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Technical and economic efficiency of led lights in green crops

ТЕХНИКО-ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ПРИМЕНЕНИЯ СВЕТОДИОДНЫХ СВЕТИЛЬНИКОВ НА ЗЕЛЕННЫХ КУЛЬТУРАХ

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Abstract

Year-round provision of fresh vegetables and green products to the population of Russian regions of 1 and 2 light zones remains an important social and economic task, despite the modern devel-opment of logistics. The need to provide fresh crop production in the context of the COVID-19 pandemic has increased. Agro-industrial greenhouses still rely mainly on traditional light sources. The purpose of this scientific study was therefore to assess the effectiveness of modern LED lights in finishing salad plants in a closed ground relative to traditional sodium light sources. The scientific hypothesis of the research carried out was a thesis about the possible effectiveness of light-emitting diode phytoplants with peak values of red (660nm) and blue (440nm) light spec-trum in comparison with traditional sodium light in artificial finishing of vegetables of protected soil. The study revealed the production, commercial and energy efficiency of salad plants from the plant lamps tested. The study resulted in practical recommendations for producers and further research on the subject.

Keywords: LED phyto-lights, effective phyto-lighting, closed ground, lettuce yield.

Аннотация

Круглогодичное обеспечение населения регионов России 1 и 2 световой зоны свежими овощами и зеленной продукцией остается важной социально-экономической задачей, несмотря на современное развитие логистики. Особенно выросла актуальность задачи обеспечения населения свежей продукцией растениеводства в условиях пандемии COVID-19. В агропромышленных теплицах до сих применяются в основном традиционные источники света. Поэтому целью данного научного исследования стала оценка эффективности современных светодиодных светильников при досвечивании растений салата в закрытом грунте относительно применяемых традиционно натриевых источников света. Научной гипотезой проводимых изысканий стал тезис о возможной эффективности светодиодных фитосветильников с пиковыми значениями красного (660нм) и синего (440нм) спектра свечения по сравнению с традиционным натриевым освещением при искусственном досвечивании овощей защищенного грунта. В результате исследования была выявлена производственная, коммерческая и энергетическая эффективность фитоосвещения растений салата на базе тестируемых фитосветильников. В итоге исследования выработаны практические рекомендации для производителей и определены дальнейшие направления научных исследований по данной тематике.

Ключевые слова: светодиодные фитосветильники, эффективность фитоосвещения, закрытый грунт, урожайность салата.

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Introduction

The objective of this scientific study was to assess the effectiveness of modern LED lights in finishing salad plants in protected soil relative to the traditional sodium light sources used. A scientific hypothesis was the possible effectiveness of red-blue LED phytoplants compared to DNAT/DNAZ sodium lamps in artificial illumination of protected vegetables. In order to achieve this objective, the following objectives have been achieved:

1. The production experience was carried out for growing lettuce plants in two versions of artificial supplementary lighting: traditionally used lighting with high-pressure sodium lamps and modern LED lighting.
2. A comparison is made of the productivity of the lettuce harvest when using LED lamps produced by LLC «GC «CET» (Perm) and traditionally used gas-discharge lamps (type DNAZ).
3. The energy saving effect of the LED artificial finishing system application is evaluated.

Year-round provision of fresh vegetables and green products to the population of Russian regions of 1 and 2 light zones remains an important social and economic task, even in spite of the modern development of logistics. The need to provide fresh crop production in the context of the COVID-19 pandemic has increased. Its solution is possible by developing modern agribusiness based on protected soil. On the world market, the share of all greenhouse products is growing, increasing by 10% annually. Recently, the development of the domestic greenhouse sector has also seen a significant acceleration. As noted by M. N. Polyakova, Y. C. Martirosyan, A. A. Kosobryukhov, according to the Ministry of Agriculture of the Russian Federation, the area of winter greenhouses in Russia has reached 1.88 thousand hectares by the beginning of 2014. The average vegetable yield was 28 kg/m^2 (Polyakova, Martirosyan & Kosobryukhov, 2015).

Optimizing the light regime of vegetable crops is of particular importance in order to increase the efficiency of indoor production, crop productivity and crop quality. Vegetable production, especially in winter, is known to rely heavily on pre-cooking.

While LED lighting in the segment of the so-called «white light» almost completely displaced luminescent and other light sources, on the market of artificial finishing of agricultural and decorative plants in the modern industrial-type hothouses are now still dominated by traditional light sources. Agrarian mentalities have always been cautious and cautious innovators and have favoured proven technologies over technological innovations that carry potential risks in addition to potential benefits (Innovative techonologies of light, 2021).

Until recently, production hothouses were mostly equipped with lamps based on sodium and/or mercury lamps with maximum radiation ranges of 550-600 and 450 nm. The group of researchers G. D. Massa, H. H. Kim, R. M. Wheeler, C. A. Mitchell emphasize that there is increasing interest in the introduction of lighting systems based on light-emitting diodes with great potential as additional or sole lighting sources for agricultural crops (Massa, Kim, Wheeler & Mitchell, 2008).

LED lighting is being actively researched and discussed by scientists and specialists around the world. Despite the growing interest of the world agricultural industry in the theme of closed-field vegetable crops, there is still a lack of verified research on this subject in the Ural region. The effective use of LED irradiators in greenhouses hinders their implementation in practice. It follows from the above that the relevance of the studies under this article is which is planned as a prelude to a whole cycle of research on the effectiveness of LED lighting in industrial greenhouses and measures for its improvement and development in the agro-industrial complex of the Russian Federation as a whole.

Literature review

At present, traditional sources of additional artificial light for vegetables and other closed soil crops dominate the market (according to the author's preliminary marketing research up to 80-90% of the market), due to a number of objective reasons: 1) a clear and proven technology that allows programming of planned yields and other results of use (this pre-processing technology has been applied for about forty years); 2) a relatively affordable cost of acquisition.

At the same time as proven strengths, traditional light bulbs have a number of serious disadvantages: 1) the light spectrum of photosynthetic active radiation generates few waves of blue light spectrum, necessary for crops during the growing season and also insufficient red light spectrum necessary for vegetables to harvest fruit; 2) during operation, the radiation of sodium lamps is shifted to the heat zone, that, with the same electricity consumption, there is absolutely no effect in the increase in yield; 3) the temperature of the combustion of gas-discharge lamps reaches 250°C, resulting in deterioration of the microclimate of the greenhouses and of plant burns; 4) the useful and effective life of traditional sodium lamps is five times shorter than that of modern LED fitting lamps; 5) gas-discharge lamps are environmentally hazardous and require a special recycling procedure; 6) traditional sources of phytophote, through the use of electromagnetic start-up and control devices, consume 10 % or more of the electricity than declared in nominal power.

A. A. Emelin, L. B. Prikupets, I. G. Tarakanov note that irradiators with a combination of red and blue LEDs are offered for growing salad and green crops, with the proportion of radiation in the red (630–690 nm) being 65–95% and in the blue (430–470 nm) - the remaining 5–35% (Emelin, Prikupets & Tarakanov, 2015).

Researchers M. Olle and A. Viršile emphasize that the use in plant production of light-emitting diodes with a high level of light emission and different spectral composition of radiation has revealed a diverse and not always clear reaction of plant species and varieties to narrowband radiation (Olle & Viršile, 2013). Scientists O. V. Avercheva, E. M. Bassarskaya, T. V. Zhigalova, Y. A. Berkovich, S. O. Smolyanina, M. R. Leontyeva, A. N. Erokhin, I. G., Tarakanov, O. S. Yakovleva, I. O. Konovalova, S. O. Smolyanina, M. A. Pomelova, A. N. Erokhin, O. S. Yakovleva, I. G. Tarakanov, S. Muneer, E. J. Kim, J. S. Park, J. H. Lee are convinced that narrowband radiation can modulate plant growth, development and morphogenesis, affect photosynthetic structure and activity, overall metabolism, biomass accumulation and chemistry (Avercheva, Bassarskaya, Zhigalova, Berkovich, Smolyanina, Leontyeva & Erokhin, 2010; Tarakanov & Yakovleva, 2011; Konovalova, Berkovich, Smolyanina, Pomelova, Erokhin, Yakovleva & Tarakanov, 2015; Muneer, Kim, Park & Lee, 2014).

Within the scope of this article, research has been carried out on a salad crop that is widely in demand in the consumer market and is cost-effective. A. V. Butkin notes that the salad (*Lactuca sativa* L.) is an exceptionally useful vegetable crop, the technology of which in production has been brought almost to perfection (Butkin, 2013). World and domestic practice shows that most salad products are produced in protected ground using artificial lighting sources. The light culture of salad is of particular relevance in the regions of the middle band of Russia, the Urals and northern regions. I. V. Dalke, A. V. Butkin, G. N. Tabalenkova, R. V. Malyshev, E. E. Grigorai, T. K. Golovko state that, on the basis of many years of observation, crop estimation and experiments with different lighting regimes, it is possible to determine the optimal parameters for the finish of leaf lettuce by mirror high-pressure sodium lamps, which ensure the production of marketable products in different seasons of the year (Dalke, Butkin, Tabalenkova, Malyshev, Grigorai & Golovko, 2013).

Materials and methods

The following scientific methods were used in the research: monographic, scientific experiment, comparison of data, systematic analysis and synthesis of data, analysis of expert estimates, and analysis of tabular and graphic methods of visualization and interpretation of the information analysed.

The activities of the author's experimental study were carried out in the following sequence and logic:

1. In order to carry out a comparative study of the physiological-biochemical characteristics of leaf lettuces (*Lactuca sativa* L.), the plants are grown at a temperature of 24± 2 °C and the CO_2 content in the air is about 400 ppm. The lighting regime is chosen on the basis of recommendations for cultivation of the crop in closed ground. Plants are grown by the method of flowing hydroponics in plastic pots with a peat mixture by the conveyor method in production conditions of agricultural enterprise LLC «Truzhenik» (Perm Region, Russia). Planned full-cycle production of plants (turnover) is about 45 days.

To accomplish the tasks set, there are two options for growing plants. The first assumes cultivation in greenhouses on tables under full LED lighting conditions using ECOLED-BIO-112-185W-D120 UniversaLED phyto-lamps (Option 1). The second method is aimed at growing plants under illumination with gas-discharge lamps (type DNAZ), with an additional supply of natural light, which is determined by weather conditions during the cultivation cycle (Option 2).

Taking into account the area of one LED lamp ECOLED-BIO-112-185W-D120 UniversaLED about 0.14 m^2, 12 LED lamps (in three rows of 4 pieces) were used to support the experiments. For the relevance of the scientific results, the test plots were isolated from the luminous flux from other light sources.

The spectral characteristic of artificial and natural light sources will be determined using a portable spectroradiometer UPRtek MK350S, radiometer TKA-PKM (Russia). Recording of daily changes in the luminous flux to the plant cenosis was carried out.

The regulation of the light regime (intensity, photoperiod) was carried out taking into account the actual receipt of photosynthetically active radiation from the used LED lamps provided by the manufacturing company LLC Group of Companies Light and Electric Technologies (LLC GC LET).
During the turnover, the microclimatic conditions of plant growth (light regime, temperature, humidity, CO_2 in the air) and the state of plant material were regularly documented. Intermediate determinations of biomass accumulation and functional indices of the assimilation apparatus (by non-damaging methods) were carried out after the arrival of about 40-50 MJ / m^2 PAR to the cenosis.

2. At the end of the turnover, the growth parameters, linear and mass characteristics of the leaf apparatus were determined for the formed plants. A comparison is made of the productivity and quality of the lettuce harvest produced with the use of LED and gas-discharge lamps. The laboratory determined the content of nutrients and the economically useful part. Also, within the framework of the experiment, it was supposed to test the market hypothesis about the high marketability of the resulting crop (its full suitability for sale in terms of sensory organoleptic properties).
3. During the period of the experiment, using the Mercury 230 ART-01-RN electric meters, separate metering of electricity was organized in the area supplemented by LED and sodium lamps.

Results

1. The variability of the luminous flux from LED luminaires was low, the coefficient of variation was within 20%. This indicates a uniform influx of photosynthetically active radiation from LED phytoirradiators, which positively influenced the formation of a cenosis uniform in height and density.

To determine the growth parameters, 20 plants of each variant were randomly selected. Plants were divided into aboveground and underground parts, weighed and dried at 70 ° C. Growth parameters, linear and mass characteristics of the aboveground part and root system were determined in plants.

Formed lettuce cenoses had a leaf index of about 6 (normal agronomic index) (Figure 1). This leaf area is capable of absorbing up to 95% of the incident light. The location of the lamps ensured a uniform distribution of light over the cenosis surface. This is evidenced by the value of the coefficient of variation, which did not exceed 20%.

Figure 1. The appearance of the cenosis of lettuce plants when illuminated by LED lamps ECOLED-BIO-112-185W-D120 UniversaLED.

The appearance of the agrocenosis of lettuce plants cultivated under traditional lighting visually looked somewhat worse than the plants supplemented with LED phyto-lamps (Figure 2). The use of LED irradiation of the lettuce plants resulted in a richer green light and a slightly richer visual perception of the volume of the leaf mass.

The PAR intensity at the plant level in December was 80–90 µmol quanta / m^2 s, in January at midday sundial the illumination could reach 120–130 µmol quanta / m^2 s PAR. During the first cycle of growing plants under LED lamps, they were receiving 240 mol quanta / m^2, which is equivalent to 54 MJ / m^2 of light energy. In the second rotation, due to a slight decrease in the suspension height of the lamps and an increase in natural insolation, the plants were receiving 35% of PAR bigger than in December.

Figure 2. The appearance of the cenosis of lettuce plants, supplemented traditional sodium lamp.

The illumination intensity of traditional sodium lamps and LED luminaires is shown in Table1.

Table 1.
Illumination intensity according to experiment options.

Lighting options	Total, lux	Active photon flux in the blue and red spectrum
Active photon flux in the blue and red spectrum	7080	1 420,0
LED phyto-lamps "ECOLED-BIO-112-185W-D120 Univer-saLED"	7757	5330

As can be seen from the table, with an increase in the total photon flux of only 9.6%, the option of supplementary illumination of lettuce plants provided an increase in photosynthetically active radiation in the blue and red spectrum by 3.75 times, while traditional light sources spent most of their energy on infrared light (heat) and on the yellow-green part of the spectrum visible to the human eye.

2. Improvement of the light regime has increased the quality of the harvest, the leaf blades of the lettuce had a normal shape, density and size. Under the conditions of LED lighting, lettuce seedlings have appeared on the third day, the data on the length of the plants were as follows. Comparative data on the growth characteristics of lettuce grown on LED and traditional light sources are shown in Figure 3.

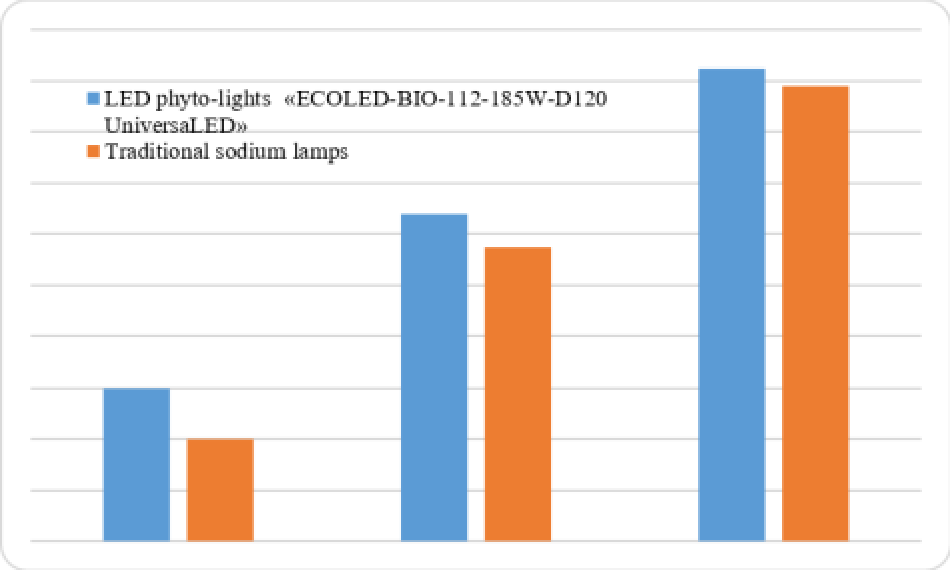

Figure 3. Comparative data on the growth characteristics of lettuce grown on LED and traditional light sources.

The weight characteristics of lettuce plants obtained as a result of the production experiment are shown in Figure 4.

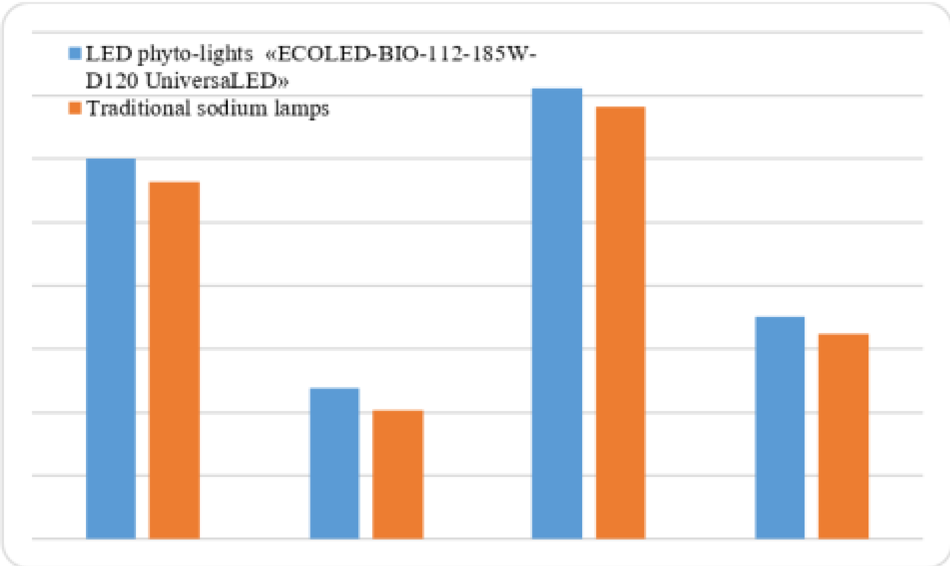

Figure 4. Comparative data on the weight characteristics of lettuce grown on LED and traditional light sources, grams.

By the time of harvest, the average height of the lettuce cenosis was approximately 23 cm (from the base of the pot to the top of the plant's leaf blade), the specific surface density of the leaves was 0.15 g / dm^2, and the leaf index was 6. The aboveground mass of freshly picked lettuce in each package sold for sale (a pot with three plants) averaged 70 g. The share of the root system did not exceed 5% of the aboveground part (Table 2). The lettuce yield was about 4.2 kg / m^2.

Table 2.
Indicators of salad productivity in traditional and LED winter lighting.

Lamp	Average mass of lettuce with pot, g	Average length of above-ground part of lettuce, cm	Average mass of above-ground part of lettuce, g
DNAZ «Reflux S400»	136,6	17,8	64,7
«ECOLED-BIO-112-185W-D120 UniversaLED»	142,4	18,5	70,1
Difference in mass (size), grams	+ 5,8	+ 0,7	5,4
Difference in mass (size), %	+4,2	+ 4	8,4

As can be seen from the Table 2, the total increase in the average mass of a salad plant together with a pot as a result of the application of LED lead was 5.8 grams or increased by 4.2%. The average size of the sheet became 0.7 cm or 4%. The most important indicator for technological and consumer use above ground increased by 5.4 grams or by more than 8%.

It should be noted that in the variant with irradiation of plants with traditional lamps, the growth rate of plants was lower in the first half of the 45-day experiment and slightly higher in the second half of this period. This fact provides some food for thought and for further research in order to increase the efficiency of LED lighting, for example, due to programmable intelligent changes in the light spectrum at different stages of morphogenesis.

This thesis can be confirmed by the fact that despite the significant, almost fourfold difference in the efficiency of LED lamps in the active spectrum of radiation in the blue and red spectrum, the increase in yield is characterized by only a few percent of the increase in leaf mass of lettuce.

From the point of view of A. Amoozgar, A. Mohammadi, M. R. Sabzalian, in production conditions, LEDs can be used not only to increase yields, but also to improve the nutritional value of salad plants (Amoozgar, Mohammadi & Sabzalian, 2017).

According to scientifically recommended consumption standards, a portion of 100 g lettuce provides up to 30% of the daily human demand for beta carotene (Provitamine A), about 10% of the recommended dose of plant polyphenols, 36% of manganese, 14% of potassium, 9% of chromium, about 5% of calcium, magnesium, phosphorus and iron (Unified sanitary, epidemiological and hygienic requirements for products subject to sanitary and epidemiological surveillance (control), Chapter II. Section 1. Fruit and vegetable products (Decision № 299, 2010). Consumers, controlling organizations and producers are naturally interested in the content not only of useful nutrients, but also safety indicators for unwanted substances, particularly nitrates.

Laboratory data from analyses of physico-chemical indicators of quality and biological value of the produced salad products show that the above-mentioned methodological recommendations are in compliance with the established standards (Table 3).

Table 3.
Nutrient content of lettuce leaves grown under LED lights, mg / 100 g

Soluble sugars	275±12	Phosphorus	38± 13
β- carotene	1.4±0.2	Magnesium	15±5
The amount of polyphenols	24.2±0.2	Iron	0.35±0.10
Potassium	344±138	Manganese	0.72±0.09
Calcium	52±20	Chromium	0.005±0.001

At the same time, the content of nitrates in the biomass of lettuce plants grown under LED lamps in winter didn't exceed the maximum permissible level, averaging 3740 mg / kg, which is almost 17% lower than the maximum permissible level.

The physicochemical composition of the lettuce harvest obtained using traditional light sources was characterized by absolutely comparable, similar values, including for nitrates (according to the experimental method, the cultivation technology hasn't been changed, only the lighting varied).

The physicochemical composition of the lettuce harvest obtained using traditional light sources was characterized by absolutely comparable, similar values, including for nitrates (according to the experimental method, the cultivation technology hasn't been changed, only the lighting varied).

The aboveground part of lettuce plants obtained as a result of this industrial and scientific test, was successfully sold on the consumer market of Perm Region at the market price prevailing at the time of sale.

3. As a result of the entire period of the experiment, the following results were obtained on energy consumption in test areas with traditional and LED lamps (Table 4).

Table 4.
Comparative electricity consumption in the area with LED phyto-lamps and sodium type DNAZ

Applicable lamps	Power consumption of the tested plot, kW
DNAZ «Reflux S400»	3460,8
«ECOLED-BIO-112-185W-D120 UniversaLED»	1373,1
Savings when using LED supplementary lighting, kW	2087,7
Savings when using LED supplementary lighting,%	60,3%

When replacing sodium lamps of the DNAZ type with LED lamps in a one-to-one ratio, it turned out that a 185-watt LED lamp can replace a 400-watt sodium lamp. At the same time, under the conditions of the set experience, the relative energy savings amounted to about 60%, or in absolute terms, 2087.7 kW.

Discussion

Despite a fairly large volume of fundamental scientific research in the field of using LED phytolight to increase the efficiency of agricultural production in hydroponic conditions and a fairly large number of production tests of LED lamps of various brands, there is still no unequivocal opinion on this issue among scientists and practitioners today.

According to the research of Professor I. G. Tarakanova, as well as O. S. Yakovleva, there is no universal photon flux spectrum that is equally suitable for all agricultural and ornamental plants. In addition, the same culture needs photosynthetically active radiation of different spectrum and intensity at different phases of its growth and development (Tarakanova & Yakovleva, 2011). The authors of this article fully agree with this opinion; indeed, at present, there are still no systemic developments on the use of photoculture as an adaptive technology for specific agricultural crops (in particular, industrially significant cucumber and tomato) for specific greenhouses located in different climatic conditions and different geographic segments of the consumer market.

To date, the effectiveness of LED lighting on green crops, in particular on salad, has been relatively studied and proven. This is proved by the works of Chinese scientists K. H. Lin, M. Y. Huang, W. D. Huang, M. H. Hsu, Z. W. Yang, C. M. Yang (Lin, Huang, Huang, Hsu, Yang & Yang, 2013). However, practice shows that the main crops that are the locomotives of the greenhouse industry – cucumber and tomato – are still cultivated in the Russian Federation under conditions of traditional sodium lighting. The same goes for one of the most profitable greenhouse industries, the floriculture industry.

Scientists M. Johkan, K. Shoji, F. Goto, S. Hahida, T. Yoshihara confirm the fact that the main effect of the use of LED phyto-lighting is provided by a reduction in energy consumption (Johkan, Shoji, Goto, Hashida & Yoshihara, 2010). This thesis is well known regarding not only phyto-lighting, but lighting in general. LED lamps solve the same problems as sodium lamps with more than twofold energy savings.

N. Gruda says that the most powerful factor limiting the development of the market for phyto-lamps based on LEDs is their relative high cost (Gruda, 2005). If energy savings are achieved at the level of more than two times, then the price of an LED phyto-light is three times higher today than that of a traditional lamp based on sodium lamps.

Therefore, in addition to saving energy, LED lighting can also affect the increase in the yield of irradiated crops. Therefore, as B. Mou emphasizes, an important point in favor of the practical use of LED phyto-lamps is that they are capable of providing an effective spectrum of photosynthetically active radiation, which is directly necessary for the plant (Mou, 2008). If sodium lamps give a peak of the photon flux in the middle of the visible spectrum of illumination (yellow-green colors), which are not decisive for photosynthesis, then in phyto-lamps the emission spectrum is shifted towards the so-called blue and red light. According to the authors, it is the possibility of varying the spectral properties of the luminaire that is the most important advantage of LED lighting systems.

According to the authors of the article, in addition to purely economic and technical factors that impede the widespread introduction of LED phyto-lighting fixtures in industrial complexes, organizational and managerial factors and thinking stereotypes of practitioners are of great importance. Indeed, when introducing LED lighting instead of traditional sodium lighting at an agricultural enterprise, it is necessary to take into account not only the financial aspects of its acquisition, but also the interests of agronomic, energy and engineering services.

Q. Li, C. Kubota state that in the modern world the desire of the population for proper nutrition with environmentally friendly products and responsibility for the state of the environment is growing more and more (Li & Kubota, 2009). In this aspect, LED phyto-lighting also outperforms gas-discharge lamps that require a special disposal procedure.

The main effect of the use of LED phyto lighting is provided by a reduction in energy costs. This thesis is well-known regarding not only the subject of phyto-lighting, but also lighting in general. LED lamps solve the same problems as sodium lamps with more than twofold energy savings.

The most powerful factor limiting the development of the market for phytolamps produced on the basis of LEDs is their relative high cost. If energy savings are achieved at a level of more than two times, then the price of an LED phytolamp today is three times higher than that of a traditional lamp based on sodium lamps (Figure 5).

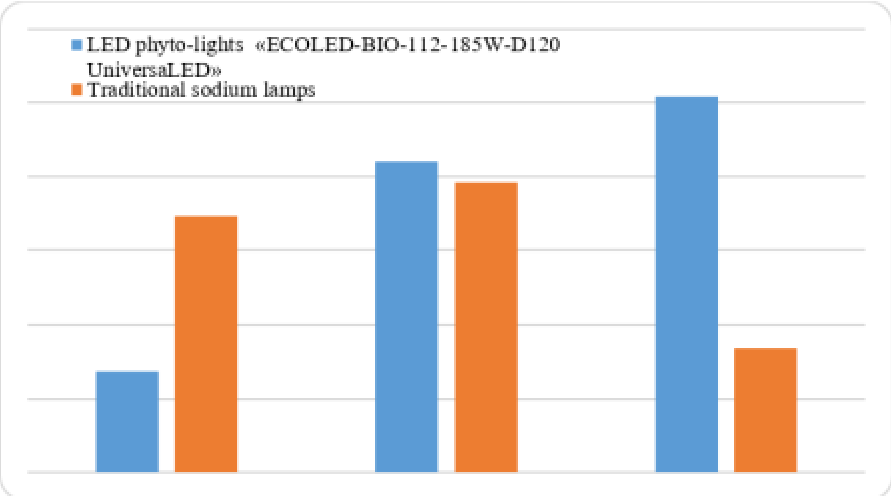

Figure 5. Summary of final technical and economic data production experience.

According to the results of the presented study, the benefits of using LEDs in growing green crops are, first of all, revealed in more than twofold energy savings, and secondly, in a small increase in yield.The opposite factor is the pricing characteristics, Figure 4 clearly shows that the initial investment cost of implementing LED lighting is about three times more expensive than using traditional high pressure sodium lamps. At the same time, the calculations of the authors show that with an average cost of electricity of 6 rubles per kW, the return on investment in LED lighting will come in less than four years with a warranty period of 5 years for the equipment.
Therefore, in addition to saving electricity, LED lighting can also affect the growth of the yield of irradiated crops. Therefore, an important point that speaks in favor of the practical use of LED phyto-lamps is that they are able to provide an

effective spectrum of photosynthetically active radiation, which is directly necessary for the plant. If sodium lamps give a photon flux peak in the middle of the visible light spectrum (yellow-green colors), which are not crucial for photosynthesis, then in phytolamps the emission spectrum is shifted towards the so-called blue and red light. According to the authors, it is the possibility of varying the spectral properties of the lamp that is the most important advantage of LED lighting systems.

According to the authors of the article, in addition to purely economic and technical factors that prevent the widespread introduction of LED phytolamps in production complexes, organizational and managerial factors and stereotypes of thinking of practitioners are important. Indeed, when introducing LED lighting instead of traditional sodium lighting at an agricultural enterprise, it is necessary to take into account not only the financial aspects of its acquisition, but also the inte-rests of agronomic, energy and engineering services.

In the modern world, the desire of the population for proper nutrition with environmentally friendly products and responsibility for the state of the environment is increasing. In this aspect, LED phyto-lighting outperforms gas-discharge lamps, which require a special disposal procedure.

In general, despite the difficulties in the development of the market for modern phyto-lighting systems, most experts and scientists believe that the future of the greenhouse industry is all about LED phyto-lighting, which in the coming years will replace traditional sodium lighting on the market.

Conclusions

Within the framework of this article, a self-sufficient scientific study was carried out where the set goal was achieved to assess the comparative effectiveness of the use of modern LED phyto-lights when supplementing lettuce plants in greenhouses with respect to sodium light sources traditionally used by greenhouse farms. This study confirmed the initial thesis (scientific hypothesis of the article) about the effectiveness of LED phyto-lights of the red-blue spectrum in comparison with sodium lamps DNAT / DNAZ under artificial lighting of protected ground vegetables.

In the conclusion of the scientific study, the following conclusions were made.

1. The mass of lettuce grown under LED phyto-lights of the ECOLED-BIO trademark was 8.3% higher than on the site using the conventional lighting technology with sodium gas-discharge lamps of the DNAZ Reflux S400 type.
2. The salad grown under the LED lamps ECOLED-BIO had a high level of quality both in terms of organoleptic and physicochemical indicators. In general, the appearance of green salad products was sufficiently marketable, which made it possible to fully realize it (with the exception of products selected for laboratory quality tests).
3. The use of the LED supplementary lighting system for lettuce plants allowed to reduce the power of lighting equipment by more than two times while maintaining and even improving the quality of the luminous flux (photosynthetically active radiation). As a result, the level of electricity consumption when using LED phyto-lights was 2.52 times less than in the version with sodium gas-discharge lamps DNAZ Reflux S400.

As a result of the use of LED lighting, the profitability of operating activities is significantly increased both due to the growth of revenues and due to the reduction in energy costs. Unfortunately, specific economic indicators are a commercial secret of the companies LLC Truzhenik and LLC Group of Companies Light and Electric Technologies (LLC GK SET), therefore the authors cannot bring them in a clear logical sequence in this article, but in general, calculations show that the payback on the purchase of LED phytolamps is about three to four years with a guaranteed useful life of 5 years.

Summarizing the above, the author's recommendation for manufacturers of green salad products is to introduce modern LED phyto-lighting systems at their enterprises.

The authors see a wide range of interdisciplinary (agronomic, technical and economic) research as opportunities for further scientific study to improve the efficiency of LED greenhouse lighting: 1) development of optimal technologies for the production of various crops of protected soil in the conditions of using LED light culture; 2) selection of the optimal spectrum of radiation for various plants and phases of their vegetation and various technologies of LED supplementary lighting, including combined methods using both LED and sodium lamps; 3) the possibility of reducing the cost of production and other pricing characteristics of LED phyto-lights; 4) improving the efficiency of lighting using modern research and development in the framework of the IOT (Internet of things).

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