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DEVELOPMENT OF TECHNICAL MEANS TO IMPROVE THE PRODUCTION OF HYDROPONIC

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ABSTRACT

Obtaining feed on a hydroponic basis is associated with significant energy costs, and therefore the development of technical means to reduce energy intensity and increase the intensity of hydroponic feed production is an urgent task. In this regard, it is advisable to electro treat germinating seeds, which allows you to increase the susceptibility of seeds to exposure and overcome their biological diversity. For sprouting seeds, a two-phase electrical treatment is proposed, including polarizing and electrifying treatment in permanent electric fields. To implement the proposed two-phase electrical treatment of germinating seeds, an electrode system consisting of two grounded-plate electrodes and a potential "needle on the plane" electrode was developed. Based on theoretical and experimental research, a fundamentally new plant has been developed that allows continuous processing of germinating seeds in permanent electric fields, the novelty of which is confirmed by a patent. The conducted research has shown the technical and economic efficiency of using two-phase processing of germinating seeds in hydroponic feed production.

Disciplinary: Food and Agricultural Sciences (Hydroculture Science).

1. INTRODUCTION

Hydroponic fodder production, which does not involve soil resources and contributes to the production of environmentally friendly, rich in vitamins, well digestible feed, is promising in modern conditions. When using hydroponic green fodder, it becomes possible to specialize in field crop production in the intensive production of grain crops, from which you can get highly nutritious, fresh forage all year round. This leads to a sharp reduction in nutrient losses during the storage of the initial biomass and to increase the stability of the animal feed supply. The introduction of hydroponic green biomass in the diet of animals helps to reduce the number of painful phenomena and improve the general condition of animals. Keeping animals on clean feed leads to the elimination of radionuclides from their body, eliminates the accumulation and formation of harmful and dangerous substances that can cause damage to human health (Atmadja, et al., 2018; Basarygina et al., 2019; Kang et al., 2017; Khoneva et al., 2018; Kline et al., 2017).

Hydroponic green fodder (HGF) is a “carpet” of young, green sprouts grown from a layer of seeds of grain crops (Kruglyakov, 1991). When using hydroponic production of plant mass, it becomes possible not to use the soil composition of the zone, which makes hydroponic cultivation of biomass the basis for the production of feed in areas with disturbed environmental conditions relevant and of great practical importance. The agrobiological basis for the cultivation of HGF is the process of seed germination, the initial stages of which are characterized by certain physiological and biochemical transformations that occur during the transition of seeds from the resting stage to the normal growth stage (Medvedev, 2013). According to various researchers, on the sixth to the tenth day of cultivation, the chemical composition of seedlings differs significantly from the composition of the original seeds. There is an increase in the content of protein, calcium, and phosphorus, vitamins E and group B, as well as the formation of carotene, vitamins C, PP, to others. A typical technological process of growing HGF contains a number of successive stages: preparation (preliminary germination) of seed material; distribution of seed over the vegetation surface of the germination (sowing); growing green seedlings; harvesting the grown fodder mass and feeding it to farm animals. The end result of the process of functioning of the equipment, determining its effectiveness, is to obtain the necessary amount of gas-cooling equipment (Ku et al., 2018; Lamba et al., 2017; Nay-Htoon et al., 2018; Rouphael et al., 2018; Saha et al., 2018; Zeleňáková et al., 2017; Blednykh et al., 2003).

The year-round production of hydroponic green fodder, carried out under controlled conditions (protected ground conditions), is associated with significant costs. In this regard, the development of technical means that intensify hydroponic fodder production is an important task.

The realization of the seeds of their potential possibilities depends on the activity of the processes of germination. Currently, various methods have been proposed for activating seed germination: chemical, physiological, physical and combined. Physiological methods, which are based on the influence of natural factors (water and temperature conditions), lead to a reduction in the duration of the hidden germination of seeds, that is, the time interval between the beginning of soaking and hatching. Soaking seeds in solutions of osmotically active substances, the introduction of biologically active substances in the form of suspensions and aerosols are chemical activation methods. The vast majority of the proposed physical effects are divided into three groups: thermal, mechanical and electromagnetic. Moreover, the effects related to the first two groups: seed exposure at low temperatures (scarification), violation of the integrity of the seed coat at low temperatures (stratification) are aimed mainly at reducing the duration of hidden seed germination. Electromagnetic effects, in turn, are divided into electrical, magnetic, optical, and nuclear - according to the application of various sections of the spectrum of electromagnetic fields. The basis of electrical physical influences (PI) is the electrical component of electromagnetic waves. Of this group, the use of constant electric fields is most developed.

The analysis of publications revealed that seed treatment in electric fields is promising since it allows you to create the necessary conditions for the seeds to realize their potential. For air-dry seeds in a state of physiological dormancy, activating doses of energy are greater than for seedlings and vegetative plants, and therefore preliminary germination of seeds before electric treatment is advisable, as it allows to increase their susceptibility to exposure, as well as to overcome biological diversity seeds at the time of electric exposure, characteristic of air-dry seeds. The technology of growing hydroponic green fodder allows for the electrical treatment of germinating seeds since it includes the operation of preliminary germination, and growing fodder under controlled environmental conditions contributes to the maximum realization of the positive effect of electrical exposure.

For seeds that have entered the germination stage and thereby partially activated, it is advisable to reduce the energy pressure. When using the proposed two-phase electric treatment of germinating seeds, such a reduction is achieved as a result of the use of the polarization treatment in the first phase, and the treatment of seeds in the final phase. In this case, constant electric fields have different intensities: the electrostatic field strength is lower than the corona discharge field strength. To implement the proposed two-phase electrical treatment of germinating seeds, an electrode system was developed consisting of two grounded plate electrodes and one potential needle on a plane. This electrode system allows you to create a uniform electrostatic field in one interelectrode space, and a corona discharge field in another. When choosing modes of exposure to germinating seeds, the requirement was met according to which the maximum dose from electrophysical exposure should not exceed the values tested in previous studies for air-dried seeds. To this end, the intensity of the electrostatic field was determined and the response of seeds (yield of feed biomass) to the proposed two-phase electric treatment was studied.

2. MATHEMATICAL MODEL

As a mathematical model of the response of seeds to the proposed two-phase electric processing, a polynomial of the second degree was adopted

$$Y = b_a + \sum_{i=1}^{n} b_i X_i + \sum_{i=1}^{k-1} \sum_{j}^{k} b_{ij} X_{ij} + \sum_{1}^{k} b_{i1} X_1^2 \qquad (1),$$

$$(j \triangleright 1)$$

where b_a, b_i, b_{ij}, b_{il} are the coefficients of the polynomial, X_i, X_j - values of the factors given in the coded form.

When processing seeds in an electrostatic field, their layer is placed on a dielectric plate between two electrodes. The study of the influence of the relative dielectric constant of seeds on the electric field in their layer is reduced in this case to the determination of the tension in different layers of a flat multilayer capacitor. After the necessary transformations, the expression for the electrostatic field strength in the seed layer (E_2, B) is obtained

$$E_2 = \frac{U}{(X_1\varepsilon'_2 - X_1 + 1)\left[d_1 + \dfrac{d_2}{X_1\varepsilon'_2 - X_1 + 1} + \dfrac{d_3}{\kappa_2\varepsilon_{32} + \kappa_1} + \dfrac{d_4}{\varepsilon_4} + d_5\right]} \qquad (2),$$

where U is the applied voltage; X_1 is the concentration of seeds in the air-seed mixture; ε_2 - relative dielectric constant of seeds; ε_{31}, ε_{32} - relative dielectric constant of air and cellular material, respectively; ε_4 is the relative dielectric constant of the dielectric plate; d_1 ... d_5 - the distance between the plates of the capacitors; κ_1, κ_2 - coefficients depending on the area of the replacement capacitors.

3. STUDY DETAILS

3.1 MATHEMATICAL MODEL

Upon receipt of the mathematical model (2), the problem associated with the series connection of capacitors was solved. In this case, the space between the plates of the first capacitor is filled with air (C_1); the space between the plates of the second capacitor is filled with an air-seed mixture (C_2); the cellular tape is represented by a parallel connection of 2 capacitors: between the plates of the first capacitor there is air (C_{31}), the second - dielectric material (C_{32}); the space between the plates of the fourth capacitor is filled with dielectric material (C_4); the space between the plates of the fifth capacitor is filled with air (C_5).

For a series connection of capacitors, the following expressions are valid

$$\frac{1}{C_\Sigma} = \sum_{i=1}^{n} \frac{1}{C_i} \quad (3);$$

$$q = const \quad (4);$$

$$U_\Sigma = \sum_{i=1}^{n} U_i = q\sum_{i=1}^{n} \frac{1}{C_i} \quad (5).$$

When connecting capacitors in series, the formulas are used

$$q_\Sigma = \sum_{i=1}^{n} q_i = U\sum_{i=1}^{n} C_i \quad (6);$$

$$C_\Sigma = \sum_{i=1}^{n} C_i \quad (7);$$

$$U = const \quad (8).$$

For the case under consideration, the total capacitance of a flat multilayer capacitor is determined by the formula

$$C = \frac{C_1C_2C_3C_4C_5}{C_2C_3C_4C_5 + C_1C_3C_4C_5 + C_1C_2C_4C_5 + C_1C_2C_3C_5 + C_1C_2C_3C_4} \quad (9),$$

because of the

$$\frac{1}{C_\Sigma} = \sum_{i=1}^{5} \frac{1}{C_i} \quad (10).$$

The capacitance of a flat capacitor is calculated by the well-known expression

$$C = \frac{\varepsilon\varepsilon_0 S}{d} \quad (11)Á$$

where ε_0 is the absolute dielectric constant; ε is the relative dielectric constant of the medium; S is the capacitor plate area; d is the distance between the plates.

Taking into account the last expression after performing the necessary transformations, the expression is used to determine the total capacity of a flat five-layer capacitor.

$$C_{\Sigma} = \frac{\varepsilon_0 S}{d_1 + \dfrac{d_2}{\varepsilon_2} + \dfrac{d_3}{\kappa_1 \varepsilon_{31} + \kappa_2 \varepsilon_{32}} + \dfrac{d_4}{\varepsilon_4} + d_5} \quad (12),$$

where ε_2 - relative dielectric constant of seeds; $\varepsilon_{31}, \varepsilon_{32}$ - relative dielectric constant of air and cellular material, respectively; d_1 ... d_5 - the distance between the plates of the capacitors; κ_1, κ_2 - coefficients depending on the area of the replacement capacitors C_{31} and C_{32}.

The dielectric constant of the seed layer is calculated by the formula of Lichteneker

$$\varepsilon_{cm}{}^{\kappa} = X_a \varepsilon_a{}^{\kappa} + (1 - X_a)\varepsilon^{\kappa}{}_b \quad (13),$$

where ε_{cm} is the relative dielectric constant of the mixture; $\varepsilon_a, \varepsilon_b$ is the relative dielectric constant of seeds and air, respectively; X_a is the concentration of the first component; κ is a power exponent.

The power exponent κ is determined by the location of the components. When the electric field vector is directed along with the layers ($\kappa = 1$), the Lichteneker equation takes the following form, taking into account the previously accepted notation

$$\varepsilon_2 = X_1 \varepsilon'_2 + (1 - X_1)\varepsilon_1 = X_1 \varepsilon'_2 + 1 - X_1 \quad (14),$$

where ε_1, is the relative dielectric constant of the air; ε_2 is the relative dielectric constant of seeds.

Given the expressions obtained, the total capacitance of a flat multilayer capacitor can be determined by the formula (Leshchenko, 2006; Leshchenko and Sazonov,2011; Leshchenko, et al., 2017; Leshchenko, et al., 2015; Leshchenko, et al., 2014)

$$C_{\Sigma} = \frac{\varepsilon_0 S}{d_1 + \dfrac{d_2}{X_1 \varepsilon'_2 - X_1 + 1} + \dfrac{d_3}{\kappa_2 \varepsilon_{32} + \kappa_1} + \dfrac{d_4}{\varepsilon_4} + d_5} \quad (15).$$

The charge on the plates of a flat multilayer capacitor is equal to

$$Q = \frac{\varepsilon_0 S U}{d_1 + \dfrac{d_2}{X_1 \varepsilon'_2 - X_1 + 1} + \dfrac{d_3}{\kappa_2 \varepsilon_{32} + \kappa_1} + \dfrac{d_4}{\varepsilon_4} + d_5} \quad (16);$$

Where U is the applied voltage.

The surface charge density σ is

$$\sigma = \frac{\varepsilon_0 U}{d_1 + \dfrac{d_2}{X_1 \varepsilon'_2 - X_1 + 1} + \dfrac{d_3}{\kappa_2 \varepsilon_{32} + \kappa_1} + \dfrac{d_4}{\varepsilon_4} + d_5} \quad (17).$$

In the general case of a flat multilayer capacitor (n - layers), the expression

$$E_j = \frac{U}{\varepsilon_j \sum_{i=1}^{n} \dfrac{d_i}{\varepsilon_i}} \quad (18);$$

Where E_j is the field strength in the j - dielectric layer $(i \le j \le n)$, d_i is the thickness of an individual layer; ε_i is the dielectric constant of a single layer.

For the case under consideration, the tension in the seed layer will be

$$E_2 = \frac{U}{(X_1\varepsilon'_2 - X_1 + 1)\left[d_1 + \frac{d_2}{X_1\varepsilon'_2 - X_1 + 1} + \frac{d_3}{\kappa_2\varepsilon_{32} + \kappa_1} + \frac{d_4}{\varepsilon_4} + d_5\right]} \qquad (19).$$

The voltage drop in the seed layer is

$$U_2 = \frac{Ud_2}{(X_1\varepsilon'_2 - X_1 + 1)\left[d_1 + \frac{d_2}{X_1\varepsilon'_2 - X_1 + 1} + \frac{d_3}{\kappa_2\varepsilon_{32} + \kappa_1} + \frac{d_4}{\varepsilon_4} + d_5\right]} \qquad (20).$$

Using the obtained expressions, the values of the total capacitance of a flat multilayer capacitor were calculated; capacitor charge; surface charge density; voltage drop in the seed layer; electric field strength in the seed layer; energy costs for charging the capacitor when changing the moisture content of the seeds and their dielectric constant in the range of 5 ... 100. The relative dielectric constant was adopted: $\varepsilon_1 = \varepsilon_5 = 1$; $\varepsilon'_2 = 5, 25, 50, 75, 100$; $\varepsilon_{31} = 1$; $\varepsilon_{32} = 4{,}2$; $\varepsilon_4 = 5$. The values of d are taken in accordance with the design parameters of the considered system of electrodes. Based on practical experiments $X_1 = 0{,}5$.

The energy efficiency of hydroponic feed production technologies was estimated using well-known expressions.

3.2 FACTORS

To obtain a mathematical model of the response to the proposed two-phase electric seed treatment, experiments were carried out using the active planning technique. The suppressive voltage to the electrodes in Table 1.

Table 1: Factors taken to build a three-level plan.

Factors are taken to build a three-level plan		Name of factors	Levels of variation			Transition Formula
coded	real		upper	lower	base	
x_1	t	electrical exposure time	2	4	3	$t = x_2 + 3$
x_2	U	voltage applied to the electrodes	30	20	25	$U = 5\,x_1 + 25$

The interelectrode distance for electrodes of the electrostatic field was 25 cm, for electrodes of the corona field — 10 cm. The exposure time for the seeds was distributed as follows. At an exposure time of two seconds, the seeds were 1 second in the electrostatic field (EF) and 1 second in the corona discharge pole (CDP). At an exposure time of three seconds, the seeds were 1 second in the CDP and 2 seconds in the EP. At an exposure time of four seconds, the seeds were two seconds in an electrostatic field and corona discharge.

4. RESULT

The results to the developed electrode system are presented in Figures 1-3. The design parameters of the corona electrode and the interelectrode distance were adopted based on the results of previous studies: the distance between the needles is 20 mm; the distance between the rows of needles is 35 mm; needle length - 15 mm; the location of the needles is chess; interelectrode distance - 100 mm (for corona discharge).

Figure 1 presents the results of determining the response of seeds to the proposed two-phase electrical treatment.

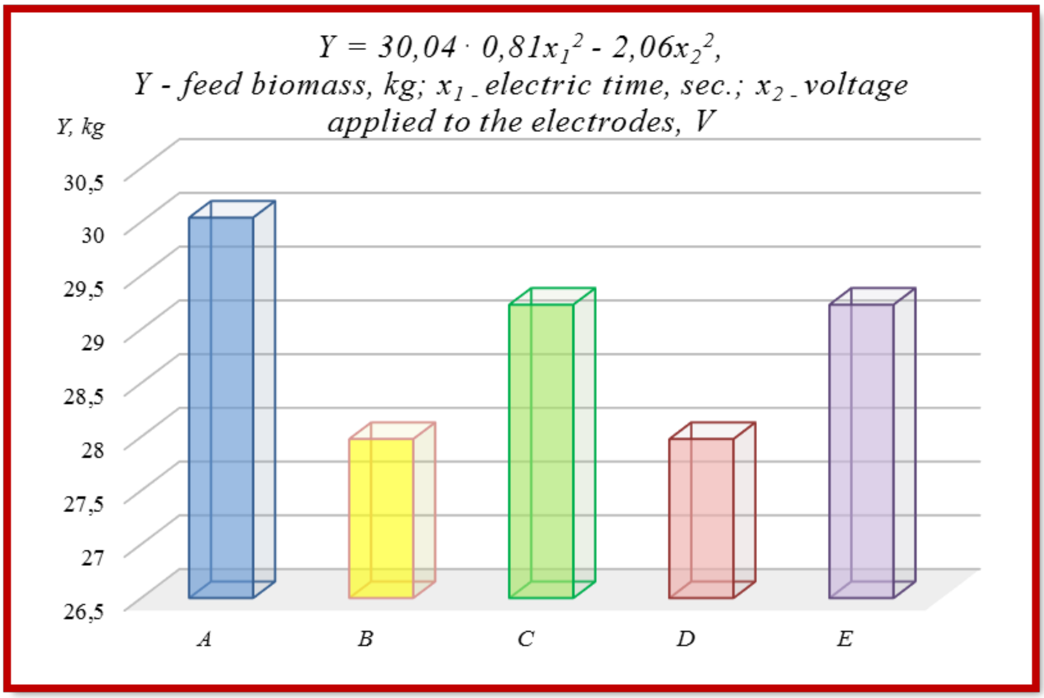

Figure 1: The response of seeds to the proposed two-phase electrical treatment: A - basic level of factors; B - base level of factor X_1, lower level of factor X_2; C - base level of factor X_2, lower level of factor X_1; D is the base level of factor X_1, the upper level of factor X_2; E is the base level of factor X_2, the upper level of factor X_1.

Figure 2 shows the following characteristics of the developed electrode system: the total capacitance of a flat multilayer capacitor; capacitor charge; surface charge density; voltage drop in the seed layer; electric field strength in the seed layer; energy consumption for charging the capacitor when changing the moisture content of the seeds and their dielectric constant in the range of 5 ... 100.

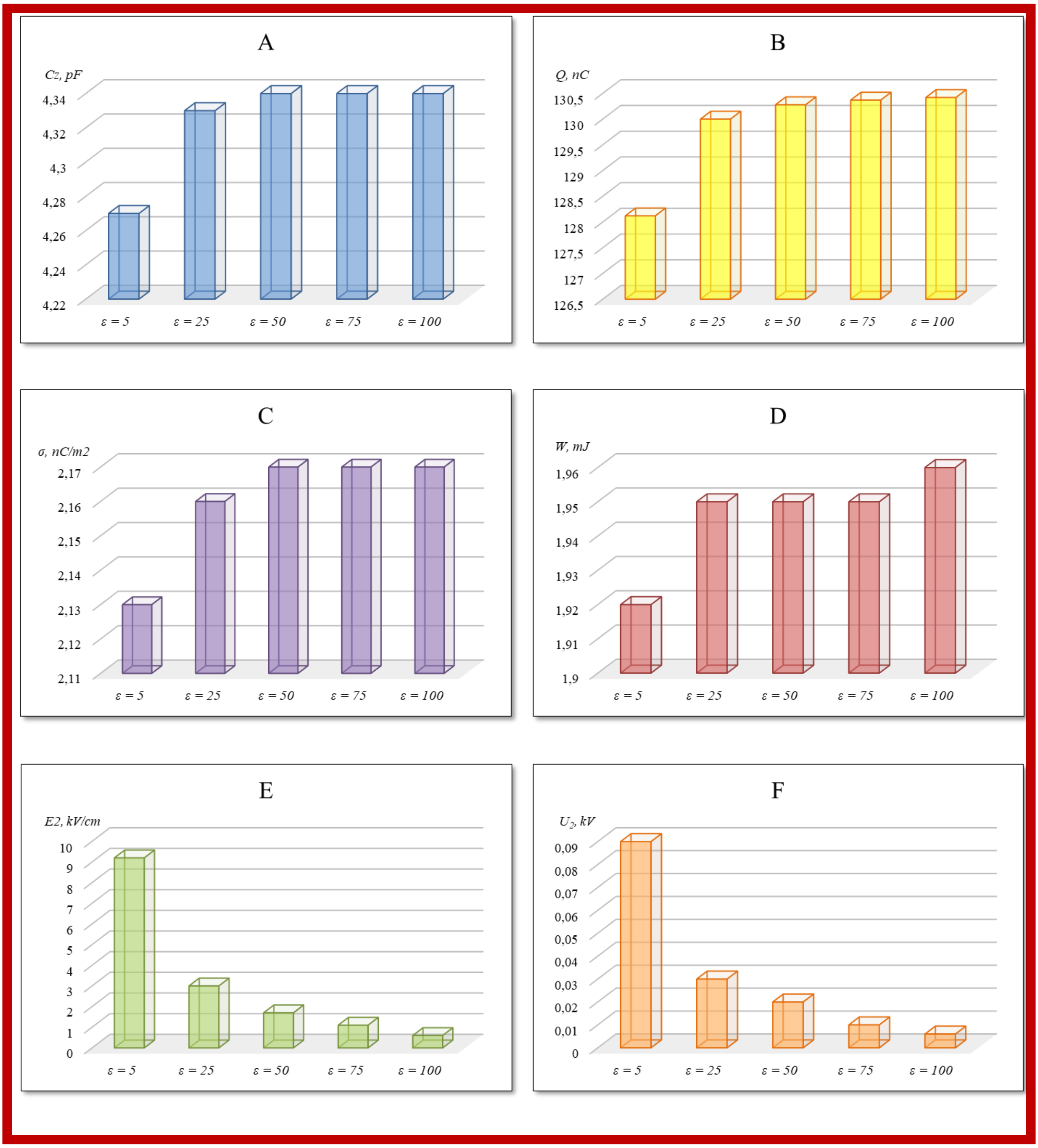

Figure 2: Characteristics of the developed electrode system for treating germinating seeds. A - Capacitor capacity; B – Charge; C - Surface charge density; D - The energy spent on charging the capacitor; E - Electrostatic field strength in the seed layer; F - Volt

Figure 3 shows the results of an energy assessment of hydroponic feed production technologies. The proposed technology included two-phase electrical treatment of germinating seeds. In basic technology, this operation was absent.

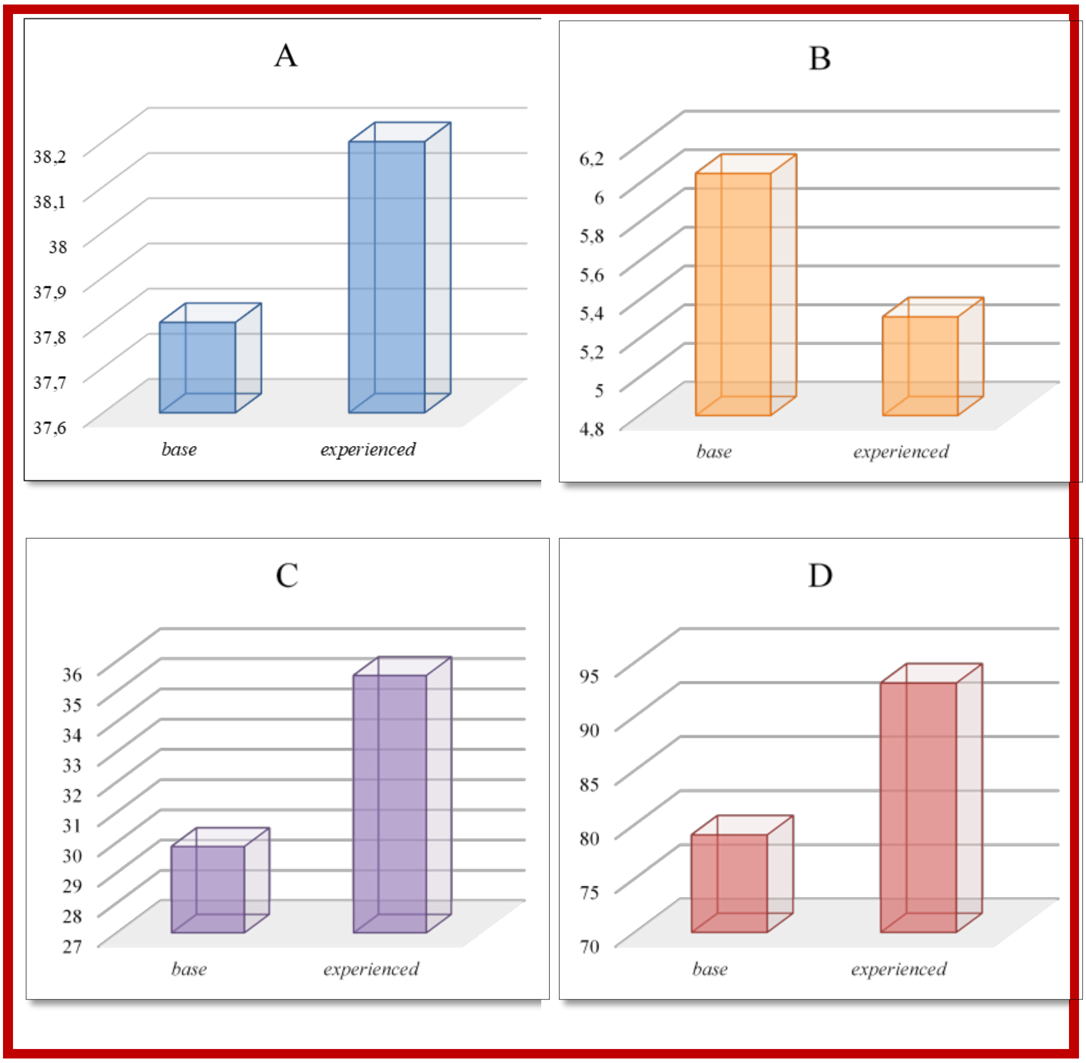

Figure 3: Energy assessment of the proposed and basic hydroponic forage production technologies: A - total specific energy consumption for the cultivation of agricultural crops, MJ/m^2; B - specific energy consumption for the cultivation of agricultural crops, M J/t; energy intensity (energy content) of the obtained products, MJ/m^2; energy efficiency coefficient,%.

5. DISCUSSION

From the analysis of the obtained mathematical model (Figure 1), it follows that the biomass of the feed obtained by two-phase electrical treatment of germinating seeds depends on both varied factors, and the second factor (X_2 is the voltage supplied to the electrodes) depends to a greater extent. An increase in seed response is observed with a decrease in both the first and second factors in the selected range (Table 1). According to the canonical form of the equation of the mathematical model ($y – 30{,}04 = - 0.81\ X_1^2 - 2.06\ X_2^2$) of the seed response, the appearance of a surface of equal level and a stationary point is determined. The view of surfaces of equal level is an ellipse, the view of a stationary point is a maximum. Therefore, in order to achieve the greatest response of germinating seeds to electric processing, it is necessary to take an exposure time of three seconds: two seconds in an electrostatic field; one second in the corona discharge field. The voltage supplied to the electrodes is 25 kV; electrostatic field strength 1 kV/cm; field strength of the corona discharge 2,5 kV/cm; corona current 7,2 μA; current density 102 x 10^{-9} A/cm^2. In this case, the control level exceeded the yield of hydroponic green fodder biomass by 10-15%. The control level is the absence of two-phase electrical treatment of germinating seeds.

An analysis of the results obtained related to the characterization of the developed electrode system (Figure 2) allows us to conclude that the total capacitance of the capacitor increases with increasing ε within 1.8%. The capacitor charge increases by 1.8%, the surface charge density - by 1.8%, that is, these values change slightly with increasing seed moisture and they are dielectric constant.

The energy spent on charging the capacitor increases by 0.0346 mJ (1.8%), that is, the energy costs for processing wet seeds increase slightly compared to air-dried seeds.

The electric field strength in the seed layer undergoes significant changes with increasing seed moisture and they are dielectric constant. There is a decrease in the voltage drop and electric field strength in the seed layer by 16.54 times with increasing ε from the minimum to the maximum value by 20 times.

A comparative energy assessment of the proposed and basic hydroponic feed production technologies allows us to conclude that the proposed technology, which includes two-phase electrical treatment of germinating seeds with the help of the developed electrode system, is more efficient (Figure 3) (Zakharova and Cherepukhina, 2007; Cherepukhina, 2012). In the proposed technology, by increasing the biomass yield of feed, the energy content of the resulting product increases by 5.66 MJ/m^2, the specific energy consumption decreases by 0.74 MJ/t and the energy efficiency coefficient increases to 93%.

Thus, the proposed two-phase electrical treatment of germinating seeds can be realized using the developed electrode system consisting of two grounded plate electrodes and a potential needle on a plane. This electrode system allows you to create a uniform electrostatic field in one interelectrode space, and a negative unipolar corona discharge field in another (Patent RU No. 38262). It was found that when the dielectric constant changes in the range $5 \leq \varepsilon \leq 100$ during seed germination, the electrostatic field decreases by 16-17 times. The optimal mode of electric processing was determined: exposure time 3 seconds (2 seconds in an electrostatic field, 1 second in a corona discharge field); voltage supplied to the electrodes, 25 kV; electrostatic field strength 100 kV/m; field strength of the corona discharge 250 kV/m; corona current 72 mA; corona current density of 0.1 μA/m^2. This mode of electrical treatment of germinating seeds increases the biomass yield by 12-15% compared with the basic version, in which there is no electrical processing of germinating seeds. Based on the theoretical and experimental studies, a fundamentally new installation has been developed that allows continuous processing of germinating seeds in constant electric fields, the novelty of which is confirmed by RU patent No. 38262.

Studies have shown the feasibility of using two-phase treatment of germinating seeds in hydroponic feed production. In the proposed embodiment, the biomass yield of hydroponic green fodder is increased by 12-15%. Due to this, there is a decrease in the energy intensity of production per unit of output by 0.17-0.19 MJ/t and an increase in energy efficiency by 10-12%.

6. CONCLUSION

Based on the materials presented, it can be concluded that, as a result of theoretical and experimental studies, new technical means have been developed: an electrode system and an installation for the electrical treatment of germinating seeds. The use of the developed technical means in hydroponic corporate production is useful because it allows you to increase the yield of the biomass of forage by 12-15%, reduce the energy intensity of production per unit by 0.17-0.19 MJ/t and increase energy efficiency by 10-12%.

7. AVAILABILITY OF DATA AND MATERIAL

Information can be made available by contacting the corresponding author.

8. ACKNOWLEDGMENT

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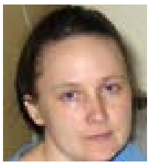

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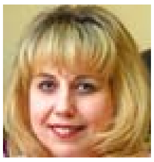

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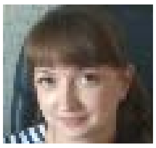

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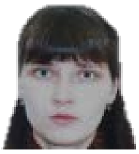

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