ATLANTIS PRESS

Advances in Engineering Research, volume 151

International Conference on Smart Solutions for Agriculture (Agro-SMART 2018)

Power - and Resource-Saving Electric Lighting Technologies in Agricultural Engineering for Protected Soil

Nadezhda Petrovna Kondrateva
Doctor of Technical Sciences, professor
Department of Automatic Electric Drives
Izhevsk State Agricultural Academy
Izhevsk, Russia
E-mail: aep_isha@mail.ru

Nikolai Vasilyevich Obolensky
Doctor of Technical Sciences, professor
Nizhny Novgorod State Engineering
and Economics University
Knyaginino, Nizhny Novgorod oblast, Russia
E-mail: obolenskinv@mail.ru

Roman Gennadyevich Bolshin
Candidate of Technical Sciences, instructor
Non-state educational institution of additional professional
education "Educational and scientific innovative center
"Omega" Izhevsk, Russia

Andrey Ivanovich Baturin
Department of Automatic Electric Drives
Izhevsk State Agricultural Academy
Izhevsk, Russia

Marina Gennadievna Krasnoluckaya
Candidate of Technical Sciences, instructor
Non-state educational institution of additional professional
education "Educational and scientific innovative center "Omega"
Izhevsk, Russia

Abstract— **Analysis of works of prominent scientists Brown (1886), Blackman (1905), Richter (1914), Emerson (1956), Warburg (1956), Mekkelson (1959), Rabinovitch (1961), Prischep (1971), Kozinsky (1978), Korzh (1975), Bolshina (1985) and others has shown that photosynthesis includes light-dependent and light-independent reactions and irradiation of a plant with light pulses of certain pulse ratio leads to more efficient use of light energy by the plant.**

Research into the influence of the pulse irradiation was conducted on meristem plants of garden strawberry, Corona cultivar, as strawberry is rich in vitamins and is in demand throughout the year. In addition, the most reliable and prospective method of propagation and recovery of small-fruit and other crops is meristem propagation.

The results have shown that the plants demonstrate most efficient energy use under pulse mode of irradiation with varying pulse ratio, thus confirming the data obtained by other scientists. This mode is energy and resource saving, as its application allows reducing the energy consumption to 45% of the amount consumed by continuously operating luminescent lamps and to 75% of the amount consumed by continuously operating LED lamps.

Keywords— Pulse radiation with varying pulse ratio, meristem plants, in vitro

I. INTRODUCTION

The main task of the planting material production system is creation of plantations of fruit and berry crops that are longstanding, annually fruitful, convenient in operation, quickly paying back and bringing stable profit, adapted to local natural and climatic conditions. During the last 10-15 years, there is a deficit of planting material meeting the modern standards in Russia, due to unfavorable environmental factors and harsh climatic conditions. Additionally, lately there is an increased demand for rehabilitated planting material due to expansion of viral, phytoplasm and fungal infections. Currently, in a number of European and American countries, it is impossible to imagine the rehabilitated planting material production system without isolated tissue culture. [1, 2]. Such planting material is grown in specialized meristem laboratories. Meristem growing is a labor and energy intensive process. Due to a sharp increase in energy costs, we are solving a task of scientific justification for the parameters of irradiation mode of the meristem plants to provide electricity savings and increased plant productivity.

Reduction of electric costs is a current issue in agriculture, as they determine a significant portion of price formation, and thus of economic stability of agricultural produce. Artificial lighting is one of the most important factors. Energy consumption for lighting in Russia constitutes, by various estimates, about 14% of the total produced electrical energy, bearing record to the scale of the problem and efficiency of any reasonable measures for its solution [1, 2]. Artificial lighting in indoor structures is the most important microclimate factor for plants.

One of prospective methods to produce healthy planting material is microclonal propagation of plants, otherwise known as a meristem technology. Meristem (from Greek *meristos* – divisible) is a tissue of plants that keeps the capability to form new cells throughout the life of the plant. Trees and plants grow by means of the meristem, forming new leaves, stems, roots, flowers.

The meristem technology assumes propagation and growing of plants *in vitro*: A dormant bud of a plant is treated with antibacterial and antiviral preparations and is sprouted in a test tube on a fertilizer substrate. This first stage (introduction) is the most complex one: several years may be spent to sprout a mother bud [1].

The plants produced by the microclonal propagation have several advantages [1]:

- the plants are immune to viruses, even if the meristem tissue was obtained from an infected plant, as the virus does not afflict meristems at the shoot apex;
- meristem nurslings show higher yields. For example, one regular strawberry bush may yield 200…300 g of berries, while a meristem bush may yield up to 1 kg;
- the microclonal propagation gives opportunity to get up to 10.000 nurslings from a single mother plant annually;
- the meristem propagation becomes the only one possible on industrial scale, if the plants taken for propagation do not produce fertile offspring by seed propagation.

During the autumn-winter period, growing of fresh vegetable and berry in the moderate climatic zone of Russia is possible only in protected ground, as only under these conditions may reduction in natural irradiation and shortening of day length be compensated by additional artificial irradiation of plants.

Artificial irradiation of plants cannot be replaced with any other agricultural technique in industrial, selection, reproduction, vegetation and other types of greenhouses and glasshouses, as normal carbon nutrition and normal plant formation proceed only under the action of optical radiation which is thus the foundation of plant existence and cropping.

The plants have photoreceptor systems that absorb the energy of the visible radiation. Thus, plants are the only type of organisms on Earth that independently synthesize organic substances from inorganic ones. This process is called photosynthesis [3]. The photosynthesis includes a light stage and a dark stage.

For the first time, duration of the light and the dark stages of photosynthesis was determined by Brown in 1886. The pulses were produced by rotating disks. The experiments have shown, that the plants use the radiated energy more efficiently under pulse irradiation.

In 1905, Blackman conducted experiments in pulse irradiation of plants and found out that the photosynthesis process increases with increased irradiation only until a certain limit and further increase is linked only to increase in temperature.

In 1914, on the ground of his experiments, A. Richter showed, that with changes of darkness exposure from 0.1 to 0.17 sec and respective reduction is light exposure from 0.1 to 0.03 sec, consumption of CO_2 per flash increases by up to 400%, but the rate of CO_2 consumption under pulse irradiation was insignificantly lower than under continuous irradiation. From this A.Richter concludes that pulse irradiation allows increasing the yield of photosynthesis per unit of light energy [3, 4].

In 1956, Emerson, on the ground of experimental research consistently proved that photosynthesis is related to two chemical reactions determined by two different pigment systems, that is, photosynthesis has light and dark stages. Existence of two stages of photosynthesis allows proposing a new mode of plant irradiation. At that, the radiating fixtures will operate only during the light stage. It will allow for rational use of electric energy for irradiation.

In 1956, O. Warburg showed that the efficiency of visual radiation energy use increased almost twofold when the duration of dark and light exposure was brought to 0.004 s. The pulses were produced by rotating disks. [3, 4].

In 1959, P. Mekkelson conducted experiments in pulse irradiation on sprouts of wheat and peas, presprouted in the dark. All the plants he divided into three groups: Group “a” got one flash in 20 s, group “b” got one flash in 40 s, group “c” got one flash in 120 s; the control group got daylight irradiation with a normal alternation of light and darkness. The pulses were produced by pulse metal halide lamp XB 81/00 manufactured by DGL Plessler Leipzig. The duration of a flash was 1/1000 of a second. The best results as for chlorophyll content in comparison with the constant irradiation were obtained in the variant with a 20 second pause. Some results of the experiments conducted by P. Mekkelson are given in Table 1.

TABLE I. RESULTS OF EXPERIMENTS CONDUCTED BY P. MEKKELSON IN PULSE IRRADIATION OF WHEAT AND PEA SPROUTS

Indicators	**Control**	**One flash in**			**Darkness**
		20 s	***40 s***	***120 s***	
Dry matter, %	13	13	11	8	8
Nitrogen, %	6	6	5	4	4

Thus, P. Mekkelson has shown that there is no significant difference between the continuous and intermittent energy supply mode as for quantity and quality of the end product, while the pulse mode allows for a significant saving of electric energy [3, 4].

E. Rabinovich, in a chapter dedicated to plant irradiation in his large monograph titled *Photosynthesis*, comes to a conclusion that the rate of photosynthetic gas exchange under condition of pulse irradiation is always lower than under continuous lighting. However, when pulse irradiation is applied, duration of dark interval associated with maximum of photosynthetic gas exchange for most plants is about 0.1…1.0 s [4].

Technical implementation of the pulse mode with such light and dark exposure were developed by L.G. Prischep, V.A. Kozinsky, O.I. Kuznetzov, K.S. Bitarov and Yeliseyev [4, 5] employing mercury discharge lamps,

Further research of influence that pulse irradiation has onto plants was conducted by B.V.Korzh in the All-Russian Institute of Crop Research named after N.I. Vavilov (VIR) [6, 7].

Studies of B.V.Korzh revealed that under the pulse irradiation, in the moment of light flash there is a flat-topped bump in CO_2 consumption with leading and falling edges shorter than 0.5 s. The amplitude of this flat-topped bump is significantly higher than the CO_2 consumption rate under continuous irradiation. On the ground of his research, B.V. Korzh suggested pulse mode parameters that will be most acceptable for most plants. Durations of flash and pause are 0.5…0.6 s, and 1.0 s, respectively. These short pulses continue for 30 s, then a pulse of 15 s is necessary. We call this irradiation mode a pulse mode with varying pulse ratio.

Technical implementation of this irradiation mode was made employing low-pressure discharge lamps by N.P. Bolshinina. Experiments on meristem perpetual carnation have shown positive results.

Thus, Blackman, Emerson, Arnold, R. Mekkel, Richter, L.G. Prischep, V.A. Kozinsky, O.I. Kuznetzov, K.S. Bitarov, B.V., Korzh, N.P. Kondratyeva proved a possibility of applying a pulse irradiation (lighting) mode to growing plants that leads to a significant saving of electric energy while keeping the quantity and quality of produce. This mode was implemented with mercury lamps, which present an environmental hazard. Besides, operation of the lamps in pulse mode significantly shortened their useful life or required developing special devices [2, 9, 10, 11, 12],

Currently, it is possible to implement the pulse mode of plant irradiation using environmentally and electrically safe LEDs, whose useful life is unaffected by their turn-on frequency [12, 13, 14, 15].

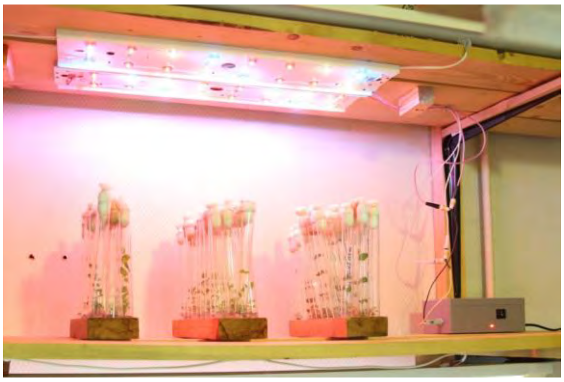

Fig. 1. A photo of a LED lamp, meristem strawberry plants and a device providing pulse irradiation mode

With respect to meristem strawberry plants, the influence of the pulse irradiation mode is understudied. Thus, increasing the efficiency of LED phytoirradiating unit for growing meristem strawberry plants using programmable logic controllers to maintain the parameters is an actionable problem.

II. Results and Discussion

The research was conducted on meristem plants of garden strawberry, var. Corona, in the Udmurt Federal Research Center of the Ural branch of the Russian Academy of Sciences (Figure 1

The meristem plants growing technology consists of three phases (Figure 2)

.

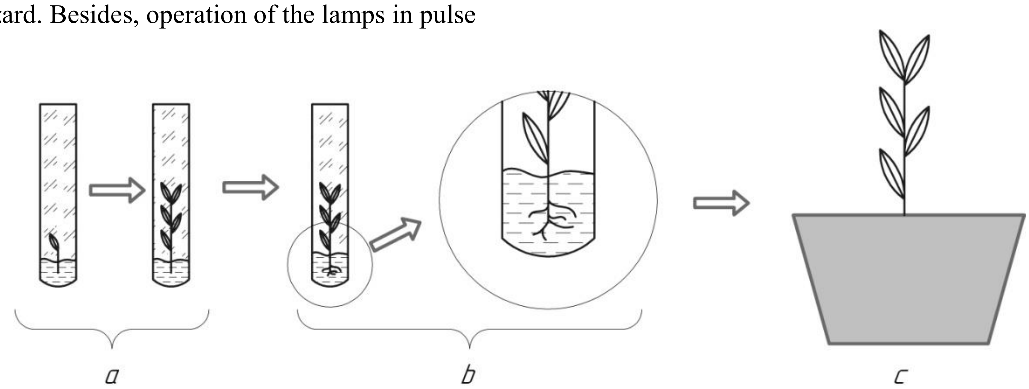

Fig. 2. Process diagram of meristem plant growing a –proliferation phase (increasing the leaf area); b – rooting phase (root development); c – adaptation phase.

Our experiments were conducted at the proliferation phase, that is, during the increase of leaf area of the meristem plants.

All the plant in the experiment were divided into three groups depending on the operation mode of the radiation source in the phytolamp:

- Group 1 – phytolamp with LEDs in pulse mode with varying pulse rate.
- Group 2 – phytolamp with LEDs in continuous mode.
- Group 3 – phytolamp with discharge lamps in continuous mode.

Photoperiod was 16 hours in all variants. The units operated for 30 days.

In Figure 3 there is a circuit diagram of a special device to implement the pulse mode with a varying pulse rate.

The principal elements of the scheme are:

- control frequency generator for fine adjustment of parameters, implemented using the elements D1.1 and D1.2 of the К561ЛН2 chip, as well as elements C1, R1, R2;
- elements D1.3 and D1.4 of the same chip are used for improving the pulse's ramp;
- counter D2 divides the frequency of input impulses in a ratio divisible by two;
- the operating algorithm of the device is implemented with the elements D1.5 and D1.6 of the К561ЛН2 chip and D3.1, D3.3 and D3.4 of the К561ЛА7 chip;
- inverter D3.2 allows starting operation with glowing LEDs;
- the initial reset unit is implemented with the elements D3.3, R3, C2;
- a compound high-gain transistor is used as a power amplifier, as the output amperage of the К561ЛА7 chip is insufficient for controlling the LEDs. The transistor is installed onto a small radiator to withdraw heat;
- circuit breakers F1 and F2 protect against current overload and short circuit;
- the D4 chip is an integrated voltage stabilizer for 12V with internal current protection;
- the scheme uses a single-phase transformer, OCM 1-0.063 with a load current capacity of 1.5 A at its secondary winding;
- an indicator LED25 indicates the operation of the device.

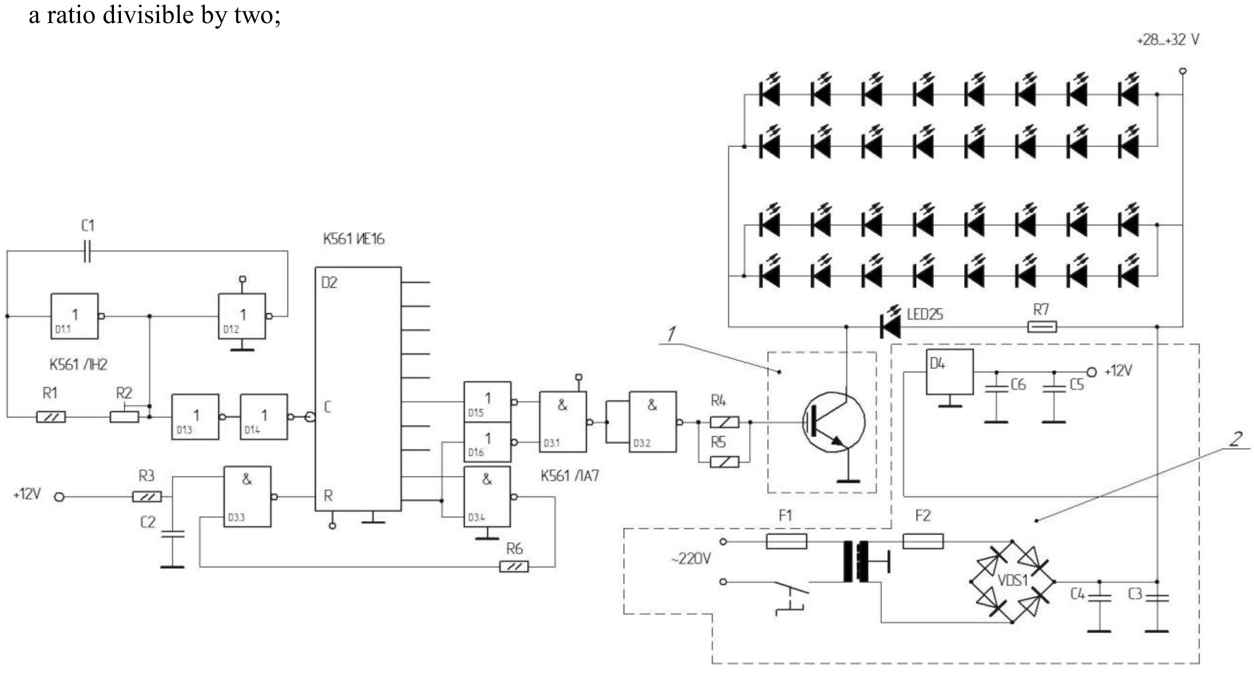

Fig. 3. Circuit scheme of the device 1 - Compound power transistor; 2 - Power supply unit

The experimental results are given in Table 2.

The Table 2 shows, that the plants demonstrate most efficient energy use under pulse mode of irradiation with varying pulse ratio, thus confirming the data obtained by other scientists. This mode is energy and resource saving, as its application allows reducing the energy consumption to 45% of the amount consumed by continuously-operating luminescent lamps and to 75% of the amount consumed by continuously operated LED lamps.

In Figure 4 there are photographs of plants at the adaptation stage.

TABLE II. EXPERIMENTAL RESULTS

Indicators		**Irradiation mode**		
		Pulse mode with varying pulse rate	*Continuous*	
			RGB	LL
Initial leaf area	cm^2	2.54	2.76	2.67
Final leaf area	cm^2	3.12	3.27	3.15
Leaf area increment	cm^2	0.58	0.51	0.48
	%wt	120	106	100
Lamp wattage	W	18	24	40
Electricity consumption	W*h	4,608	6,144	10,240
	%wt	45	60	100
	%wt	75	100	-

[a.] RGB –a phytolamp with RGB LEDs

[b.] LL – a phytolamp with luminescent lamps

[c.] .

a)

b)

Fig. 4. Photos of experimental plants at the third adaptation stage: a) garden strawberry cultivar Corona and climbing rose culitvar Camelot, grown under luminescent lamps (control); b) garden strawberry cultivar Corona and climbing rose culitvar Camelot, grown under a LED irradiation apparatus operating in a pulse mode with varying pulse rate

III. CONCLUSION

The following conclusions may be made from the research conducted and results obtained:.

1) Analysis of works of prominent scientists Brown (1886), Blackman (1905), Richter (1914), Emerson (1956), Warburg (1956), Mikkelsen (1959), Rabinovitch (1961), Prischep (1971), Kozinsky (1978), Korzh (1975), Bolshina (1985) and others has shown that photosynthesis has light-dependent and light-independent reactions and irradiation of a plant with light pulses of certain pulse ratio leads to more efficient use of light energy by the plant.

2) Research was conducted on meristem plants of garden strawberry, Corona cultivar, as strawberry is rich in vitamins and is in demand throughout the year. In addition, the most reliable and prospective method of propagation and recovery of small-fruit and other crops is meristem propagation.

3) 3. The research has shown that the plants demonstrate most efficient energy use under pulse mode of irradiation with varying pulse ratio, thus confirming the data obtained by other scientists. This mode is energy and resource saving, as its application allows reducing the energy consumption to 45% of the amount consumed by continuously operating luminescent lamps and to 75% of the amount consumed by continuously operating LED lamps.

References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first ...”

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors’ names; do not use “et al.”. Papers that have not been published, even if they have been submitted for publication, should be cited as “unpublished” [4]. Papers that have been accepted for publication should be cited as “in press” [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

[1] N.P. Kondratyeva, R.I. Korepanov, I.R. Ilyasov, R.G. Bolshin, M.G. Krasnolutskaya, E.N. Somova, M.G. Markova, “Efficiency of a microprocessor-based automatic control system for LED irradiation units”, Agricultural Machines and Technologies, 2018, Vol. 12, No. 3, pp. 32-37.

[2] N.P. Kondratyeva, I.R. Vladykin, I.A. Baranova, S.I., Yuran, A.I. Baturin, R.G. Bolshin, M.G. Krasnolutskaya, “Development of an electric equipment automatic control system for enerty saving electric technologies”, Annals of NGIEI, 2018, No. 6 (85), pp. 36-49.

[3] E. Rabinovitch, “Photosynthesis”, Nauka i Tekhnika, 1976, p. 192.

[4] A.A. Shakhov, “Light pulse stimulation of plants”, Moscow: Nauka Publishing, 1971.

[5] V.A. Kozinsky, “Electric lighting and irradiation”, Moscow: Agropromizdat, 1991.

[6] B.V. Korzh, “Revisiting the issue of plant growing under pulse lighting. A new irradiation mode. In: Photoenergetics of plants”, Theses of reports at the 5th All-Union Conference on Photoenergetics of plants, Alma-Ata, 1978, pp. 128-129.

[7] B.V. Korzh, “Using short series of pulse lighting for studying photosynthesis process and plant respiration process under light”, Dissertation for a Candidate degree in Biological Sciences, Leningrad: 1976, p. 134.

[8] Yu.V. Gerasimchuk, N.N. Srkypnic, B.V. Korzh, “Light pulse irradiation unit for protected ground facilities”, In book: Problems of photoenergetics of plants and increasing yields, Lviv, 1984, p.240.

[9] P.G. Nikolenko, N.V. Mordovchenkov, N.V. Obolensky, “Import substitution is an efficient organizational and economic mechanism of optimal development of agriculture”, Economics and Entrepreneurship, 2015. No. 10-1 (63), pp. 123-128.

[10] E.A. Kozyreva, “Automation of plant growing under artificial irradiation”, In Proc. of All-Russia scientific and practical conference, Izhevsk State Agricultural Academy, 2013, pp. 40-44 [Agrarian Science to innovative development of agriculture in modern conditions Materials, 2013].

[11] E.A. Kozyreva, “A Universal system of growing plant microclones”, In Proc. of All-Russia Scientific and Practical conference, Izhevsk State Agricultural Academy, 2015, pp. 137-140 [Theory and Practice to sustainable development of the agricultural complex, Ministry of Agriculture of the Russian Federation, 2015].

[12] O.Yu. Kovalenko, S.A. Ovchukova, V.V. Belov, “Influence of radiation source parameters onto a biological subject”, Annals of the International Academy of Agricultural Education, 2016, No. 30, pp. 122-126.

[13] V.V. Belov, S.A. Ovchukova, O.Yu. Kovalenko, V.M. Maksimov, Yu.N. Semenov, “Photosynthesis as presented for calculations. Annals of the International Academy of Agricultural Education”, 2014, No. 20. pp. 7-10.

[14] S.A. Ovchukova, O.Yu. Kovalenko, V.M. Maksimov, D.V. Gubanov, “Possibility of applying LED irradiation units in protected ground crop farming”, In Proc. of the XII All-Russian Scientific and Technical Conference with International Participation within the framework of the III All-Russian Lighting Technology Forum with International Participation, O. E. Zheleznikova Ed. Mordvin University named after N. P. Ogaryov, 2015. p. 86-91 [Issues and development prospects of Russian lighting technology, electrical engineering and energetics, 2015].

[15] L.Yu. Yuferev, L.K. Alferova, “Lighting technology in Agriculture”, Moscow, 2016, p. 215.