system, operating pressure and temperature of the nutrient solution should be set at 100 kPa and 28 °C, respectively. These parameters yield a peak concentration of dissolved oxygen at 6.92 mg/L which translates to 102.06 leaves, 21.73 cm in height, 2.25 mm stem diameter, and 5.7 g of total leaves per plant. In the root zone at 22 °C and 100 kPa (one bar), the maximum recorded root length for peppermint is 48 cm. The temperature of the nutrient solution also governs the amount of essential oil, which reaches maximum value of 2.73% at 28 °C. Furthermore, the water productivity of peppermint is optimal at 28 °C and peaks at 0.099 kg/m^3.

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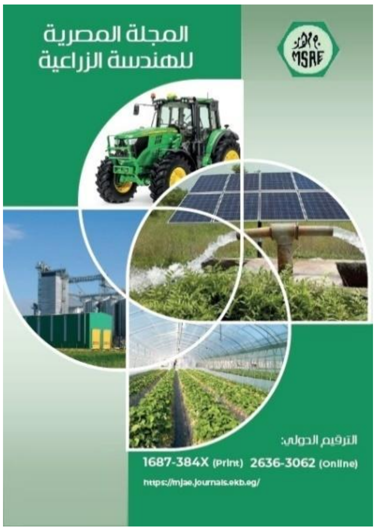
بعض العوامل الهندسية المؤثرة في ري النعناع في ظل نظام الزراعة المائية

أسعد عبد القادر دربالة[١]، شيماء عبدربه[٢] و مي محمد عامر[٣]

[١] أستاذ الهندسة الزراعية – قسم الهندسة الزراعية – كلية الزراعة – جامعة طنطا – مصر.
[٢] طالبة دكتوراه بقسم الهندسة الزراعية – كلية الزراعة – جامعة طنطا – مصر.
[٣] أستاذ مساعد الهندسة الزراعية – قسم الهندسة الزراعية – كلية الزراعة – جامعة طنطا – مصر.



الكلمات المفتاحية:
الزراعة بدون تربة؛ انتاج النعناع بدون تربة؛ ضغوط التشغيل؛ درجة حرارة المحلول المغذي؛ مستوى الاكسجين في المحلول المغذي؛ انتاجية للمياه

الملخص العربي

لدراسة تأثير درجة حرارة منطقة الجذر على مستوى الأكسجين وكذلك تأثير ضغط التشغيل على نمو النعناع، أجريت هذه الدراسة لقياس وإدارة المعاملات التشغيلية لنظام الزراعة المائية. تم إجراء سلسلة من التجارب لفحص معايير مختلفة، بما في ذلك دراسة تأثير أربعة مستويات مختلفة من ضغوط التشغيل (٠,٥٠ و٠,٧٥ و١,٠٠ و١,٢٥ بار)، وأربعة مستويات مختلفة من درجات حرارة المحلول المغذي في منطقة الجذر (١٦، ٢٢، ٢٨ و٣٤) درجة مئوية، لشتلات النعناع والتي كان عمرها أسبوعين على كل من مستوى الأكسجين، إنتاج النعناع وإنتاجية المياه. أشارت النتائج الى الحصول على اعلى إنتاجية عند عمر النعناع ٤٥ يوماً، ودرجة حرارة منطقة الجذر ٢٨ درجة مئوية، وضغط التشغيل واحد بار.

حيث كان تركيز الأكسجين الذائب في المحلول المغذي ٦,٩٢ مجم/لتر، وعدد أوراق النبات حوالي ١٠٢ ورقة، وارتفاع النبات ٢١,٧٣ سم، وقطر الساق ٢,٢٥ مم، والوزن الإجمالي ٥,٧ جم/ لأوراق النبات الواحد.

عندما كانت درجة حرارة منطقة الجذر ٢٨ درجة مئوية، وصلت كمية الزيت العطري إلى أقصى قيمة لها وهي ٢,٧٣٪. بلغت إنتاجية النعناع ذروتها حيث كانت ٠,٠٩٩ كجم/م^{٣}.