

ORIGINAL RESEARCH ARTICLE

Determining optimal cultivation parameters for a portable hydroponic system using the nutrient film technique

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Abstract: Changes in climatic conditions in Ukraine and around the world pose a certain threat to food security and force us to seek new technological opportunities for growing agricultural products. This study aims to identify the optimal cultivation parameters for growing vegetable and berry plants in a portable, compact, and easy-to-maintain hydroponic nutrient film technique (NFT) system. The goal is to achieve high product quality and maximize plant yields by utilizing phytomatrix equipped with red and blue light-emitting diode (LED) elements in a 4:1 ratio, combined with a nutrient solution based on biological products. An experimental portable hydroponic NFT system was developed, incorporating these phytomatrices for additional lighting. This specific red-to-blue light ratio enhances photosynthesis efficiency, promotes yield increases, and ensures the quality development of plant structural parts. In addition, the use of a roller system allows for easy movement of the plants as needed. The study examined the effects of several factors on the growth performance of basil plants (Rutan variety), including seed treatment with the effective microorganisms (EM)-5 concentrate, air and nutrient solution temperature, and nutrient solution concentration. It was determined that the optimal conditions for basil growth include an air and nutrient solution temperature range of 24 – 26°C. Furthermore, increasing the nutrient solution concentration to an optimum level of 2.4 – 2.5 mS/cm resulted in significant improvements across all measured growth parameters of Rutan basil plants. Therefore, growing vegetable crops in a hydroponic installation with phytomatrices with red and blue LED emitting elements in a ratio of 4:1 and using a nutrient solution based on EM preparations will make it possible to increase their productivity.

Keywords: Basil plants; Effective microorganism preparations; Hydroponic plant; Lighting; Nutrient solution; Phytomatrix

1. Introduction

Global and Ukrainian food security depends on multiple factors; primarily the population's ability to meet daily energy needs and maintain a nutritionally balanced diet.

The ongoing war in Ukraine has further intensified the food crisis, worsening the challenges related to ensuring stable and sufficient food supplies.¹

In the context of increasingly risky farming conditions in northern and central Ukraine, the

cultivation of moisture-demanding vegetable crops has become particularly challenging.^{2,3} Similar problems are also inherent in southern Europe, where climate change negatively impacts agricultural productivity. In response, vertical farming offers a promising solution to overcome the problem of land shortage.^{4,6} In risky farming zones, vegetable crops are primarily cultivated using various irrigation methods.^{7,8} Techniques such as drip irrigation, injection irrigation, and hydroponics elements are the main components of the technological process of growing these crops.

Hydroponics represents a breakthrough in agricultural production, enabling plants to grow in nutrient-rich water solutions instead of soil. This method offers several advantages, including higher yields, improved water efficiency, and adaptability to poor soil conditions. Various hydroponic systems – such as the nutrient film technique (NFT), deep water culture (DWC), aeroponics, and vertical farming – facilitate plant growth by supplying nutrients and oxygen directly to the roots.^{6,9} In addition, hydroponic systems offer advantages over traditional farming, particularly due to their suitability for urban environments.^{10,11} When integrated with smart technologies, hydroponic farming supports sustainable agricultural development by combining low maintenance costs with high yields. This results in significant economic benefits, making it an attractive option for suburban farms and urban settings.^{12,13} Moreover, installing photovoltaic panels on greenhouse rooftops can reduce the intensity of solar radiation reaching the plants, creating a shading effect that is beneficial for heat-sensitive crops such as tomatoes, peppers, and onions. This approach not only minimizes heat stress but also improves the overall energy efficiency of the system.¹⁴ Furthermore, in greenhouse cultivation, light-emitting diode (LED) lighting can be used to support efficient photosynthesis. Optimized LED light spectra can enhance the accumulation of antioxidants, phenolic compounds, and total sugars in plants such as lettuce, cabbage, cucumber, and spinach.¹⁵

There are various types of hydroponic systems, each characterized by specific features depending on crop type, space availability, equipment complexity, and overall economic cost.^{15,16} The main types of hydroponic systems include (Table 1):

- (i) Candlewick (wick)
- (ii) DWC
- (iii) Periodic flooding
- (iv) NFT
- (v) Aeroponics.

The wick system is one of the most affordable hydroponic methods, requiring no specialized equipment. In this system, the wick or cord passes through the bottom of the pot and is immersed in a nutrient solution, which gradually delivers nutrients to the plant roots. In the DWC system, plants are supported on floating materials, such as foam or specialized nets, with their roots completely immersed in the nutrient solution. Oxygen is supplied to the roots using an air pump. The periodic flooding method involves the use of a tidal system where the nutrient solution is delivered at set intervals controlled by a timer. When the supply stops, the solution drains back into the tank through special holes by gravity. This cycle is repeated several times a day. In the NFT system, plants are positioned in a tank with an irrigation channel through which a thin layer of nutrient solution flows. This solution washes the roots as it moves down the channel and then returns to the tank. The nutrient solution can be supplied either continuously or in cycles, with cyclical supply offering improved root aeration.¹⁷ In the aeroponics system, plants grow in an open, airy environment where their roots are continuously enveloped in a mist of nutrient solution. This system provides high oxygen availability to the roots, enhancing nutrient absorption and accelerating plant growth.¹⁸

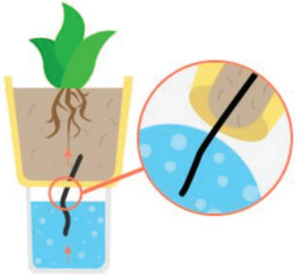

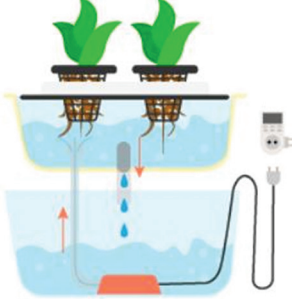
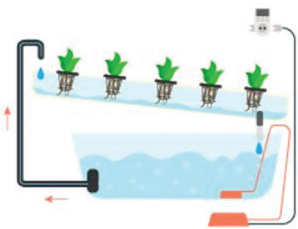
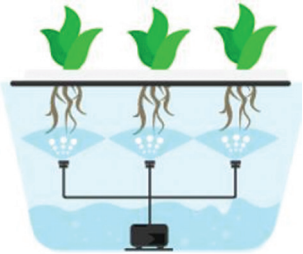
The advantages and disadvantages of each hydroponic system are presented in Table 1.

As shown in Table 1, the choice of hydroponic system depends on the plant type. Therefore, selecting an appropriate system requires a clear understanding of the equipment needed for the soilless cultivation of specific crops.

Regardless, a hydroponic NFT system is considered the most suitable option for growing plants in limited spaces. One of its major advantages is the efficient use of water, as the nutrient solution is continuously recirculated. Furthermore, the constant flow helps prevent the accumulation of salts on plant roots, supporting healthier growth. In addition, the NFT system is a vertical hydroponic technique that maximizes space utilization and conserves water. It offers a promising solution for sustainable agricultural development, particularly in regions facing climate challenges and located in risky farming zones.¹⁹

This study aims to identify the optimal technological components for cultivating plants in a portable, compact, and easy-to-maintain hydroponic NFT system. The goal is to achieve high-quality products and plant yields through the integration of phytomatrix with radiating elements and the application of a nutrient solution enriched with biological products.

Table 1. Hydroponic systems and their advantages and disadvantages

Hydroponic system	General view of the system	Advantages	Disadvantages
Candlewick system		Ease of use, low cost, reliable, and suitable for growing small plants with low water consumption	Lack of oxygen slows plant development due to passive nutrient supply
Deep water culture		Easy to use; low cost; promotes rapid plant development; and suitable for growing large, fast-growing plants	If not cleaned properly, root system diseases such as mold and root neck rot may occur
Periodic flooding		Ease of use; fully automated system requiring no expensive equipment; provides good nutrient saturation, with some nutrients retained in the substrate	Power outage prevents the system from operating
Nutrient film technique		No substrate is used, reducing overall crop production costs; provides constant moisture and aeration to the roots, promoting rapid plant growth	Pump failure or power outage completely disrupts the system, causing roots to dry out quickly
Aeroponics		Enrichment of plant roots with oxygen, water, and nutrients promotes plant growth	The timer controlling water supply requires monitoring; nutrient-dispersing nozzles are prone to clogging

2. Materials and methods

The study was conducted from 2022 to 2024 in a controlled environment at the hydroponic vegetable

growing laboratory, located in a dome greenhouse at the Department of General Agriculture, Central Ukrainian National Technical University. The experimental material consisted of elite seeds of the early variety

“Rutan” basil (*Ocimum basilicum*), developed by the “Mayak” Research Station of the Institute of Vegetable and Melon Growing of the National Academy of Agricultural Sciences, Ukraine. The vegetation period for this variety ranges from 60 to 66 days.

The main parameters of the study included:

- (i) A standard hydroponic nutrient solution formulated for leafy crops, containing micro- and macroelements within the recommended concentration range for basil.²⁰ To enhance the nutrient solution, the effective microorganisms-5 (EM-5) preparation was incorporated. This preparation contains beneficial microorganisms known to stimulate root system activity, improve physiological processes, and increase plant yields.¹⁶
- (ii) Phytomatrices with red and blue LED emitting elements in a ratio of 4:1 were used for lighting.^{21,22}
- (iii) The temperature regime was maintained within

the range of 20 – 24°C, with a relative humidity of 60 – 70%.

To enhance the efficiency of growing vegetable and berry crops, the Central Ukrainian National Technical University developed a pilot portable hydroponic NFT unit incorporating phytomatrix.^{7,21} This unit operates on the NFT principle and features a vertical column-shaped structure that ensures compactness and allows a fixed number of plants to be grown within a limited space (Figures 1 and 2A).

As illustrated in Figure 1, the hydroponic column (number 8) is a pipe that contains a nutrient solution supply pipe (number 7), which is fed from a reservoir (number 9) to the top of the column through a pumping system and water pump (number 11). Inside the reservoir, a sensor (number 10) monitors the minimum nutrient solution level to maintain proper operation. At the upper part of the hydroponic column (number 8), there is an air valve (number 1), a nutrient solution distribution unit (number 2), and a phytomatrix attachment unit (number 3) equipped with radiating elements. Below this is the nutrient solution supply unit (number 4), to which phytomatrix components (number 5) are attached and extended downward. Equally spaced around the

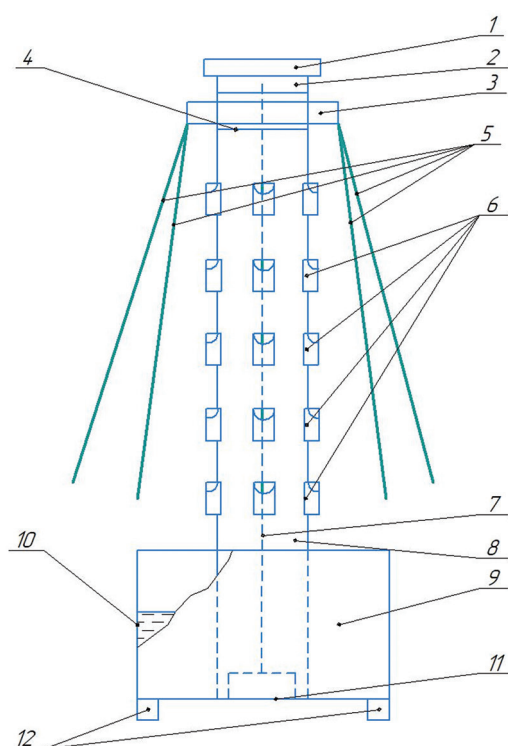


Figure 1. Schematic diagram of the portable hydroponic nutrient film technique system: (1) air valve; (2) nutrient solution distribution unit; (3) phytomatrix fastening unit; (4) nutrient solution supply unit; (5) phytomatrix with radiating elements; (6) hydroponic baskets; (7) nutrient solution supply pipeline; (8) vertical hydroponic column; (9) tank; (10) sensor of the minimum level of nutrient solution at the tank; (11) pumping system with a water pump; and (12) roller system

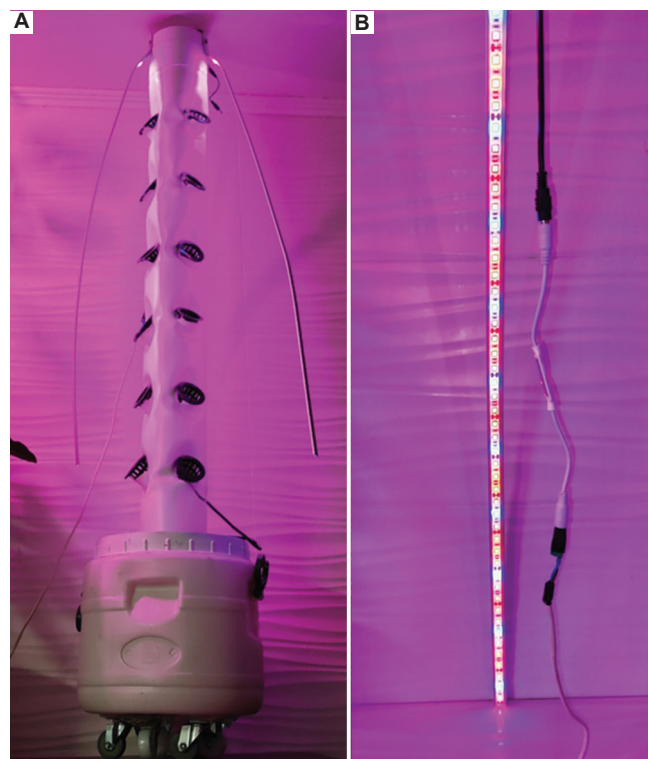


Figure 2. General view of (A) portable hydroponic nutrient film technique system and (B) phytomatrix with radiating elements

perimeter of the column are holes for hydroponic baskets (number 6), through which the nutrient solution is delivered. The hydroponic plant structure is mounted on the roller system (number 12), allowing it to be moved as needed.

The system was operated as follows: The nutrient solution from the reservoir (number 9) was supplied using a pumping system and a water pump (number 11), flowing through the nutrient solution supply pipelines (number 7) to the hydroponic baskets (number 6), where the plants received the nutrient solution in a thin layer. The hydroponic plants used phytomatrix (number 5) equipped with red and blue LED emitting elements in a 4:1 ratio for additional lighting (Figure 2B).^{9,22,23} The red light (650 – 700 nm) is crucial for photosynthesis as it stimulates growth, flowering, and fruit formation. Blue light (400 – 500 nm) is important during the early stages of plant development, supporting strong root formation, stem strengthening, and leaf growth. The high proportion of red light accelerates photosynthesis and increases yields, while blue light ensures the quality development of the plant’s structural parts. This combination is suitable for growing various types of crops, including vegetables and herbs.

This study aimed to implement a central compositional matrix plan 2³ to evaluate the effects of factors – such as the EM-5 concentrate, air temperature, nutrient solution temperature, nutrient solution concentration, and operational parameters – on the performance of the portable NFT system to ensure maximum efficiency in growing vegetable crops.

An experimental planning matrix is shown in Table 2.

The EM-5 concentrate was selected based on recommendations from earlier research,⁷ which identified 0% and 2% as appropriate concentrations for seed treatment. Similarly, the air and nutrient solution

temperatures were set at 18°C and 26°C, respectively, as these values were found to support optimal plant development in previous research.^{18,21} The nutrient solution concentration was selected according to findings from earlier studies.^{17,21} which identified 0.5 mS/cm and 2.5 mS/cm as effective levels for nutrient uptake.

Based on the conditions described above, the optimization criteria for growing vegetable crops in the improved portable hydroponic NFT system were defined as follows:

- (i) Plant height (cm)
- (ii) Time to reach the baby leaf stage (days)
- (iii) Fresh weight (g)
- (iv) Number of leaves (pieces).

The reproducibility of the experiments was evaluated using Cochran’s test:²⁴

$$G = \frac{S_{u\max}^2}{\sum_{u=1}^n S_u^2} \leq G(0.05; n; f_u) \quad (I)$$

Where:

- (i) $G(0.05; n; f_u)$ is the tabular value of Cochran’s test,
- (ii) $S_{u\max}^2$ is the largest variance among all experimental conditions,
- (iii) 0.05 is the mean 5%-th level of importance,
- (iv) n is the number of independent variance estimates (number of experiments),
- (v) $f_u = (m_0 - 1)$ is the number of degrees of freedom,
- (vi) m_0 is the number of repeated measurements (repeatability).

$$S_u^2 = \frac{1}{m_0 - 1} \cdot \sum_{i=1}^{m_0} (Y_{ui} - \bar{Y}_u)^2 \quad (II)$$

Where:

- (i) s_u^2 is the variance representing the dispersion of

Table 2. An experiment planning matrix 2³

Number of experiments	Effective microorganisms-5 concentrate (%)	Air and nutrient solution temperature (°C)	Concentration of nutrient solution (mS/cm)
	x_1	x_2	x_3
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

results in the u -the experiment,

- (ii) m_0 is the number of repeated measurements (repeatability),
- (iii) i is the number of repetition,
- (iv) Y_{ui} is the output parameter at the i -th repetition.

The reproducibility of the experiments was determined using Cochran's test (G -test), where the condition $G^P < G^T$ must be satisfied. If $G^P > G^T$, this indicates a deviation from the hypothesis, suggesting that the effectiveness of adjustments to the object under study and the measuring instruments needs to be verified.

The variance of reproducibility (error of the experiment) was determined by the formula:

$$S_y^2 = \frac{1}{n} \cdot \sum_{u=1}^n S_u^2 \quad \text{(III)}$$

Where:

- (i) u is the observation index,
- (ii) n is the number of experiments,
- (iii) S_u^2 is the variance representing the dispersion of results in the u -the experiment.

The coefficients of the mathematical model were determined by the following formulas:

$$b_0 = \frac{1}{n} \cdot \sum_{u=1}^n \bar{y}_u, \quad \text{(IV)}$$

$$b_i = \frac{1}{n} \cdot \sum_{u=1}^n x_{iu} \cdot \bar{y}_u, \quad \text{(V)}$$

$$b_{ij} = \frac{1}{n} \cdot \sum_{u=1}^n x_{iu} \cdot x_{ju} \cdot \bar{y}_u \quad \text{(VI)}$$

Where:

- (iv) x_{iu} is the value of the i -th code factor in the matrix row in the u -th trial,
- (v) x_{ju} is the value of the j -th code factor in the matrix row in the u -th trial,
- (vi) b_0 is the free member of a regression equation,
- (vii) b_i is the experimental coefficient, which indicates the degree of influence of the corresponding factor on Y ,
- (viii) b_{ij} is the experimental coefficient, which reflects the degree of influence of factors on Y ,
- (ix) n is the number of experiments,
- (x) u is the observation index,
- (xi) \bar{y}_u is the mean value of the dependent variable Y .

The adequacy of the equation was assessed using Fisher's test (F -test). Adequacy is confirmed if:

$$F = \frac{S_{ad}^2}{S_y^2} < F(0.05; f_{ad}; f_y) \quad \text{(VII)}$$

Where:

- (i) Δb_a is the variance of adequacy,
- (ii) SS_y^2 is the reproducibility dispersion,
- (iii) $F(0.05; f_{ad}; f_y)$ is the critical value of Fisher's test at 5% significance level,
- (iv) $f_{ad} = n - k - 1$ is the degrees of freedom for adequacy variance,
- (v) k is the factor's number,
- (vi) f_y is the degrees of freedom of the playback variance, where $f_y = n(m_0 - 1)$.

Variance of adequacy (S_{ad}^2) was calculated using the formula:

$$S_{ad}^2 = \frac{1}{n - k - 1} \cdot \sum_{u=1}^n (Y_u - \bar{Y}_u)^2 \quad \text{(VIII)}$$

Where Y_u is the calculated value of the response in the i -th experiment.

The significance of the regression coefficients was determined using Student's t -test. A coefficient b_a is considered significant if the following condition is met:

$$|b_a| \geq \Delta b_a = t(0.05; f_y) \cdot \frac{S_y}{\sqrt{n}} \quad \text{(IX)}$$

Where:

- (i) b_a is the regression coefficients b_0, b_1, b_2 , and $b_{1,2}$,
- (ii) Δb_a is the confidence boundary (threshold),
- (iii) $t(0.05; f_y)$ is the critical value of the Student's t -test at a 5% significance level with degrees of freedom of reproducibility variance f_y .

The significance of the regression coefficients was assessed by setting the coefficients of the quadratic regression terms to zero (null hypothesis). To evaluate this, additional experiments were conducted at the center point of the experimental design. The average value of the optimization \bar{Y}_0 criterion at the center was determined, and the deviation from the predicted value ($b_0 - \bar{Y}_0$) was calculated. This deviation characterizes the curvature of the response surface. The null hypothesis is accepted if the observed deviation does not exceed the experimental error. The significance of this deviation ($b_0 - \bar{Y}_0$) was evaluated using Student's t -test:

$$t_d = \frac{(b_0 - \bar{Y}_0) \sqrt{N}}{\sqrt{S_y^2}} \quad \text{(X)}$$

- (xii) b_0 is the free member of a regression equation,
- (xiii) N is the number of degrees of freedom,

- (xiv) $b_0 - \bar{Y}_0$ is the deviation from the predicted value,
- (xv) S_y^2 is the reproducibility dispersion.

The calculated value t_d was then compared to the critical value from the statistical tables,²⁴ selected based on the significance level of $\alpha = 0.05$ and degrees of freedom $f_i = N$. If the inequality, $|b_i| < |\Delta b_i|$ was satisfied, the corresponding factor was considered for reassessment, particularly regarding the possibility of adjusting its variation interval. In such a case, all relevant experiments were repeated. If, after reassessment, the coefficient continued to meet the same condition, it was concluded that the influence of the factor x_i on the optimization parameter was statistically insignificant Y_i .

The purpose of interpreting the resulting statistical model is to analyze the influence of factors on the optimization criterion. The degree of influence of each factor was assessed based on the value and sign of the corresponding regression coefficient b_i . A positive sign (+) indicates that an increase in the factor x_i leads to an increase in the optimization parameter Y_i , while a negative sign (-) indicates that an increase in x_i results in a decrease in Y_i .

3. Results and discussion

A central compositional matrix plan 2³ was established to evaluate the effects of several factors, including the EM-5 concentrate, air and nutrient solution temperature, and nutrient solution concentration. In addition, the experiment was performed to identify the optimal

parameters and operating modes of the improved portable hydroponic NFT unit to ensure maximum efficiency in plant growth and development. The results obtained from the implementation of the experimental matrix are presented in Table 3.

The experimental data were processed using the STATISTICA 12 software package (StatSoft, USA),²⁴ which was used to construct statistical mathematical models for the following response variables: Y_1 (plant height), Y_2 (time to reach the baby leaf stage), Y_3 (fresh weight), and Y_4 (number of leaves).

The resulting regression equations are as follows:

$$Y_1 = 3.46 + 0.16x_1 + 0.26x_2 + 0.66x_3 + 0.01x_1x_3 + 0.01x_1x_2 + 0.01x_2x_3 + 0.01x_1x_2x_3 \quad \text{(XI)}$$

$$Y_2 = 14.5 - 0.5x_1 - 1.0x_2 - 2.0x_3 \quad \text{(XII)}$$

$$Y_3 = 0.95 + 0.05x_1 + 0.1x_2 + 0.2x_3 \quad \text{(XIII)}$$

$$Y_4 = 5.625 + 0.375x_1 + 0.875x_2 + 1.875x_3 + 0.125x_1x_2 + 0.125x_1x_3 + 0.125x_2x_3 + 0.125x_1x_2x_3 \quad \text{(XIV)}$$

The significance of the obtained regression coefficients was evaluated using Student's t -test. For a reliability level (P_H) of 0.95 and degrees of freedom $f = 7$, the tabulated t -value is $t = 2.365$.²³

After verification, simplified regression equations for Y_1 , Y_2 , Y_3 , and Y_4 were obtained:

$$Y_1 \text{ (plant height): } Y_1 = 3.46 + 0.16x_1 + 0.26x_2 + 0.66x_3 \quad \text{(XV)}$$

$$Y_2 \text{ (time to reach baby leaf stage): } Y_2 = 14.5 - 0.5x_1 - 1.0x_2 - 2.0x_3 \quad \text{(XVI)}$$

$$Y_3 \text{ (fresh weight): } Y_3 = 0.95 + 0.1x_1 + 0.2x_3 \quad \text{(XVII)}$$

Table 3. Results obtained from the implementation of the experimental planning matrix 2³

Number of experiment	Factors			Criteria			
	Effective microorganisms-5 concentrate (%)	Air and nutrient solution temperature (°C)	Nutrient solution concentration (mS/cm)	Plant height (cm)	Time to reach the baby leaf stage (days)	Fresh weight (g)	Number of leaves (pieces)
	x_1	x_2	x_3	Y_1	Y_2	Y_3	Y_4
1	0	18	0.5	2.4	18	0.6	3
2	2	18	0.5	2.8	17	0.7	3
3	0	26	0.5	3.0	16	0.8	4
4	2	26	0.5	3.3	15	0.9	5
5	0	18	2.5	3.6	14	1.0	6
6	2	18	2.5	4.0	13	1.1	7
7	0	26	2.5	4.2	12	1.2	8
8	2	26	2.5	4.4	11	1.3	9

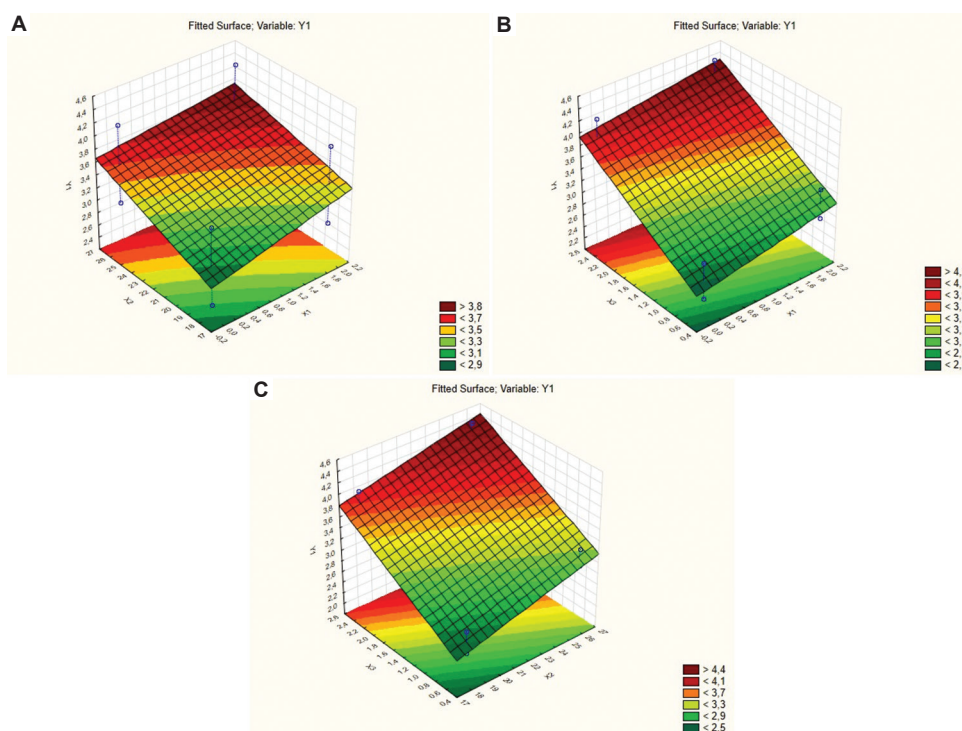


Figure 3. The response surface for plant height (Y_1): (A) $Y_1 = f(x_1, x_2)$; (B) $Y_1 = f(x_1, x_3)$; and (C) $Y_1 = f(x_2, x_3)$

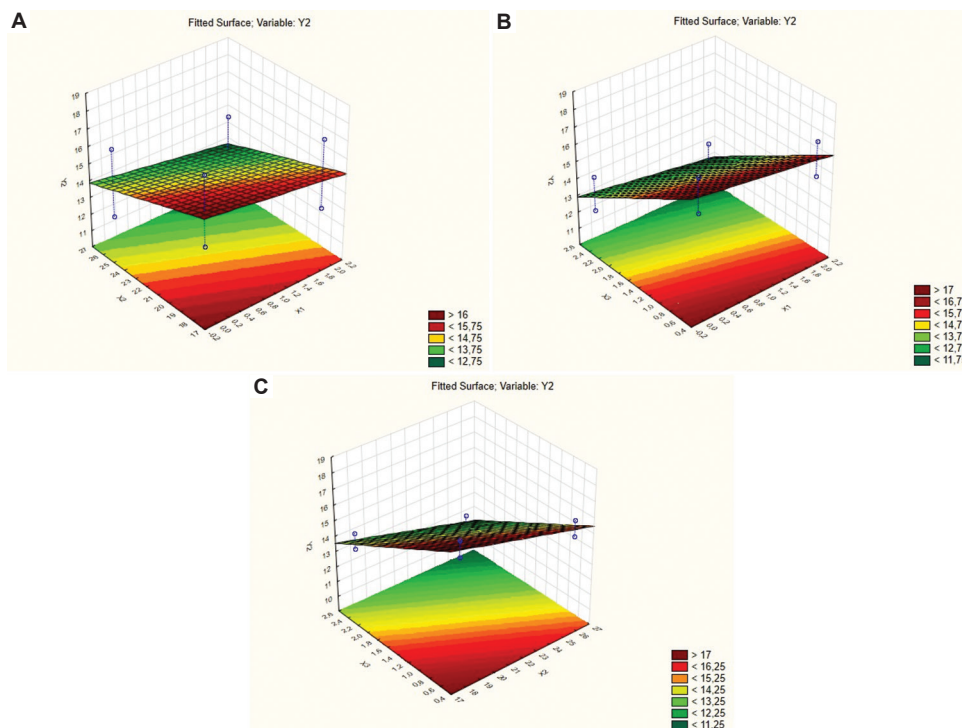


Figure 4. The response surface of time to reach the baby leaf stage (Y_2): (A) $Y_1 = f(x_1, x_2)$; (B) $Y_1 = f(x_1, x_3)$; and (C) $Y_1 = f(x_2, x_3)$

$$Y_4 \text{ (number of leaves): } Y_4 = 5.625 + 0.375x_1 + 0.875x_2 + 1.875x_3 + 0.125x_1x_2 + 0.125x_1x_3 + 0.125x_2x_3 + 0.125x_1x_2x_3 \quad \text{(XVIII)}$$

The statistical evaluation of the results confirms that the experiments are correct and reproducible, as the calculated values of the Cochran's test G^p for the optimization

The portable hydroponic system

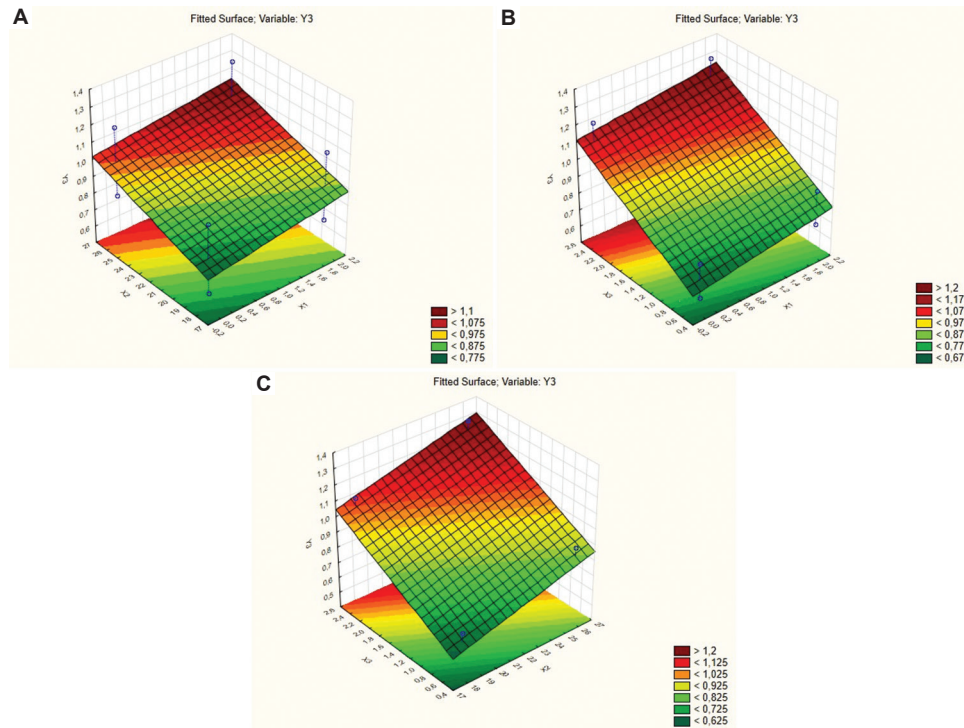


Figure 5. The response surface of fresh weight (Y_3): (A) $Y_1 = f(x_1, x_2)$; (B) $Y_1 = f(x_1, x_3)$; and (C) $Y_1 = f(x_2, x_3)$

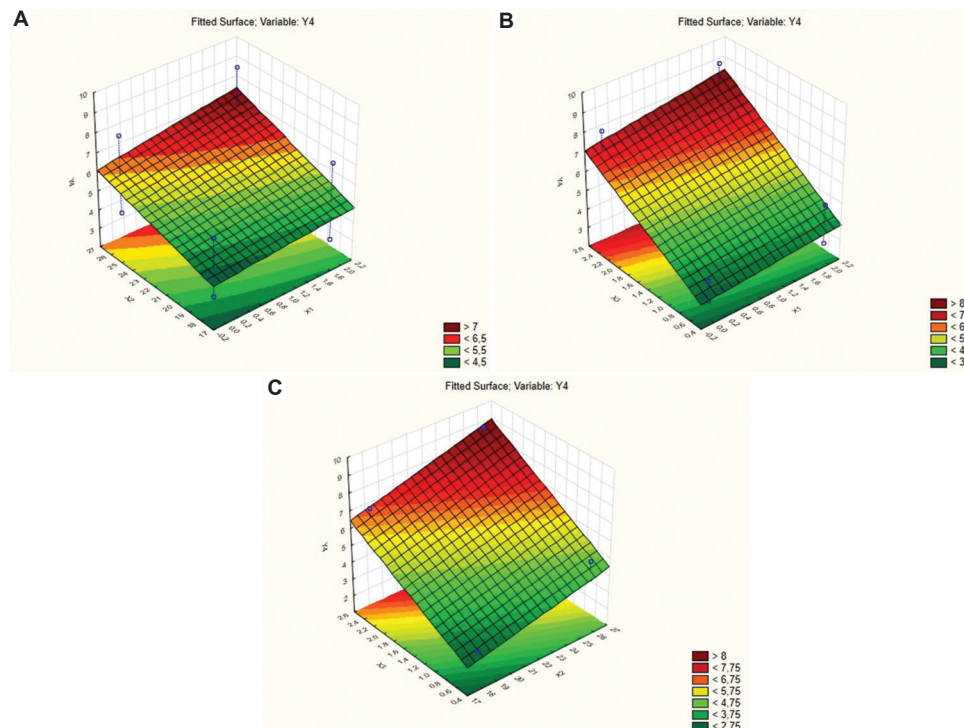


Figure 6. The response surface for number of leaves (Y_4): (A) $Y_1 = f(x_1, x_2)$; (B) $Y_1 = f(x_1, x_3)$; and (C) $Y_1 = f(x_2, x_3)$

parameters Y_1 , Y_2 , Y_3 , and Y_4 are $G_1^p = 0.483$, $G_2^p = 0.488$, $G_3^p = 0.499$, and $G_4^p = 0.500$, respectively, all of which are lower than the tabulated value $G^T = 0.516$.²³

The adequacy of the regression equations was evaluated using Fisher's test, where the tabulated value is $F^T = 4.15$ for a reliability level (P_H) of 0.95 and the degrees of freedom $f = 8$.²³ The calculated values – $F_1 = 0.54$,

$F_2 = 0.00$, $F_3 = 0.00$, and $F_4 = 1.87$ – do not exceed the tabulated value, confirming the adequacy of all models.

Response surfaces and scatter plots with histograms for plant height (Y_1), time to reach the baby leaf stage (Y_2), fresh weight (Y_3), and number of leaves (Y_4) are shown in Figures 3-6. Based on the response surface analysis for the plant height, the optimal value was observed to be between 3.8 and 4.4 cm. The analysis also identified the following rational values of the studied factors:

- (i) The EM-5 concentrate for pre-sowing seed treatment ranged from 1.8% to 2.0%,
- (ii) The temperature of air and nutrient solution was maintained within 24 – 26°C,
- (iii) The nutrient solution concentration ranged from 2.3 to 2.5 mS/cm.

Among these, the concentration of the nutrient solution had the greatest impact on plant height. Based on the response surface analysis for the time to reach the baby leaf stage, the optimal duration was observed to be

between 11 and 13 days. In addition, the analysis identified the following rational values of the studied factors:

- (i) The EM-5 concentrate for pre-sowing seed treatment ranged from 1.8% to 2.0%,
- (ii) The temperature of air and nutrient solution was maintained within 24 – 26°C,
- (iii) The nutrient solution concentration ranged from 2.3 to 2.5 mS/cm.

All factors were found to reduce the time required to reach the baby leaf stage, with the concentration of the nutrient solution having the greatest influence. Based on the response surface analysis for the fresh weight, the optimal weight was observed to be between 1.1 g and 1.3 g. The analysis also identified the following rational values of the studied factors:

- (i) The EM-5 concentrate for pre-sowing seed treatment ranged from 1.9 to 2.1%,
- (ii) The temperature of air and nutrient solution was maintained within 25 – 26°C,

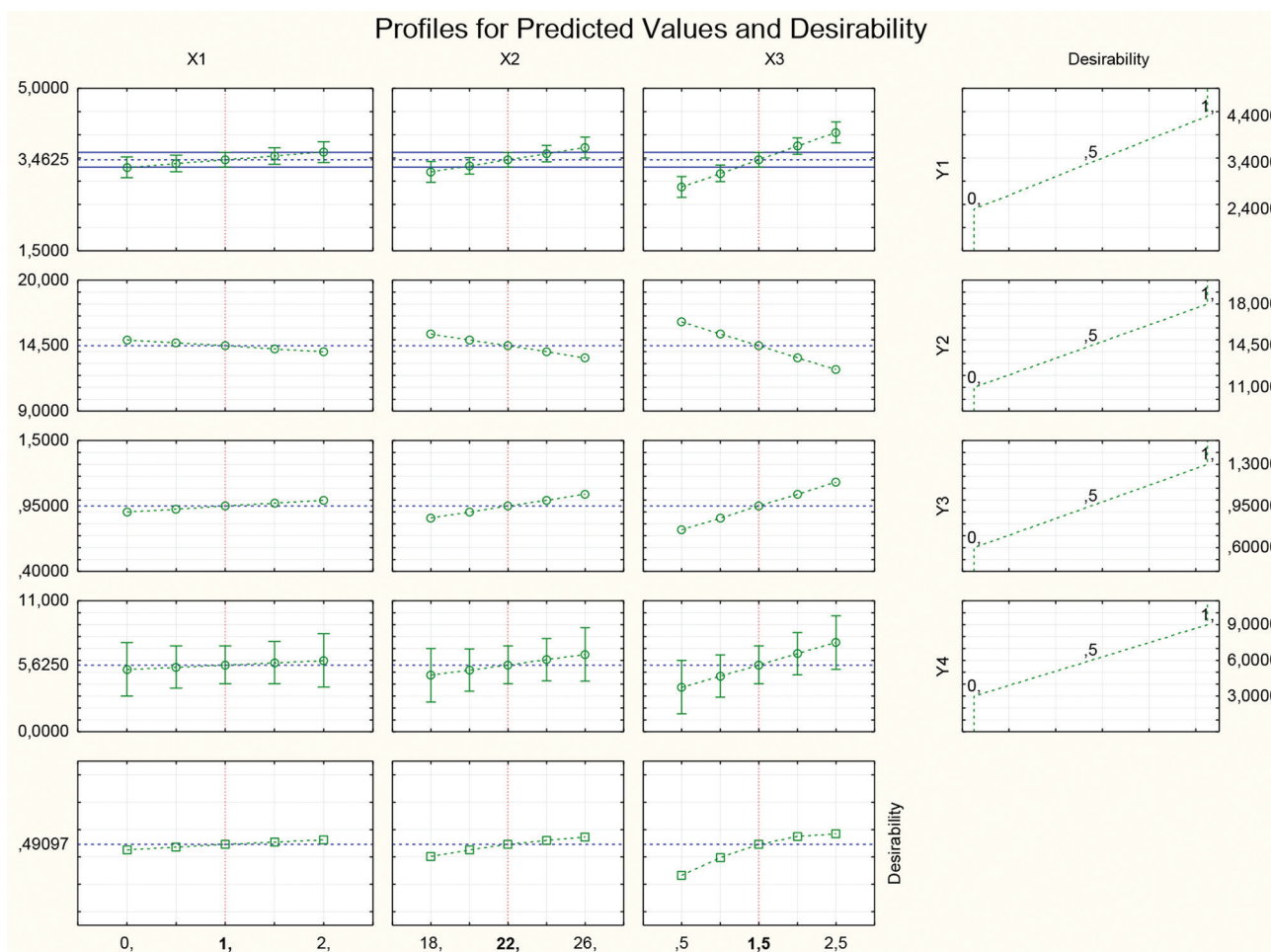


Figure 7. Scatter plots with histograms illustrating the impact of the studied factors on plant height, time to reach the baby leaf stage, fresh weight, and number of leaves

- (iii) The nutrient solution concentration ranged from 2.4 to 2.5 mS/cm.

Fresh weight was significantly influenced by the concentration of nutrient solution and the temperature of both air and nutrient solution. Based on the response surface analysis, the optimal number of leaves was observed to be between 7 and 9 pieces. In addition, the analysis identified the following rational values of the studied factors:

- (i) The EM-5 concentrate for pre-sowing seed treatment ranged from 1.9% to 2.1%,
- (ii) The temperature of air and nutrient solution was maintained within 25 – 27°C,
- (iii) The concentration of nutrient solution ranged from 2.4 to 2.5 mS/cm.

All factors—along with their interactions—were found to influence the number of leaves.

To analyze the influence of the studied factors on the optimization criteria, experimental scatter plots with histograms (Figure 7) were generated. These visualizations help identify the rational values of each parameter and estimate the actual values for plant height, time to reach the baby leaf stage, fresh weight, and number of leaves.

Therefore, the proposed technological improvements in the portable hydroponic NFT system, combined with the use of the microbial preparation EM-5 concentrate, offer a promising strategy to enhance seed germination and growth, reduce maturation time, and improve plant weight and number of leaves during pre-sowing seed treatment. Optimizing the temperature of both the air and the nutrient solution also contributes to an increase in the studied parameters and enhances their qualitative characteristics. Among all factors, the nutrient solution concentration is the most influential. An increased concentration ensures a continuous supply of nutrients to the plants, thereby promoting improved plant growth.

4. Conclusion

The proposed improvements to the portable hydroponic NFT system – including the use of a roller system – allow for easy movement of the plant as needed. In addition, upgrading the lighting system with a phytomatrix containing red and blue LED elements in a 4:1 ratio promotes optimal acceleration of photosynthesis and the development of structural plant components. This improvement contributes to increased yield, as confirmed by the experimental findings.

Pre-sowing seed treatment with the EM-5 concentrate enhanced key growth parameters, including plant

height, fresh weight, number of leaves, and the time to reach the baby leaf stage. The optimal concentration range for EM-5 was 1.8 – 2.0%. The microorganisms in EM-5 positively affected the root system, enhancing nutrient and water absorption, which in turn improved overall plant health and development.

The optimum temperature for both air and nutrient solution for the growth of Ratan basil was 24–26°C. This temperature range promoted plant height, accelerated development to the baby leaf stage, and increased leaf weight and number. However, temperatures exceeding 26°C may induce plant stress and reduce overall quality.

Furthermore, a reduced nutrient solution concentration (0.5 mS/cm) fails to supply sufficient nutrients for normal plant development, resulting in slower growth, lower plant weight, and fewer leaves. In contrast, increasing the concentration to the optimum level (2.4 – 2.5 mS/cm) significantly enhanced all growth parameters.

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Conflict of interest

The authors declare that they have no competing interests.

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Availability of data

The data are available from the respective authors (Kateryna Vasylykivska and Mykola Kovalov) upon reasonable request.

References

1. Vasytkovska K, Vasytkovskyi O, Popova S, Malakhovska V. The directions for optimizing Ukraine's export potential of grain crops in the context of changing climatic conditions. *Ser V Econ Bull Transilvania Univ Brasov*. 2021;14(63):129-136. doi: 10.31926/but.es.2021.14.63.1.14
2. Kovalov M, Vasytkovska K, Reznichenko V, Mostipan M. Agro-ecological aspects of the change of sulphate sulphur content in chernozem of the buh-dnipro interstream area in Ukraine. *WSEAS Trans Environ Dev*. 2019;15:319-323.
3. Vasytkovska K, Andriienko O, Malakhovska V, Vasytkovskyi O, Andriienko A, Shepilova T. Analysis of effective sunflower cultivation zones using the example of Ukraine. *Agron Res*. 2024;22(3):1362-1376. doi: 10.15159/AR.24.097
4. Bersani C, Ruggiero C, Sacile R, Soussi A, Zero E. Internet of things approaches for monitoring and control of smart greenhouses in industry 4.0. *Energies*. 2022;15(10):3834. doi: 10.3390/en15103834
5. Gavrić T, Marković S, Čengić L. Feasibility of growing basil as an alternative crop for adaptation to climate change in Bosnia and Herzegovina. *Chil J Agric Res*. 2023;83(1):43-51. doi: 10.4067/S0718-58392023000100043
6. Patel K, Chauhan D, Mishra P, et al. Design and development of a modular hydroponic tower with topology optimization. *Int J Interact Des Manuf*. 2024;19:4243-4252. doi: 10.1007/s12008-024-02052-1
7. Kovalov MM, Vasytkovska KV. Influence of the Salt Composition of Nutrient Solution on the Cultivation of Different Varieties of Romaine Lettuce in Hydroponic Columns. In: *Proceedings of the II International Internet Conference 'The Current State of Science in Agriculture and Nature Management: Theory and Practice'*. 2020. p. 81-83.
8. Žlabur JŠ, Opačić N, Žutić I, et al. Valorization of nutritional potential and specialized metabolites of basil cultivars depending on cultivation method. *Agronomy*. 2021;11(6):1048. doi: 10.3390/agronomy11061048
9. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. *J Soil Water Conserv*. 2018;17(4):364. doi: 10.5958/2455-7145.2018.00056.5
10. Burlaka S, Lyts P, Kupchuk I. Evaluation of productivity and energy consumption in hydroponics. *Herald Khmelnytskyi Natl Univ Tech Sci*. 2024;339(4):290-295. doi: 10.31891/2307-5732-2024-339-4-46
11. Kupchuk I, Melnyk O. Mathematical modelling of the effect of irradiation on the productivity of the process of growing plant products in a hydroponic plant. *Herald Khmelnytskyi Natl Univ Tech Sci*. 2024;331(1):83-88. doi: 10.31891/2307-5732-2024-331-14
12. Azhari, Simanjuntak D, Hakim L, Sabar. Design and control system of temperature and water level in hydroponic plants. *J Phys*. 2022;2193(1):012018. doi: 10.1088/1742-6596/2193/1/012018
13. Christofi A, Margariti G, Salapatras A, et al. Determining the nutrient content of hydroponically-cultivated microgreens with immersible silicon photonic sensors: A preliminary feasibility study. *Sensors*. 2023;23(13):5937. doi: 10.3390/s23135937
14. Hao W, Tablada A, Shi X, Wang L, Meng X. Efficiency analysis of the photovoltaic shading and vertical farming system by employing the artificial neural network (ANN) method. *Buildings*. 2023;14(1):94. doi: 10.3390/buildings14010094
15. Nájera C, Gallegos-Cedillo VM, Ros M, Pascual JA. LED lighting in vertical farming systems enhances bioactive compounds and productivity of vegetables crops. *Biol Life Sci Forum*. 2022;16(1):24. doi: 10.3390/IECHo2022-12514
16. Kovalov MM, Vasytkovska KV, Reznichenko VP, Mostipan MI. *Patent No. 142316 U Ukraine: A Cold Method of Preparing Straw Substrates Using EM Preparations*. 2020.
17. Vasytkovska K, Kovalov M, Andriienko O, Kornicheva H. Technical support of hydroponics as a progressive type of growing vegetable crops. *Natl Interag Sci Tech Collect Work Des Prod Exploit Agric Mach*. 2022;52:81-86. doi: 10.32515/2414-3820.2022.52.81-86
18. Sahara A, Saputra R.H, Asis M, Lawasnitro A. Design of Hydroponic Planting Media Based on Solar Cell Power. In: *Conference: 2021 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE)*. Malang, Indonesia: IEEE; 2021. doi: 10.1109/ICEEIE52663.2021.9616657
19. Shrivastava A, Nayak CK, Dilip R, Samal SR, Rout S, Ashfaq SM. Automatic robotic system design and development for vertical hydroponic farming using IoT and big data analysis. *Mater Today Proc*. 2021;80:3546-3553. doi: 10.1016/j.matpr.2021.07.294
20. Hussain AS, Brown PB. Current status of the propagation of basil in aquaponic systems: A literature review. *Aquac Res*. 2025;2025(1):1-13. doi: 10.1155/are/1320019
21. Kovalov MM. The influence of climate support parameters on microgreen cultivation under the conditions of a film greenhouse. *Taurian Sci Her*. 2022;126:153-162. doi: 10.32851/2226-0099.2022.126.21
22. Baranovskyi V, Boretska T, Kohut V. Interactive impact

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- of the spectral composition of additional lighting and root zone temperature on the productivity of hydroponic lettuce. *Vib Eng Technol.* 2024;115(4):24-30.
doi: 10.37128/2306-8744-2024-4-3
23. Budavári N, Pék Z, Helyes L, Takács S, Nemeskéri E. An overview on the use of artificial lighting for sustainable lettuce and microgreens production in an indoor vertical farming system. *Horticulturae.* 2024;10(9):938.
doi: 10.3390/horticulturae10090938
24. Wambua RM. *Engineering Research Methods: Research Proposal, Structure of a Paper, Data Collection and Analysis.* Munich, Germany: GRIN Verlag; 2022. p. 110.