RESULTS OF EXPERIMENTAL STUDIES OF HYDROPONIC SOLUTION PROCESSING WITH ACOUSTIC-MAGNETIC FIELD EFFECT TO CUCUMBER YIELD IN HYDROPONIC GREENHOUSES

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Abstract. The aim of the research is to study the effect of hydroponic solution processing with an acoustic-magnetic field effect to the cucumber yield. The scientific hypothesis expresses the possibility of influencing the vegetative processes of cucumber growth by means of physical fields to the hydroponic solution used in growing crops. The research was conducted using an empirical method. Observations of plant growth were made by internode distances of the cucumber liana measuring at the experimental and control plots. The hydroponic solution used for growing agricultural crops was treated with an acoustic-magnetic field created by an acoustic-magnetic device at the experimental plot. The hydroponic solution was not treated at the control plot. The method of paired comparison of each plot yields has fairly accurate results. Various modes of the acoustic-magnetic device operation were considered using experiment planning at three levels of significant factors: voltage, frequency, and device working zone length for comparison. The cucumber liana internode distance is taken as the resulting indicator. The model is based on regression analysis. According to the study results, it was found that internode distance increasing leads to yield increasing, and cucumber yield is related to the mode of operation of the acoustic-magnetic device, the supplied voltage frequency and the size of the device. It is possible to design devices which operation parameters create a resulting indicator acceptable value. This fact proves the efficiency of calculating parameters methods used for design of acoustic-magnetic devices.

Keywords: hydroponic solution, acoustic and magnetic device, regression analysis, experiment planning.

Introduction

The world's population increases and needs food of good quality. Use of hydroponics in agriculture is one of the ways to solve the emerging problems. Besides that, small and medium-sized farms could organize new jobs by means of this technology. It is possible to increase by 30 % the crop yield by hydroponic technologies, compared with soil cultivation technologies. Hydroponic technology allows to provide plants with all the necessary mineral salts through solutions, because this form is the best way of nutrient absorbing by plants. Thus, a plant does not need a large root system to ensure the consumption of nutrients and so the upper part of the plant grows more intensively. Among the many advantages of hydroponics, the most significant advantages are water and nutrient savings. The traditional methods of growing plants in the soil lead to senseless losses of chemical fertilizers and to contamination of groundwater. There is no water loss in closed hydroponic systems, and water is used just in the volume that plants consume and evaporate.

Modern hydroponic greenhouses operate with various technologies, but all technologies have general features: a nutrient solution is prepared in a large tank, in which the main nitrogen, phosphorous, potassium salts and trace elements are dissolved; dispensers pour a portion of these solutions into a common tank, where they are diluted with water to the necessary concentration; the nutrient solution is delivered to roots of plants. Plant roots gradually change the composition of the nutrient solution. The concentration of nutrients decreases, the value of the hydrogen index changes, so it is necessary to adjust the composition of the solution in accordance with technological requirements. Electrodes of two devices are immersed in the mixing tank for this purpose. One of them gets the values of electrical conductivity and concentration of the solution. It gives a signal to dispensers to add the missing amount of salt mixture. Another device measures the value of the solution hydrogen index. It is necessary to support the nutrient concentration and pH value of the solution in a certain interval characteristic for particular species plants (most often in the range from 6 to 7) for optimal plant growth condition providing. The process is regulated by chemical reagents, but it is laborious and capital intensity process. The aim of the research is to study the effect of the hydroponic solution processing with an acoustic-magnetic field effect to the cucumber yield. The scientific hypothesis expresses the possibility of influencing the vegetative processes of cucumber growth by means of physical fields to the hydroponic solution used in growing crops. The reagent-free way of factor balance maintaining with an acoustic-magnetic device is discussed in this article.

Materials and methods

The process of treatment a hydroponic solution with acoustic and magnetic fields is represented as a dependency:

$$\xi_{\mathrm{ra}} = (P_1, P_2, P_3), \tag{1}$$

where $P_1 = l$ – length of the working zone of the acoustic-magnetic device;
$P_2 = f$ – frequency of the voltage applied to the acoustic-magnetic device;
$P_3 = U$ – voltage applied to the acoustic-magnetic device.

The efficiency of treatment a hydroponic solution with the acoustic-magnetic device is determined from formulae:

$$\xi_{ra} = \frac{M\text{-}H}{H}, \tag{2}$$

where M – internode distance of cucumber liana grown on hydroponic solution treated with the acoustic-magnetic device;
H – internode distance of cucumber liana grown on untreated hydroponic solution.

Levels of the device parameter (Table 1) variation are:

(–) P_{n1} = 61 mm; (0) $P_{n1(0)}$ = 9.5 mm; (+) P_{n1} = 122 mm;

(–) P_{n2} = 25958 Hz; (0) $P_{n2(0)}$ = 27548 Hz; (+) P_{n2} = 29138 Hz;

(–) P_{n3} = 12 V; (0) $P_{n3(0)}$ = 24 V; (+) P_{n3} = 36 V.

Table 1

Levels and code designation of experiments

Top level (+)	122	29100	36
Base level (0)	91.5	27500	24
Bottom level (–)	61	25900	12
Code designation	P_{n1}	P_{n2}	P_{n3}

The encoded factors are [1]:

$$P'_{n1} = \frac{P_{n1}\text{-}P_{n1(0)}}{\Delta P_1} = \frac{P_{n1}\text{-}91.5}{30{,}5}; P'_{n2} = \frac{P_{n2}\text{-}P_{n2(0)}}{\Delta P_2} = \frac{P_{n2}\text{-}27500}{1600}; P'_{n3} = \frac{P_{n3}\text{-}P_{n3(0)}}{\Delta P_3} = \frac{P_{n3}\text{-}24}{12}. \tag{3}$$

The experimental data at the optimum region of treatment the hydroponic solution process with acoustic and magnetic fields are presented in Table 2.

Table 2

Performance and factor variable for a linear model

Experiments	**Code designation**					
	P'_{n1}	P'_{n2}	P'_{n3}	ξ_{ra1}	ξ_{ra2}	$\xi_{ra} = (\xi_{ra1} + \xi_{ra2})/2$
1	(–)	(–)	(–)	0.840	0.860	0.850
2	(+)	(–)	(–)	0.850	0.900	0.875
3	(–)	(+)	(–)	0.820	0.870	0.845
4	(+)	(+)	(–)	0.964	0.976	0.970
5	(–)	(–)	(+)	0.890	0.912	0.901
6	(+)	(–)	(+)	0.930	0.917	0.924
7	(–)	(+)	(+)	0.850	0.890	0.870
8	(+)	(+)	(+)	0.978	0.990	0.984

The assumptions of regression analysis about the homogeneity of sample variances are based on the Cochran's criterion $G_{\max} < G_{critical}$, where

$$G_{\max} = \frac{S_{u\max}^2}{\sum_{u=1}^{N} S_u^2},$$

and $G_{critical}$ is found from the table of critical values of the Cochran's distribution at the significance level α and the number of degrees of freedom $f_1 = n\text{-}1$; $f_2 = N$ [2].

Sample variance values are equal to

$$S_1^2 = \frac{\sum_{i=1}^{n}\left(\xi_{ra}\text{-}\bar{\xi}_{ra}\right)^2}{n\text{-}1} = \frac{(0.84\text{-}0.85)^2 + (0.86\text{-}0.85)^2}{1} = 2\cdot 10^{-4};$$

$$S_2^2 = 12.5\cdot 10^{-4}; S_3^2 = 12.5\cdot 10^{-4}; S_4^2 = 0.72\cdot 10^{-4}; S_5^2 = 2.42\cdot 10^{-4}; S_6^2 = 0.85\cdot 10^{-4};$$

$$S_7^2 = 8\cdot 10^{-4}; S_8^2 = 0.72\cdot 10^{-4}. \quad (4)$$

The process is reproducible, since the inequality $G_{\max} < G_{critical}$ is true [3]:

$$G_{\max} = \frac{S_{u\max}^2}{\sum_{u=1}^{N} S_u^2} = 0.315 < 0.6798 \cdot \quad (5)$$

So, the hypothesis of variance uniformity is accepted. Since the experiment process is reproducible, the values of regression coefficients are determined by the experiment results. The regression coefficient estimates are equal to [3]:

$$\beta_0 = \frac{\sum_{u=1}^{N} \bar{\xi}_{ra}}{N} = 0.902, \quad (6)$$

$$\beta_1 = \frac{\sum_{u=1}^{N} \bar{\xi}_{ra} \mathrm{P}'_{\mathrm{n1u}}}{N} = 0.036, \quad (7)$$

$$\beta_2 = \frac{\sum_{u=1}^{N} \bar{\xi}_{ra} \mathrm{P}'_{\mathrm{n2u}}}{N} = 0.015, \quad (8)$$

$$\beta_3 = \frac{\sum_{u=1}^{N} \bar{\xi}_{ra} \mathrm{P}'_{\mathrm{n3u}}}{N} = 0.017, \quad (9)$$

where N – number of experiment.

Further it is necessary to check the statistical significance of the regression coefficients with the Student's criterion:

$$|\beta_i| \geq \Delta\beta_i = t_{\alpha;m} \cdot S_\beta, \quad (10)$$

where $t_{a;m}$ – critical value of the Student's distribution at the significance level α and the number of freedom degrees $m = N\text{-}1$.

The reproducibility variance is equal to

$$S_{\mathrm{repr}}^2 = \frac{\sum_{u=1}^{N} S_u^2}{N} = 5.0\cdot 10^{-4}.$$

The variance of the regression equation coefficients is equal to

$$S_\beta^2 = \frac{S_{repr}^2}{n_s} = 3.0\cdot 10^{-5}, \quad (11)$$

where $n_s = Nm^*$ – number of experimental values;
m^* – number of parallel measurement.

All the coefficients are statistically significant at 0.95 level of reliability [4], and the resulting regression equation is:

$$\hat{\xi}_{ra} = 0.902 + 0.036P_{n1}^{'} + 0.015P_{n1}^{'} + 0.017P_{n3}^{'} . \qquad (12)$$

Fisher's criterion is used to test the hypothesis of model adequacy. The total variance is compared with the remainder variance

$$S_{\xi_{ra}}^{2} = \frac{\sum_{i=1}^{N}\left(\xi_{ra_i} - \bar{\xi}_{ra_i}\right)^2}{N\text{-}1}, S_{\xi_{ra}rem}^{2} = \frac{\sum_{i=1}^{N}\left(\xi_{ra_i} - \hat{\xi}_{ra_i}\right)^2}{N\text{-}l}, \qquad (13)$$

where $l = k + 1$ $l = k + 1$ – number of terms of the approximating polynomial;
k – number of factors.

The experimental value of the F- criterion was found

$$F_{calculated} = \frac{S_{\xi_{ra}rem}^{2}}{S_{\xi_{ra}}^{2}} = \frac{0.00127}{0.00397} = 2.555 \leq F_{(0.05; f_{rem}; f_u)} = 4.37 , \qquad (14)$$

where $F_{(0.05; f_{rem}; f_u)}$ – critical value of the Fisher's distribution at the significance level α and the number of degrees of freedom $f_{rem} = N\text{-}l$; $f_u = N\text{-}1$.

The conducted statistical analysis of the experiment results reveals homogeneity of the experiment variance and the experiment reproducibility variance. The average relative error of the approximation is equal to:

$$\bar{e}_{deviation} = 0.029 \ \% . \qquad (15)$$

This small value of average relative error of the approximation demonstrates a high level of accuracy of the constructed model and possibility of its practical use.

Results and discussion

The experimental studies of acoustic-magnetic treatment of hydroponic solution carried out in 2016-2019 at the JSC "Raduga" (greenhouse complex) allow increasing by 30 % the crop yield [5].

The observations of plant growth are carried out by means of cucumber liana internode distance measuring at the experimental and control plots. The hydroponic solution used for growing agricultural crops at the experimental plot was treated with an acoustic-magnetic device (Fig. 1) [6]. At the control plot the hydroponic solution used for growing agricultural crops was not treated [7]. Figure 2 shows the result of cucumber liana internode distance measuring at the control plot.

Fig. 1. **Acoustic-magnetic device installed in the hydroponic solution supply system**

Fig. 2. **Measuring of cucumber liana internode distance at the control plot**

Figure 3 shows the result of the measuring of cucumber liana internode distance at the experimental plot. According to the study results, it was found that liana internode distance increasing leads to yield increasing, and the cucumber yield is interrelated with the operating mode of the acoustic-magnetic device (the frequency of the applied voltage and the size of the device).

Fig. 3. **Measuring of cucumber liana internode distance at the experimental plot**

The optimal level of relative humidity was maintained (beside 75 %) during the experiments. Cucumber fruit (long-fruited cucumber) reaches good commercial and taste qualities in the state of technical ripeness with a mass of 350-400 g. At the first stage of the experiment, cucumber fruits were removed from the stem, when they were smaller, so that the load to the stem was not too large. Harvesting of unripe greens leads to large crop losses due to upset of balance of a plant. Therefore, it was important to conduct daily collection of fruits. During the experiment, observations were carried out of air temperature, substrate temperature and substrate humidity, etc. Biological observations were made for the number of flowers and fruit on the main stem plants, the growth of vegetative mass, the number of leaves, the area of the leaf surface, the stem diameter, the cucumber liana internode distance.

These observations demonstrated the significant impact to the growth and development of plants, the formation of the ovary due to the treatment of the hydroponic solution with the acoustic-magnetic device. There are the integrated biometric indicators of the cucumber plant reaction to the hydroponic solution at the experimental and control plots of the greenhouse in Table 3.

Table 3

Biometric indicators of cucumber plants

Hydroponic solution	Treated	Untreated
Stem length before elimination, cm	290	290
Leaves plates length, cm	30	25-27
Quantity of leaves	30	24-26
Total areaof leaves plates, cm2	12600	9100
Number of flowers	40	15-22
Number of fruit	26-30	22-26
Stem diameter, cm	0.98	0.9
Internode distance, cm	12	9.5

The obtained results of observations are the scientific basis for explaining the differences in cucumber yield and fruit quality. Harvesting and crop accounting is the final stage of the experiment. The quality and accuracy of harvesting and crop accounting determine the complex of work results during the entire production cycle.

Similar experiments on hydroponic solution processing are described in [9-12]. The experiment was carried out in the Laboratory of the Soils and Water Department (Faculty of Agriculture, Al-Azhar University, Assiut, Egypt). As a result of the experiments, the effect of magnetic fields and various nutrient solutions on growth of lettuce plants under hydroponic system was revealed. This study suggests that the effects of magnetic field treatments act as a protective application of organic nutrition solution in the hydroponic organic system.

Conclusions

According to the study results the following facts were found:

1. The treatment of hydroponic solution used for growing agricultural crops with an acoustic-magnetic device leads to cucumber liana internode distance increasing: when processing the hydroponic solution, the liana internode distance is 12 cm, and without processing the hydroponic solution the liana internode distance is 9.5 cm.
2. The increasing of the internode distance determines the yield increasing.
3. The cucumber yield is interrelated with the operating mode of the acoustic-magnetic device (the frequency of the applied voltage and the size of the device).
4. The results of observations demonstrate that processing the hydroponic solution with an acoustic-magnetic device significantly increased the growth and development rate of the plant, the amount of ovary formed.
5. These facts determine the possibility of design and creating such acoustic-magnetic devices, which operation parameters result in the indicator acceptable value.

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