EFFICIENCY ESTIMATION OF TYPE OF THE ELECTRICAL EXPOSURE ON PLANTS AT THEIR PROCESSING

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Abstract. In variety of technological operations in agriculture and the processing industry to intensify processes associated with plants and plant raw materials, there are used effects of electromagnetic nature. Electrical effects on plants can be organized to stimulate their growth and development, increase yields, in order to achieve lethal damage to accelerate maturation, weed control and in-line weeding of crops, and to process vegetable raw materials for drying fruits, berries, vegetables and melons, increasing their juice yield during processing, etc. The action itself can be performed by means of electric and magnetic fields, various types and stages of electrical discharges, dissimilar electric currents: constant, pulse, alternating sinusoidal, alternating non-sinusoidal, currents with and without electric spark discharge, etc. Therefore, both from energy and technological points of view, it is interesting to represent the detection of the most effective type of electrical exposure acting on the plant or raw material. Basing on the results of experimental research and studying electric processing of sunflower, tobacco and various weed plants, there was compared efficiency of different current types (sinusoidal and pulsed) used in processing. Theoretical comparison of energetically equal sinusoidal and pulsed currents at exposing on plant tissues to achieve lethal (irreversible) damage made it possible to state that the electric treatment of plant objects by discharge voltage pulses is more effective than the action of energy equal to the sinusoidal voltage, while impulse action on plant tissue is more effective, than the impact of sinusoidal voltage in 1.7 times. The experimental verification completely confirmed the theoretical conclusions that the pulsed electric current, the depth of damage (damage degree) of tissues of different plants (tobacco, sunflower, weed plants) from which is more effective than the sinusoidal current for obtaining lethal, irreversible damage to plant objects in 1,3-3,4 times.

Key words: electric current, energy, impulse current, sinusoidal current, half of period, energetically equivalent values, damage degree, lethal (irreversible) damage.

1 Introduction

The electrical effect on plants can be carried out with the purpose of stimulating their growth, development, increasing yield and with the purpose of achieving lethal damage to accelerate the ripening sunflower and tobacco plants, drying fruit and vegetable crops, increasing the yield of fruit, berries, vegetables, etc., including hard-to-root and quarantine ones, etc. (Armyanov, N. 1999; Baev, V.I. 2002; Diprose, M.F. 1980; Kaufman, K.R. 1980; Недялков, Н. 1996; Reed J. 2009; Stankovic, M. 2016; Stankovic, M. 2012; Vigneault, C. 2001; Rodrigues, S., Fernandes, F.A.N. 2012; Jeyamkondan, S. 1999; Barsotti, L. 1999; Judajev, I.V. 2008; Yudaev, I.V. 2004; Yudaev, I.V. 2012). To achieve the technological effect of such processing, it is necessary to know the optimal parameters of the electric exposure: the amplitude value of the voltage, the repetition rate of the pulses or the acting current, the value of the electric or magnetic field strength in the plant tissue, the amount of energy absorbed by the tissue, and so on. But the initial research task is to determine the kind of impact that allows to achieve the set purpose of the electrical processing of plants or raw materials. The effect can be carried out by electric, electromagnetic and magnetic fields, various types and stages of electrical discharges, dissimilar electric currents: constant, pulsed, variable sinusoidal and variable non-sinusoidal, using an electric spark discharge and without it, etc. If to focus on impulse discharges and sinusoidal currents, as the most simply technically feasible electrotechnologies, then it is very important from the energy and technological point of view to identify the most effective of these impacts, which is the purpose of the research of the presented article. Let's consider the solution to this problem using the example of an electrical treatment to obtain a lethal tissue damage of sunflower and tobacco plants in order to increase ripening and drying of achenes, leaves and weeds to destroy them.

2 Methodology

Since the interaction of any damaging factor with a vegetable object, is energetic one, the amount of energy produced in a plant tissue is accepted as the criterion for the assessment of current type effectiveness (Baev, V.I. 2002; Yudaev, I.V. 2004; Yudaev, I.V. 2012). All variants of the impact by different types of current must be equal by energy. This means that the same patterns of plant stems should be fed with the same amount of energy by different sorts of currents and at that the energies released in tissues shall be compared: the efficiency of current type depends on the amount of energy.

In order to perform a comparison let's use a known equivalent electrical circuit of substitution and the conductive properties and parameters of a plant tissue (Baev, V.I. 2002; Cole, K.S. 1949; Zhang, M.I.N. 1990; Yudaev, I.V. 2012; Yudaev, I.V. 2004; Yudaev, I.V. 2012).

Due to the presence of plant tissue substitution of an electrical capacity and because of the possible polarization of the working electrodes constant current will be less effective than the AC and pulse currents, particularly at the beginning of processing, when the capacitive properties of the cell membranes are not broken yet. Therefore we compare further only two kinds of currents: pulse and alternating one. Alternating non-sinusoidal current because of the similarity with the sinusoidal one, the variety of possible options and the relative complexity of their production is not considered.

The voltage pulse was taken as a calculated one, which may be obtained on a pilot device, and which may be used then for the experimental verification of theoretical conclusions.

The comparison is conducted according to two basic options: 1) voltage pulse and sinusoidal voltage equivalent to it during a half of a period equal to the pulse duration (Fig. 1); 2) sinusoidal voltage during half a period with the frequencies of 50 and 400 Hz, and its equivalents in the amount of several voltage pulses (Fig. 2).

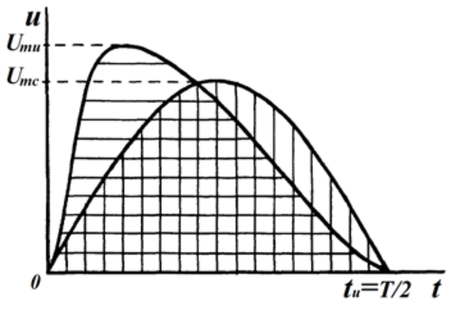

Figure 1: Equivalent voltage pulse and sinusoidal varying voltage during half a period equal to the pulse duration

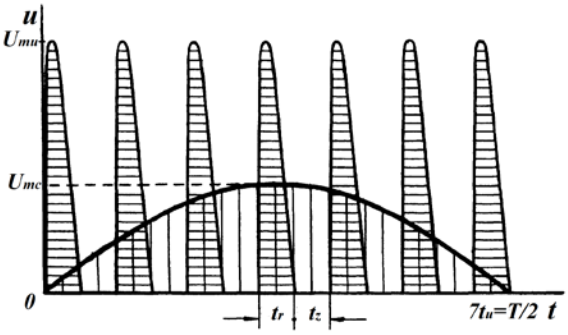

Figure 2: The half-sinusoidal voltage and its equivalent total voltage pulses

The equality of actual voltage values of these current types is taken for the criterion of energy equal voltage impulse and sinusoidal voltage is taken for half a period. Thus, for the comparison of the first option (Fig. 1) the operating values at the same duration of $4{,}5 \cdot 10^{-6}$s will be the following ones

$$U_u = \sqrt{\frac{\sum_1^k u_i^2 \cdot \Delta t_i}{t_u}}; \qquad U_C = \frac{U_{m_{''}}}{\sqrt{2}}. \qquad (1)$$

where U_u; U_c – acting value of voltages of impulse and sinusoidal currents, kV; U_{mc} – amplitude value of sinusoidal voltage, kV; t_u – pulse duration, s.

Based on their equality, the peak value of sinusoidal voltage may be calculated according to the following formula

$$U_{m_C} = \sqrt{2\frac{\sum_1^k u_i^2 \cdot \Delta t_i}{t_u}} = 2\sqrt{\frac{\sum_1^k u_i^2 \cdot \Delta t_i}{T}}. \qquad (2)$$

where T – period of sinusoidal current, s.

The energies absorbed by plant tissue will be determined by the expressions for the impulse excitation

$$W_u = \frac{\sum_1^k u_i^2 \cdot \Delta t}{R_u} \qquad (3)$$

and for the impact by sinusoidal voltage during half a period

$$W_C = \frac{1}{R_C}\int_0^{T/2} U_{m_C}^2 \cdot \sin^2 \omega t \cdot dt = \frac{U_{m_C}^2 \cdot T}{4R_C}. \qquad (4)$$

where W_u; W_c – amount of absorbed energy for pulsed and sinusoidal actions, J; R_u; R_c – equivalent resistance of the tissue during the action, respectively, of the voltage pulse and sinusoidal voltage, Ohm; ω – angular frequency of the current, rad / s.

The resistances R_u and R_c are the equivalent resistances of the fabric during the operation time, respectively, the voltage pulse and sinusoidal voltage. The value R_u is calculated according to the experimental oscillograms of current and voltage on the fabrics (Baev, V.I. 2002) and is equal to 190 ohms. From the oscillograms (2) we find that U_{mc}=7,81 kW.

According to the experimental current-voltage characteristic of sunflower plant tissue (2), for the average diameter of a sunflower stem in the 15 mm place of processing, we find the equivalent resistance of the stem R_c=280 Ohms.

The calculations according to (3) and (4) provide the values of W_u=0,8 J and W_c=0,47 J. These values indicate that the impulse effect on the plant tissue is 1,7 times more effective than the impact by sinusoidal voltage.

The practical interest is presented by the comparison of these currents initial impact on living plant tissue the capacitive properties of its cell membranes are not violated. In this case, the tissue resistance may be determined as the input impedance of its equivalent substitution circuit.

And using the same expressions (3) and (4) we obtain W_u=0,02 J and W_c=0,0177 J, i.e. and at the beginning of processing the pulse impact is more efficient than sinusoidal one by 13%.

For the second variant of comparison (Fig. 2) let's take the duration of exposure on the tissue equal to half period of the sinusoidal voltage at some low standard frequency f, such as 50 Hz or 400 Hz. Such frequencies should be considered because of the relative ease of the method practical implementation using standard power equipment as small power generators and transformers with such frequencies frequency are produced by industry.

During the half of the received frequency period the impact m will be provided for the tissue as in the first variant of pulses

$$m = \frac{T/2}{t_{зар} + t_{раз}}. \qquad (5)$$

where t_z; t_r – time of charge and discharge of capacitors in the discharge circuit of the generator of impulse voltages, s.

For these pulses the actual voltage will be the following one

$$U_u = \sqrt{\frac{\sum_1^k u_i^2 \cdot \Delta t_i}{t_{зар} + t_{раз}}}. \qquad (6)$$

For the equivalent sinusoid (Fig. 2) the current value should be the same, and its amplitude will be the following one

$$U_{m_C} = \sqrt{2}U_u = \sqrt{\frac{2\sum_1^k u_i^2 \cdot \Delta t_i}{t_{зар} + t_{раз}}}. \qquad (7)$$

Based on the capacity of the discharge circuit experimental values and the energy of a single pulse, the duration of the discharge, the spark channel deionization rate, the duration of the charge capacitors the highest frequency of discharges in the circuit will be the following one 5,6·10^3 Hz and $T_u = t_{зар} + t_{раз} = 180 \cdot 10^{-6}$ s.

At the standard frequency of compared sinusoid f = 50Hz during the half the number of chargers will make m = 55...56 according to (5). The amplitude of the sinusoidal voltage will be 1310 V according to (6) and (7). The average tension on a plant stem will be the following one: $E = \frac{U_{m_C}}{d_{cm}} = \frac{1310}{15} \approx 87$ W/mm.

By the extrapolation of current-voltage characteristics of plant tissue (2) volt-ampere characteristic according to obtained tension we will obtain the current $i \approx 81 \cdot 10^{-3}$ A. And then we get the resistance R_c = 1074 ohms equivalent to a discharge.

The energy released in tissues from the sinusoidal voltage during 0.01 s will be 7.87 J according to (4). The total energy of 55 pulses for the same period will make 44.4 J, i.e. 5.6 times more.

If we compare the effects by a pulsed voltage and a sinusoidal voltage with the frequency of 400 Hz, we get the following values: of $T_c/2$ = 0.00125 s; m = 7 discharges; $7W_u$ = 5.6 J; W_c = 0.98 J. I.e. during the impact by the sinusoidal voltage of 400 Hz 5.7 times less energy is released in the plant tissue is released than at the plant tissue processing by pulse voltage.

It should be noted that in fact the greatest value of released energy W_u and W_c ratio will be less than the calculated one as the average resistances are accepted as equivalent resistances of an object to simplify the calculations. In fact, the resistance is the function of the energy released in the tissues. Furthermore, the change in the amplitude of the sinusoidal voltage will likely lead to the changes in the intensity of damaging plant tissue factor that is not taken into account in the abovementioned considerations.

Thus, the abovementioned theoretical analysis shows that the electrical processing of plant objects by discharge voltage pulses is more effective than the impact by sinusoidal voltage of equal energy.

Experimental verification of this conclusion was carried out by comparing the degrees of same sunflower stem damage from the effects of sinusoidal voltage with the amplitude of 1310 V during half of the period at the frequency of 50 Hz and 55 voltage pulses at the amplitude of 9.16 kV and the duration of 4,5x10^{-6} s. This technique is based on experimentally tested assumption that the extent of the plant tissue damage is proportional to the amount of absorbed energy.

The degree of plant tissue damage Sn refers to the quantity the numerical value of which is equal to the ratio of tissue impedance active component after the electric treatment resistance at a fixed frequency of the measuring current, in this case at the frequency of f = 10 kHz, which does not lead to the occurrence of near-electrode polarization phenomena that affect the quality of measurements (Baev, V.I. 2002; Yudaev, I.V. 2004; Yudaev, I.V. 2012).

The plant stem was fixed between the electrodes at the direct contact with them. Half of the sinusoidal voltage period is applied to the stem using a specially designed circuit in which the role of the key, closing the circuit with a plant object was performed by a controlled ball spark gap (Baev, V.I. 2002). The duration of the discharge in this interval was 0.01 s.

The treatments of stems with discharge pulses of voltage were performed from a high voltage pulse generator (VPG) with adjustable amplitude and pulse energy. The technique of conducting research was described in (Baev, V.I. 2002; Yudaev, I.V. 2004; Yudaev, I.V. 2012), where the method of plant tissue damage degree measuring is described.

The results of the experiments and their processed data are summarized in Table 1 (as an example) and are presented at Figure 3.

Table 1 Experimental effectiveness of current types

Current type	Impact period	Voltage amplitude, kW	Active voltage, kW	Repeatability	Damage degree, g.u.	Damage degree relation
Pulse	55 imp. according to 4,5·10^{-6} s	9,16	0,928	6	$S_{пи}$=1,5	$\frac{S_{ПИ}}{S_{ПС}} = 1{,}3$
Sinusoidal, f=50 Hz	0,01 s	1,308	0,928	6	$S_{пс}$=1,15	

Table 1 demonstrates the main parameters of single energy equal effects on tobacco stalks in the transverse direction and at sinusoidal and pulse voltages.

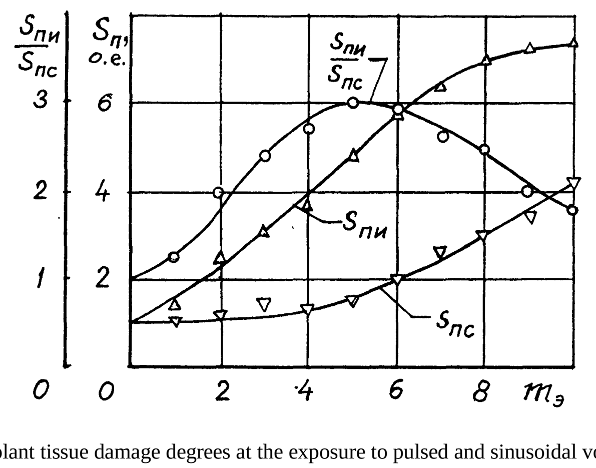

Figure 3: The dependences of plant tissue damage degrees at the exposure to pulsed and sinusoidal voltages and their relation from the number m of single energy equal effects

Fig. 3 shows the dependences of pulsed and sinusoidal elements at the current frequency of 50 Hz from the number mэ of individual energy equal effects on the same plants.

Since the processing energies of plants are proportional to the number of effects, the both dependencies on the extent of tissue damage $S_{пи}$ and $S_{пс}$ on the number mэ, have S-shaped form. However, for a sinusoidal form of the active voltage the affecting degree of damage $S_{пс}$ is significantly shifted to a larger number area (about two times) of single exposures. Approximately the same number of influences after $S_{пс}$ will reach its maximum value in comparison with $S_{пи}$ (outside the right part of the figure). Therefore, it is evident that the ratio of the damage degree $S_{пи}$ to $S_{пс}$ at the beginning and at the end of processing is numerically equal to one, and in the middle part of dependence on mэ it has a pronounced maximum: when damage is not present, then $S_{пи} = S_{пс} = 1$ and at the end of limit processing for both types of current the damages have the same maximum degree, and their ratio is equal to one.

The biggest difference between the degrees of damage $S_{пи}$ and $S_{пс}$ and the greatest value of their relationship depend on the physiological development and the state of plant stems, on their geometric dimensions, etc. That is, all numerical values in all three dependences will vary from plant to plant, but their characters will be the same with fig. 3.

The presented material shows that the electrical processing of sunflower and tobacco plants, in order to achieve their lethal damage by discharge voltage pulses is more efficient than the processing by varying sinusoidal current, it enables to use the potential of power supply better.

Similar studies were carried out for weeds (Yudaev, I.V. 2004; Yudaev, I.V. 2012). Separate fragments of city Mari weeds (*Chenopodium urbicum L.*) and thrown back amaranth (*Amaranthus retroflexus L.*) were taken as the objects of processing.

At the determination of damage degree numerical values of cultivated weed tissues the stipulation was also set that the amount of energy delivered to the tissue in comparable cases should be the same, or very close by value. In order to conduct the experiments the scheme was developed that allows to cut one, two and four periods of the sinusoidal current voltage of industrial frequency and supply it to the input of a step-up transformer, providing the impact on the studied plant tissue. VPG was used with the regulated parameters of a discharge contour in order to perform the pulse processing of plants (Baev, V.I. 2002;Yudaev, I.V. 2004,Yudaev, I.V. 2012).

The amount of absorbed energy by the tissue under study was evaluated by the following expressions:

- for sinusoidal impact:

$$W_c = \int_0^t u(t) \cdot i(t) dt = \int_0^t U_{mc} \cdot I_{m_c} \cdot \sin^2 \omega t \cdot dt \quad (8)$$

where U_{mc}, I_{mc} is the peak value of sinusoidal form voltage and current, kV and A; t - time during which the absorption of energy is considered, c; ω - current angular frequency, rad/s.

- for high voltage pulse impact:

$$W_{имп} = 0{,}5 \cdot k_p \cdot m \cdot C_k \cdot U_0^2 \quad (9)$$

where k_p is the degree of discharge capacity (by voltage), taken at 0.9...0.95; U_0 - initial voltage of discharge circuit applied to the area of plant tissue with the length l_{pm} and the diameter d_{pm}, kV; C_k – discharge contour capacity, F.

The experimental studies performed in vitro with the fragments of weed stems allowed to obtain the following results (see Table 2).

Table 2 Comparative indicators of weed stem tissue damage at sinusoidal and pulsed high-voltage exposure

Weed type	High voltage (U_{max} = 2 kV) sinusoidal impact of:			High voltage impulse impact (U_0 = 2 kV) with the pulse number m, at C_k = 1000 pF:		
	One period t=0,02 c	Two periods t=0,04 c	Four periods t=0,08 c	m= 200	m=400	m=800
Thrown back amaranth (*Amaranthus retroflexus L.*)	**Affecting energy, J:**			**Affecting energy, J:**		
	0,485	0,970	1,865	0,380	0,760	1,520
	Plant tissue damage level Sпи, r.u.			**Plant tissue damage level Sпс, r.u.**		
	1,47	2,03	2,46	3,72	4,13	4,75
City pigweed (*Chenopodium urbicum L.*)	**Affecting energy, J:**			**Affecting energy, J:**		
	0,394	0,857	1,701	0,380	0,760	1,520
	Plant tissue damage level Sпи, r.u.			**Plant tissue damage level Sпс, r.u.**		
	1,43	1,80	2,29	4,10	6,10	6,90

The table shows that an electric pulse treatment of weeds is more effective technologically than the treatment with high-sinusoidal voltage. Therefore, it is necessary to develop appropriate pulse schematic solutions for the technical implementation of electric weeding.

3 Conclusion

The electrical treatment of sunflower, tobacco and weeds in order to achieve technologically necessary lethal damage demands the use of the most effective electric current type. This statement is developed on the basis of the theoretical premises and experimental study data to assess the extent of different plant tissue damage treated with the energy equivalent sinusoidal and pulsed currents.

Thus, an experimental comparison of the damage level of tobacco plant tissue when samples are subjected to discharge voltage pulses and sinusoidal current at frequency of 50 Hz, provided at the equal value of the acting voltage, shows that in the first case the damage level is 1.3 times greater than at treatment by sinusoidal current. These results confirm the theoretical justification of the technological efficiency of pulsed processing of tobacco plants before drying and sunflower plants before harvesting.

The analysis of experimental data allows to say that the effects of discharge voltage pulses for lethal damage of plant weed tissues are more effective than those ones of an energetically equal sinusoidal voltage. At the same time, the damage level during treatment by voltage impulses is even greater than at processing sunflower and tobacco plants, and in respect of sinusoidal influence it is more by 1.6-3.4 times.

4 Summary

Thus, the presented materials of theoretical estimate and the experimental study results suggest the possibility of an influencing factor use - a pulse mode of electrical processing of plants and plant raw materials in the processes of crop production and the processing of raw materials from it with the best technological performances and minimal energy consumption.

Literature:

1. Armyanov, N. *Basic treatment parameters in electric spark processinc of plants and their impact upon its effectiveness* / N. Armyanov, V. Bayev, V. Savchuk, M. Diprose, S. Stefanova, T. Stoyanova, N. Nedyalkov // Agricultural engineering. Reserch papers, 31(3). Lithuanian institute agricultural engineering Lithuanian university of agriculture. Radondvaris, 1999, Pp.67-82.

2. Baev, V.I. *Electropulse pre-harvest processing of sunflower and tobacco: monograph* / V.I. Baev, I.F. Borodin. Volgograd: The village 2, 2002, 230 p.

3. Diprose, M.F. *Death to weeds by electrocution / M.F. Diprose, F.A. Benson* // Power Farming Magazine, 1980, V.89, №2, Pp.24-25.

4. Kaufman, K.R. *Energy requirements and economic analysis of electrical weed control* / K.R. Kaufman, L.M. Schaffner // American Society of Agricultural Engineers, 1980, №80-1008, 16 p.

5. Недялков, Н. *Възможност за повишаване ефективността на електроискровата обработка на плевели* / Н. Недялков // Селскостопанска Техника, 1996, Г.33, №1, С.22-24.

6. Reed J. *Electrical weed control in field vegetables* / J. Reed, P. Cornish, S. Miles // Agriculture and Horticulture Development Board, FU 346, Silsoe Technology ltd, 2009, 18 p.

7. Stankovic, M. *Ecological importance of electrical devices innovative in the process of anti Ambrosia artemisiifolia l* / M. Stankovic, M. Cvijanovic, V. Dukic // Economics of Agriculture, 2016, №3, Pp.861-870.

8. Stankovic, M. *Electric destroyer of weeds and plants* / M. Stankovic // 3rd International Innovation and Invention Conference «Global Future – Environment and Health», August 2012, Taipei, Republic of China, 2012, Pp. 39-41

9. Vigneault, C. *Electrical weed control: Theory and applications, in Physical control methods in plant protection* / C. Vigneault, D.L. Benoit, C. Vincent, B. Panneton, F. Fleurat-Lessard. Springer-Verlag: Berlin, Germany, 2001, 329 p.

10. Rodrigues, S., Fernandes, F.A.N. *Advances in fruit Processing technologies* / S. Rodrigues, F.A.N. Fernandes. Boca Raton, London, New York, CRC Press Taylor & Francis Groop LLC, 2012, 459 p.

11. Jeyamkondan, S. *Pulsed electric field processing of foods: A review* / S.Jeyamkondan, D. S. Jayas, R. A. Holley // J. of Food Protection, 1999, 62(9), Pp.1088-1096.

12. Barsotti, L. *Food process sing by pulsed electric fields. II. Biological aspects* / L. Barsotti, J.C. Cheftel // Food Review International, 1999, 15(2), Pp.181-213.

13. Klimov, A.A. *About some electrophysical parameters and the properties of plant tissue as an object of electric-spark effect* / V.I. Baev, A.A. Klimov, V.N. Savchuk // Electronic processing of materials, 1970, № 1, Pp. 66-71.

14. Cole, K.S. *Dynamic electrical characteristics of the squid axon membranes* / K.S. Cole // Arcives Des Sci Physiologiques, 1949, №3, Pp, 253-258.

15. Zhang, M.I.N. *Electrical Impedance Analysis in Plant Tissue: Symplastic Resistance and Membrane Capacitance*. In the Hayden Model / M.I.N. Zhang, D.G. Stout, J.H.M. Willison // Journal of Experimental Botany. 1990. №41. Pp. 371-380.

16. Judajev, I.V. *The definition of electro impulses used in weed control* / I.V. Judajev, T.P. Brenina // Journal of agricultural sciences. Published by University of Belgrade. Republic of Serbia. Faculty of Agriculture, Belgrade, 2008, V.53, №1, Pp.37-44.

17. Yudaev, I.V. *Weeds as an object of electric weeding:*

biological characteristics and electrical physical properties: monograph / V.I. Baev, T.P. Brenina, D.S. Yeliseyev, I.V. Yudaev. Volgograd: The village 2, 2004, 128 p.
18. Yudaev, I.V. *Fundamentals of electropulse weeding: electrophysical properties of weeds: monograph* / I.V. Yudaev. Saarbrucken: LAMBERT Academic Publishing, 2012, 268 p.

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