International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

TuEngr Group

http://TuEngr.com

PAPER ID: 11A16V

USING AN ELECTRIC FIELD TO STIMULATE THE VEGETABLE CROPS GROWTH

Sergey Mashkov [1*], **Sergey Vasil'ev** [1*]
Marat Fatkhutdinov [1], **Tat'yana Gridneva** [1]

[1] *Department of Electrification and Automation of Agro-industrial Complex, Samara State Agrarian University, RUSSIA.*

ARTICLEINFO

Article history:
Received 30 July 2020
Received in revised form 07 September 2020
Accepted 24 September 2020
Available online 29 September 2020

Keywords:
Electrical technology; LED vegetation; LED phyto lamp; Biomodule; Supplementary lighting; Electric field; Electrical plant stimulation; Plant growth.

ABSTRACT

This paper presents the development of a set of energy-saving elements of the technology for growing vegetables under controlled conditions. The proposed adaptive lighting method and a device for electrical stimulation form a complex of energy-saving elements of growing vegetable crops' technology. The developed methods of adaptive lighting and electrical stimulation are applicable for the cultivation of organic vegetable products, making it possible to obtain a multiplicative effect, expressed in their accelerated growth, development, and increase in productivity in general.

Disciplinary: Plant and Crop Sciences, Bioscience and Biotechnology, Electrical Technology.

1. INTRODUCTION

Growing vegetable crops in greenhouses or even more controlled conditions (in high-tech cultivation facilities) is accompanied by high energy costs, both thermal, to maintain optimal microclimate parameters, and electric, to illuminate (supplement) the plants. In the context of rising energy prices, the task of reducing energy costs becomes more and more urgent, i.e., improving the energy efficiency of lighting equipment [1].

Instead of luminescent ones, the introduction of LED phyto-lamps to illuminate greenhouses contributes to a partial solution to this problem. However, new ones arise, related to the spectral composition of the light emitted by LED lamps. The composition of the spectrum of an LED luminaire often does not match the needs of plants. As a result of this discrepancy, they may lag in development when illuminated by fluorescent light sources, the spectrum of which is more consistent with the spectrum of natural sunlight [2, 3].

*Corresponding author (Sergey Mashkov) Email: mash_ser @ mail.ru

The optimal characteristics of the light spectrum for each cultivated crop, at present, are not substantiated and even poorly studied [2].

Similar problems arise in the cultivation of meristemic plants, for example, in the production of virus-free seeds of domestic breeding potatoes. In the process of breeding work, a significant part of the time is spent on growing the selected microclonal shoots to the required size. It reduces the intensity of selection and leads to an increase in material costs. A problem arises with the acceleration of microtonal shoots' growth and, consequently, the selection's acceleration.

At the same time, it is important to create environmentally friendly methods and technologies to ensure the acceleration of selection.

One of the options for ensuring accelerated selection and growing vegetable crops under controlled conditions is modern electrical technologies, including electromagnetic stimulation and plants' adaptive lighting [4-11]. Thus, it is obvious that there is a need to develop energy-saving devices that promote plant growth acceleration and are applicable in technologies for growing plants under controlled conditions.

2. MATERIALS AND METHODS

For research, an automated biotechnological installation, the "Bio-module ESS RGB-250" was developed and manufactured (Figure 1).

a - general view; b - adaptive lighting system

1 - case; 2 - a compartment for placement of electronic control and monitoring units (CMU); 3 - CMU compartment cover; 4 - walls of the working chamber; 5 - the door of the working chamber; 6 - the regulator of luminous flux intensity; 7 - a compartment for RGB lamps; 8 - RGB lamp; 9 - aeration fan of the working chamber; 10 - supply and exhaust ventilation system; 11 - block of temperature and humidity sensors; 12 - dielectric bottom of the working chamber

Figure 1: General view of the biomodule for accelerated plant growth under controlled conditions.

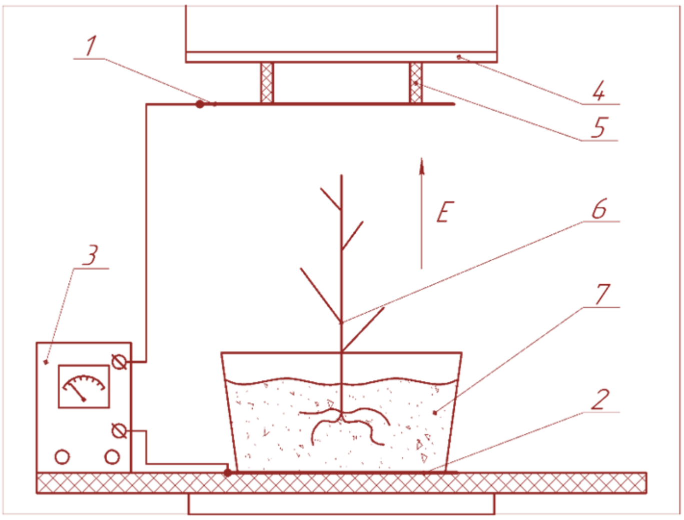
Planting trays with grown plants are placed in the working chamber. A compartment for RGB lamps is located in the upper part of the unit. These luminaires contain a specially selected combination of single color LEDs (red, green, and blue), tri-color RGB LEDs and white light LEDs. With the possibility of independent regulation of each of the three groups of LEDs' brightness, this combination allows you to create a luminous flux of any spectral composition.

The regulator carries out operational regulation of the intensity of the light flux. Fine-tuning of the luminous flux's spectral composition and intensity is carried out from a mobile application or computer using a Wi-Fi connection.

In the biotechnology facility described above, plants grow in a controlled environment. Environmental parameters are controlled by factors such as temperature and humidity and the illumination of the aboveground part. The working chamber of the biomodule is periodically ventilated according to the supply and exhaust ventilation scheme.

In the simulation process, a pulsed, pulsating, or other form voltage of a given frequency and amplitude is applied to the electrodes.

The stimulating effect is carried out as follows: plants are located between two electrodes of different polarity (regardless of their shape and size). There is an electrode with a positive potential under the plants' roots and above the plant with a negative one. The direction of the external electric field applied to the plant will coincide with plant growth (Figure 2).



1 - upper electrode (with negative potential); 2 - lower electrode (with a positive potential); 3 - generator power plant with a control unit; 4 - bar for fixing the upper electrode; 5 - insulators; 6 - stimulated plants; 7 - soil

Figure 2: Scheme of plant electrostimulation

For ensuring the safety of service personnel and plants, the upper electrode one must be reliably insulated, and the lower electrode two must be reliably grounded. In this case, the upper electrode's insulation will not affect the electric field's shape and characteristics because the insulation material is dielectric. That is, it has a high dielectric constant.

The grounding of the lower electrode two also cannot affect the electrical circuit's characteristics. From the point of view of electrical safety, grounding will play potential equalization between the grounded metal parts of the electrical installation and the stimulation unit's electrode.

For plant stimulation required, high-voltage equipment. At this stage of research, the equipment has been developed. That generates an alternating voltage with a frequency of 50 Hz (i.e., without a frequency generator) and regulating the output voltage value in the range from 0-50 kV. The electrical diagram of the developed installation is in Figure 3.

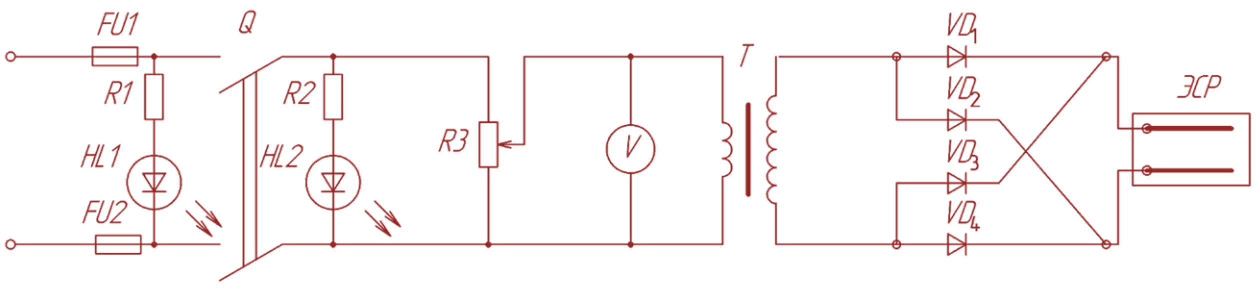


Figure 3: Diagram of a high-voltage device for electrical plant stimulation

Each variant of the studied factor was set in four replicates, including the control variant, when the plants were not subjected to electrical stimulation. The arrangement of replicates by variants is in Table 1.

Table 1: The layout of the plants in the experiment with "ϒ" sign (corresponding to Figure 5).

Repetitions	Top view layout							
	-	V3	-	V2	-	V1	-	C
1	space	ϒ	space	ϒ	space	ϒ	space	ϒ
2	space	ϒ	space	ϒ	space	ϒ	space	ϒ
3	space	ϒ	space	ϒ	space	ϒ	space	ϒ
4	space	ϒ	space	ϒ	space	ϒ	space	ϒ

Table 1 shows the top view layout of the plants in the experiment. To reduce electric fields' mutual influence, a free space is provided between neighboring options, marked with the word "space". The test plants are marked with the "ϒ" sign. This is shown in Figure 5.

The V3-V1 values are described in the test. Options V3-V1 are arranged to decrease electric field strength to reduce the field's possible effect on the control option (C).

The plants were also supplemented with LED phyto-lamps with a power of 100 W, produced by the RosSvet company in the experiment. Artificial supplementary lighting in research is necessary to simulate natural sunlight for normal plant growth, that is, to recreate their natural growing environment as accurately as possible. Illumination, at the level of seedlings, was 7250.6 lux, which meets the regulatory requirements.

3. RESULT AND DISCUSSION

During the experiment, the plants were planted in three pieces in plastic cups. This group of plants represents one replication of the experiment.

Each variant of the study contained four replicates. There are four variants of experiments, including the control variant. Thus, the total number of replicates was 16, and the test plants were 48.

The scheme of experiment on dill is similar, in general, to the scheme of experiment on tomatoes, which was described earlier. Still, there are differences in the parameters of stimulation.

An electric field was created between several pairs of electrodes located at a certain equal distance from each other, to which a voltage of a given value was supplied from generating installations. The voltage was rectified, pulsating. The ripple frequency in all variants was 100 s^{-1}

(sinusoidal voltage with a frequency of 50 Hz, rectified by a bridge rectifier). Three variants (gradations) of voltages equal to 40 V, 220 V, and 10 kV, and, accordingly, field strengths were investigated. For the first option (V1), the intensity was E = 0.15 kV / m, for the second (V2) option, E = 0.75 kV / m, and for the third option (V3), respectively, E = 37.0 kV / m.

Additional lighting was during periods of insufficient natural lighting, in the morning from 4.00-10.00, in the evening from 17.00-23.00. The total daily duration of additional illumination was 12 hours.

Plants' electrical stimulation was in the morning and evening, lasting 4 hours, from 6.00-10.00, and from 16.00-20.00. The total daily duration was 8 hours, see Figure 4.

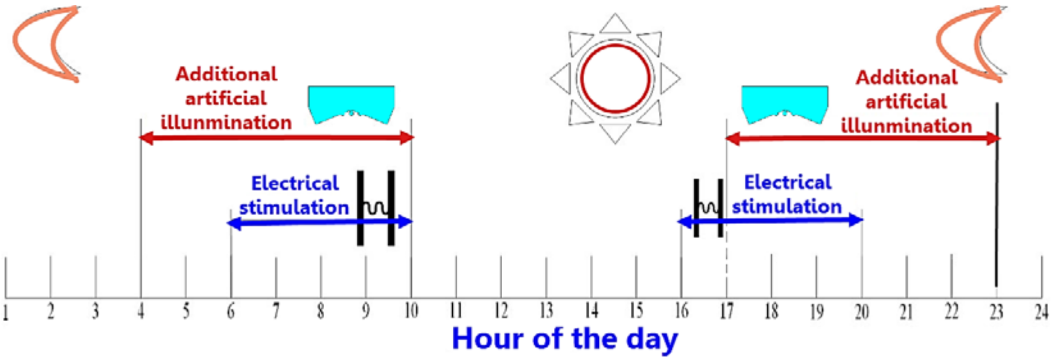


Figure 4: Schematic of the experiment of additional artificial light and electrical stimulation.

The experiment lasted 40 days. Seedlings began to appear on days 7-14. At the end of the experiment, all plants were cut at soil level, measured along the length of the aboveground part and mass.

Figure 5: General layout of plants by variants and replicates.

During the experiment, plants were watered using a measuring cup with the same volume of water. The volume of water depended on environmental factors (temperature and humidity) and changed during the experiment, but it was the same for all variants.

At the end of the experiment, the plants' height and the mass of their green (aboveground) parts were measured. Table 2 shows the results of measurements of plant heights only.

Figure 6: Results of measurements when investigating the optimal electric field strength

Table 2: The results of measuring the height of dill plants for option V1

Repetition number	Plant number in the i-th replication			Average repeat height, mm	Average height according to variant V1, mm
	1	2	3		
1	181	175	192	182.67	179.92
2	179	170	168	172.33	
3	155	199	161	171.67	
4	195	174	210	193.00	

The replicates of each variant are groups of dill plants grown in one glass. Accordingly, in each variant, there are four replicates. Each replication contains three plants (in some, two and one, since some did not emerge).

Table 2, the average plant height for variant V1 is 179.92 mm and does not correspond to this dill variety's expected height. The maximum replication height is 193 mm, and that of a single plant is 195 mm, which is closer to the standard value.

Table 3: Results of the analysis of experimental data for option V1

Repetition number	SD of replicates σ_r, mm	Coefficient of variation for replicates υ_r	SD by option V1 σ_{v1}, mm	Coefficient of variation by variant V1 υ_{v1}
1	8.62	0.05	16.30	0.09
2	5.86	0.03		
3	23.86	0.14		
4	18.08	0.09		

From the analysis of the data in Table 3, it can be seen that the coefficient of variation for the first and third replicates exceeds 5%. Moreover, in the third replication, it is 14%. The maximum standard deviation is close to 24 mm. That is, the plants of this experiment differ significantly from each other in height. Option V1 was carried out with the lowest field strength.

The plant height must be comparable to the control, i.e., with non-stimulated plants. However, the variation coefficient is significantly higher than in the control $\upsilon_{V1} >> \upsilon_C$. Stimulation with a weak electric field gives the opposite effect - there is no increase in height, but the variation increases.

The table's data indicate that the average height of the green mass, which is 264.7 mm, exceeds the control, but not significantly. That is, stimulation with a field strength of 0.75 kV/m is not effective.

According to the V2 variant, the plants have a significantly higher height than in the V1 variant, more precisely, 162.08 mm more. That is, the result of stimulation, in this case, manifested itself significantly. Also, the plant height significantly exceeds the plant height in control (180 mm).

Table 4: The results of measuring dill plants in height, according to option V2

Repetition number	Plant number in the *i*-th replication			Average repeat height, mm	Average height according to V2 option, mm
	1	2	3		
1	368	362	346	358.67	345
2	360	348	356	354.67	
3	311	344	320	325.00	
4	352	341	332	341.67	

Table 5: Results of the analysis of experimental data for option V2

Repetition number	The standard deviation of replicates σ_r, mm	Coefficient of variation for replicates υ_r, %	Standard deviation according to variant V2 σ_{V2}, mm	Coefficient of variation for variant V2 υ_{V2}, %
1	11.37	0.03	17.03	0.05
2	6.11	0.02		
3	17.06	0.05		
4	10.02	0.03		

Data analysis Table 5 shows that the coefficient of variation for option V2 is 5%, which is less than for control and option V1. That is, the plants, according to this option, are more aligned in height. Simultaneously, in the second replication, it is significantly less than in the control and is only 2%.

Table 6: Results of measuring dill plants in height, according to variant V3

Repetition number	Plant number in the *i*-th replication			Average repeat height, mm	The average height for the V3 option, mm
	1	2	3		
1	358	380	379	372.3	378.1
2	382	374	371	375.7	
3	395	375	360	376.7	
4	381	392	390	387.7	

That is, the plants are well aligned and have a good presentation. Moreover, in all individual replicates, the variation coefficient does not exceed 5%; incentives for this option are quite acceptable and have a positive effect. The average height of the green mass, according to this experience, is 378.1 mm, which significantly exceeds the control by 197.33 mm, and also exceeds the indicators of the previous variants V2 and V1. Stimulation with a tension of 37 kV / m has the greatest positive effect on plant growth. Stimulation with these parameters is most effective.

Table 7: Results of the analysis of experimental data for option V3

Repetition number	SD of replicates σ_r, mm	Coefficient of variation for replicates υ_r, %	SD according to V3 variant σ_{V3}, mm	Coefficient of variation for variant V3 υ_{V3}, %
1	12.42	0.03	11.51	0.03
2	5.69	0.02		
3	17.56	0.05		
4	5.86	0.02		

An increase in the growth rate of plants, in this experiment, is accompanied by a significant decrease in the coefficient of variation, which is 3%, which is approximately 5% lower than in the control.

It is also important that a low level of the standard deviation of plant height (11.51 mm) was obtained for the variant as a whole. It indicates the best uniformity of plant heights throughout the experiment. The greatest increase in the standard deviation was observed in the third replication - 17.56 mm. In this replication, one of the plants reached a record height of 395 mm.

Thus, stimulation of plants with an electric (electromagnetic) field of medium intensity allows the plants to be aligned in height and obtain maximum biomass growth for a given experiment.

Table 8: Results of measuring the height of dill plants according to option C

Repetition number	Plant number in the i-th replication			Average repeat height, mm	The average height for the C option, mm
	1	2	3		
1	186	175	181	180.67	180.75
2	177	169	173	173.00	
3	158	195	166	173.00	
4	195	184	210	196.33	

The average plant height in the control for the variant is comparable to the plant height for the V1 variant and it is significantly less than in the V2 and V3 variants.

The plants in control, without stimulation, and plants of the V1 variant, which were stimulated by the low-intensity field, have a comparable increase in biomass.

Table 9: Results of the analysis of experimental data for option C

Repetition number	SD of replicates σ_r, mm	Coefficient of variation for replicates υ_r, %	SD by option C σ_C, mm	Coefficient of variation for option C υ_C, %
1	5.51	0.03	14.40	0.08
2	4.00	0.02		
3	19.47	0.11		
4	13.05	0.07		

In the control experiment, the coefficient of variation was unexpectedly high, amounting to 8%. Such a high value was because the plants have a significant variation in height, and, as a result, a large standard deviation of 14.4 mm, while the average value of the plant height is also not large.

For a visual presentation of the results of the analysis of experimental data, graphs and histograms (diagrams) reflecting the height of plants by variants and replicates, coefficients of variation v and standard deviations σ by variants and replicates, as well as by mean values in each variant, including control (Figures 5-7). The investigated options on the diagram are arranged in the same order they were located during the experiment (Figure 5). That is, they arranged in decreasing order of the electric field strength. This arrangement is necessary to reduce the influence of the electric field on the control variant.

In the diagram (Figure 6), the total plant height for variant V3 is almost 1500 mm and exceeds all other variants. In terms of replicates, the highest height is observed in the 4th replication for all variants. It may be because this replica was located closest to the source of natural light.

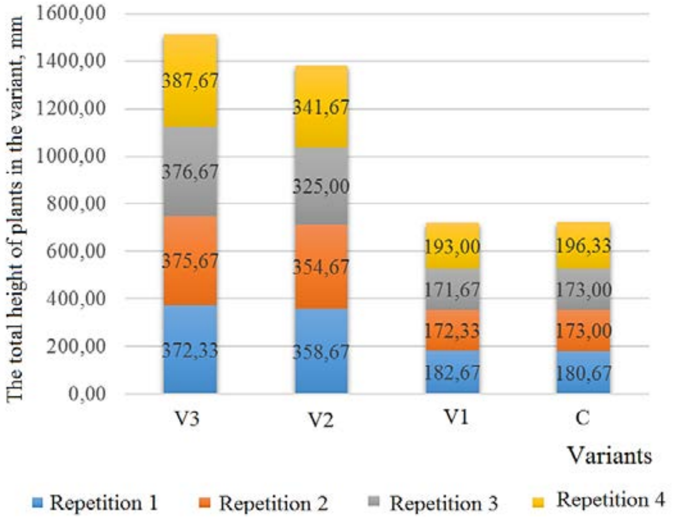


Figure 7: Distribution of plants by height by replicates, variants, and total in each variant

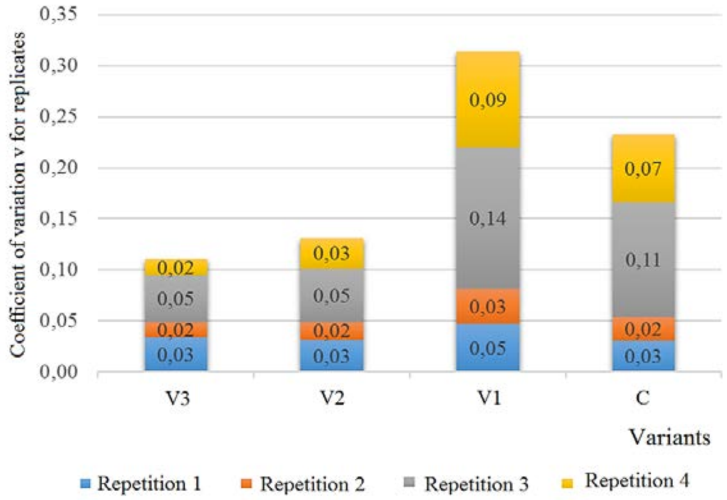


Figure 8: Change in the coefficient of variation υ for variants and replicates in the variants

The greatest value of the coefficient of variation is observed in the third replication for all variants. The reason for this is not yet known. The third replicate was located closer to the center of the container. The illumination level and field strength did not differ from the neighboring replicates.

In the control experiment, there was also a significant scatter in the coefficients of variation in replicates, from 2-11%. The reason for this is not yet clear, since all control replicates were located next to each other.

Diagram Figure 9 is the most informative for assessing the effectiveness of incentives. The diagram compares such parameters as plant height, coefficient of variation, and standard deviation by options.

Diagram Figure 9 shows that the best result was obtained in the V3 variant. On average 378.08 mm, the coefficient of variation was only 3% with the highest plant height.

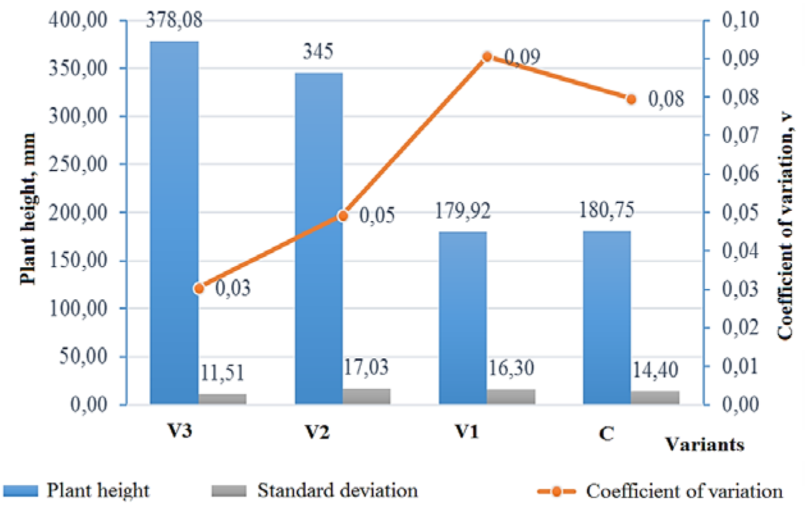


Figure 9: The distribution of the coefficients of variation ν and SD σ by options

The worst results are observed in the 1st variant V1. With a plant height of only about 180 mm, the coefficient of variation reached 9%.

In this study, the effectiveness of stimulation was assessed by the state of the aboveground green part of plants. Simultaneously, not for all vegetable crops, such as tomatoes, the growth of biomass is not important, but, for example, it is fundamentally important for green vegetable crops.

4. CONCLUSION

Plants of green and vegetable crops, being under the influence of an electric field, begin interacting with it. The nature of the interaction is largely determined by the nature and nature of the field: electric or magnetic; constant, pulsating, or variable. It was theoretically established that the substances of biological objects - plants, interacting with a pulsating electric field, create two types of current - through and polarizing. Electric currents and magnetic fields affect the intensity of movement of substances (which are electrolytes) in the plant body. Ultimately, this should lead to an acceleration of photosynthesis and, as a consequence, an accelerated growth of plant biomass. The most effective is stimulation with an electric (electromagnetic) field of medium intensity. It allows for alignment of the plants in height, which is fundamentally important in producing green vegetable products for sale and obtaining a significant increase in biomass compared to control. A pulsating electric (electromagnetic) field of a positive direction on plants has a positive effect. It is an environmentally friendly way and can be used in the production of green vegetable crops.

5. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

6. REFERENCES

[1] Yudaev, I.V., Charova, D.I., Feklistov, A.S. (2017). Growing lettuce in LED irradiation. *Sel'skiy mekhanizator*, 1, 20-21.

[2] Vasilev, S.I., Mashkov, S.V., Syrkin, V.A. (2018) Results of studies of plant stimulation in a magnetic field. *Journal of Pharmaceutical, Biological and Chemical Sciences*, 9(4), 706-710.

[3] Kasakova, A.S., Yudaev, I.V., Fedorishchenko, M.G. (2018). New approach to study stimulating

effect of the pre-sowing barley seeds treatment in the electromagnetic field. *OnLine Journal of Biological Science, 18*(2), 197-207.

[4] Yudaev, I., Ivushkin, D., Belitskaya, M., Gribust, I. (2019). Pre-sowing treatment of ROBINIA PSEUDOACACIA L. seeds with electric field of high voltage. *IOP Conference Series: Earth and Environmental Sciences*. 403(1), article # 012078.

[5] Budnikov, D.A., Vasiliev, A.N., Vasilyev, A.A. (2019). The Application of Electrophysical Effects in the Processing of Agricultural Materials. *Advanced Agro-Engineering Technologies for Rural Business Developments*, 1-27.

[6] Lartsev, V.V. (2005). *Method of electrical stimulation of plant life*. Patent 2261588 Russian Federation.

[7] Loginov, V.V. (1999). *Method for stimulating plant growth in greenhouses*. Patent 2182759 Russian Federation.

[8] Nugmanov, S.S., Gridneva, T.S., Vasiliev, S.I., Fatkhutdinov, M.R. (2015). Improvement of electrophysical methods and technical means for control and impact on agricultural objects. Research report (intermediate), 49 p.

[9] Nugmanov, S.S., Gridneva, T.S., Vasiliev, S.I., Fatkhutdinov, M.R. (2018). Improvement of electrophysical methods and technical means for control and impact on agricultural objects. Research report (final), 160 p.

[10] Vasiliev, S.I., Mashkov, S.V., Fatkhutdinov, M.R. (2016). Electromagnetic stimulation of seeds and plants. *Sel'skiy mekhanizator*. 7, 8-9.

[11] Vasiliev, S.I., Mashkov, S.V., Syrkin, V.A., Gridneva, T.S. (2018). Development of intensive technology and technical means (biomodule) for the production of organic vegetable products. *Innovative achievements of science and technology of the agro-industrial complex*. Kinel, Russia, 576-579.

Sergey Mashkov is an Associate Professor and Acting Rector of the Samara State Agrarian University. He is a Candidate of Economic Sciences. His research interests are Economic Assessment of Agricultural Machinery in Crop Production Technology

Sergey Vasil'ev is, an Associate Professor of the Department of Electrification and Automation of the agro-industrial complex. He is a Candidate of Technical Sciences. His research interests are Electrical Engineering and Electronics, Electrical Networks and Systems, Electrical Materials.

Marat Fatkhutdinov is an Associate Professor of the department of Electrification and Automation of the Agro-Industrial Complex. He is a Candidate of Technical Sciences. His research interests are Electrical Equipment Operation.

Tat'yana Gridneva is an Associate Professor of the Department of Electrification and Automation of the Agro-Industrial Complex. She is a Candidate of Technical Sciences. Research interests: Power Supply, Automation