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СТРАТЕГИЯ АКТИВНОГО ОПЫТА ПО ВЫРАЩИВАНИЮ ЗЕЛЕНОГО ЛУКА В УСЛОВИЯХ СВЕТОВОЙ КУЛЬТУРЫ: ОБЗОР

[1]Ключка Е.П., [1]Зотов А.А.

[1]Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация

Аннотация. В статье рассматривается эффективная концепция регрессионного анализа при моделировании сложных систем и процессов. Цель работы заключается в модификации традиционной стратегии планирования экспериментов, использующей текущую информацию следующего уровня экспериментов. Такая стратегия называется последовательным планированием эксперимента или планированием активных экспериментов на основе регрессионного и дисперсионного анализа. Стратегия активного эксперимента требует использования программного информационного продукта: по мере поступления информации от объекта исследования стратегия эксперимента меняется. Этот метод целесообразно реализовать в виде автоматизированных систем обработки результатов эксперимента. В дальнейшем метод формализованного получения структуры многофакторной регрессионной модели и устойчивой оценки ее коэффициента будет использован для построения высокоточных статистических моделей процесса выращивания растений в условиях искусственного освещения.

Ключевые слова. Моделирование, активный эксперимент, светокультурная технология.

STRATEGY FOR AN ACTIVE EXPERIMENT ON GROWING GREEN ONIONS UNDER LIGHT CULTURE: A REVIEW

[1]Klyuchka E.P., [1]Zotov A.A.

[1]Don State Technical University, Rostov-on-Don, Russian Federation

Abstract. The article considers an effective concept of regression analysis in modeling complex systems and processes. The purpose of the work is to modify the traditional experiment planning strategy, which uses the current information of the next level of experiments. Such a strategy is called a sequential planning experiment or planning active experiments based on regression and variance analyses. The strategy of an active experiment requires the use of a software information product: as information is received from the object of study, the strategy of the experiment changes. It is expedient to implement this method in the form of automated systems for processing the results of the experiment. In the future, the method of formalized obtaining the structure of a multifactorial regression model and stable estimation of its coefficient will be used to build high-precision statistical models of the process of growing plants under artificial lighting conditions.

Keywords. Simulation, active experiment, light culturing technology

Introduction. Currently, green crops are actively grown in a controlled microclimate with light culture technology: feather onion, batun, leek, radish, celery, sorrel, rhubarb, spinach, parsley, and more [1]. Green crops have a very short growing season and low heat requirements [2]. Green crops are grown in greenhouses in several rotations. Green onions are the most popular and sought-after product. Onions contain vitamins B1, B2, B6, PP, E, a large amount of vitamin C and essential oils. Onion is a source of glycosides, proteins, carotenes, flavonoid quarticin, enzymes, saponins, mineral salts of calcium, chlorine, sulfur, potassium, sodium, magnesium, phosphorus, and iron. Bulbs contain 8...14% sugars and 1.5...2% proteins, as well as phytoncides. The bulb and green leaves have an essential oil that has a specific smell and pungent taste and contains sulfur-containing compounds, iodine, organic acids (malic and liminone), pectins and glycosides. Onion stimulates the secretion of digestive juices, has a diuretic, sedative, anti-cancer effect. Onion phytoncides reveal the bacterial and antigestamine properties of plants [3]. Thus, green onions, which have all the qualities of a functional product, are an indispensable plant product. Economic efficiency depends on the amount of electricity used, and is also determined by the amount of crop, the cost of which must exceed the cost of planting material by at least 30%. The process of growing onions will be profitable if the correct selection of types and varieties of onions is carried out; and also correctly choose the way to grow them at different times of the year. Profit is determined by knowledge of the biological characteristics of the onion and the requirements for growth conditions. Growth conditions determine the degree of susceptibility to diseases and the preservation of the presentation during storage of onions [4, 5]. Onion becomes the most susceptible to diseases in greenhouse conditions of a controlled microclimate [6].

Green crops give a high yield increase at a daytime air temperature of +29, a night air temperature of +15 when forcing almost all green crops [7, 8]. Green onion is a vegetable crop that is most demanding on mineral nutrition when forming green mass. Nitrogen plays the main role in mineral nutrition [6]. Green onions are demanding in terms of light energy, moisture and have high cold tolerance [9]. However, the factors that influence green crops are not unambiguously interpreted. Temperature, humidity, atmospheric pressure, CO_2 vary within a certain range of parameters (Levine and Paré, 2009) that are most favorable for plants. The nutrient solution depends on the quality of the water (pH, temperature, presence of impurities), and also depends on the amount of elements and their ratio in the total composition of the elements [10]. Light energy is characterized by several parameters, both quantitative and qualitative: intensity, spectrum composition, photoperiod, exposure gradient, exposure dynamics [11, 12]. Thus, the microclimate has many specific requirements that determine the features of technologies, in particular light culture [13].

Thus, optimizing the process in which green onions are grown is an unresolved problem. Analysis of the literature does not answer a number of questions: there is no methodology for the substantiated selection of onion varieties for light culture technology; there is no technique for choosing the right way to grow green onions; onions are highly susceptible to diseases in greenhouse conditions of a controlled microclimate. Process optimization requires a new methodological approach to form a methodology for studying the process of growing green onions for light culture in a controlled microclimate.

Artificial microclimate and artificial lighting. The problem of using LED lighting for growing plants is debatable. Experiments demonstrate a positive experience, but the practice of using LEDs reveals that the biological effect is lower than expected and is unstable and unpredictable. LEDs are technically imperfect, and the plant control mechanism does not have generally accepted patterns. Another reason is that when creating LED lighting, technological and engineering issues are developed separately and not deep enough.

Ecologization of light culture technology depends on the set of parameters of the artificial microclimate. The optimization of the light environment is part of a larger problem, which is aimed at finding the optimal technology for growing onions. The mechanism that explores the influence of environmental factors on a biological system depends on the effect of a living system on the dose of exposure to various physical fields (light, electric, magnetic, electromagnetic, and much more). Dose is a rather conditional concept and denotes the impact of a factor of a certain intensity during the time of its action. The dose value is estimated from the response of the living system. Biological response assessment uses adequate dynamic characteristics of biological systems and results in an S-shaped dose curve. The position of the characteristic points shifts on the dose curve depending on many reasons: the functional state of the object, the degree of specificity of the influencing factor, the time of response registration, and others [14].

The dose is formed from several norms. The norm determines the optimal conditions for plants separately for each element of the light environment: by spectrum, by intensity, by exposure time. The choice of the norm of individual elements of the light environment is chosen empirically, according to the scientific literature based on the results of past experiments on various crops and plant varieties. There is no information about the optimal ratios (proportions) between the elements of the light environment within the whole norm. The optimal dose will change its value at different ratios of different norms of the elements of the light environment. The ratio of norms that belong to different elements of the light environment is an independent factor. At present, this approach is poorly researched and not practiced. The problem in which it is necessary to find the optimal ratio of the norms of individual elements is a more complex and time-consuming task. Indeed, the dependence of plant productivity on the general level of illumination is characterized by a curve on a plane. Plant productivity, which depends on the three elements of the light environment (spectrum, intensity, exposure time) should be expressed by a response dome in three-dimensional space. This assumption is based on the property of biological curve analysis [15].

Methods of mathematical modeling. Optimization of the technological process requires the use of scientific methods of mathematical modeling. The task of optimization is to determine the significance of the main technological factors and to find the optimal conditions for the implementation of the technological process. The technological process, which combines plants, technical equipment and artificial microclimate conditions, is a complex object for modeling and optimization. The plant depends on at least three factors (light, heat and humidity), in the absence of at least one factor, the existence of the plant is impossible. Light is the most ambiguous factor with many characteristics: spectral component, intensity, duration of exposure, exposure directional gradient. Light installations that create the required light for plants must have certain characteristics: technical, electrical, light, photometric, lighting. Light installations have technical and physical limitations. For example, the quality of light provided by lighting installations depends on the quality of electricity in the power supply system: the uniformity and constancy of the parameters of the light environment, the frequency of luminous flux pulses (flickers), and more. An important role is played by abiotic environmental factors: weather, temperature difference, atmospheric pressure difference and much more. Thus, the technological process that ensures the growth and development of plants in an artificial microclimate depends on a large number of controllable and uncontrollable factors, some of which are stochastic.

The specificity of such technological processes lies in the fact that the input parameters depend on the choice of technical systems, and the output parameters on the state of the biological object (plant). The technological process in its context carries mass and heat transfer, biokinetics, many simultaneously occurring biochemical reactions in the plant itself, this allows us to qualify this process as a poorly organized system. The problems of research and optimization of such systems are solved using the ideas and methods of multivariate mathematical statistics.

Kafarov V.V. et al. [16] discuss some approaches to creating models to describe such systems, where the derivation and application of technological processes of polynomial models is considered. The processes, which are considered as a kind of "black box", depend on the input and output parameters, are formally represented, according to well-developed regression analysis algorithms, in the form of regression equations. However, the cognitive capabilities of polynomial models are very limited, since it is impossible to restore the original functions that describe the mechanism of the process from the numerical values of the coefficients. Polynomial models, which are used in practice, are very useful, since they make it possible to predict the values of output parameters with a certain accuracy within the studied region of the factor space. They can be used to solve extreme problems, i.e. to optimize processes. This approach has the advantage of versatility. Universality allows you to apply the same techniques and algorithms for modeling and optimizing a wide variety of processes. Classical regression analysis has a certain degree of universality and a number of disadvantages that must be taken into account when processing the results of a multivariate "passive" experiment.

Regression analysis requires a large number of labor-intensive computational operations. The polynomial may change form after eliminating some coefficients, and it is necessary to recalculate all regression coefficients. The decision to exclude coefficients from the regression by significance is crucial, that is, on the one hand, the polynomial becomes less complex, on the other hand, it changes the interpretation of the results. The decision of the significance of the coefficients has a huge difference in the regressions for the factors that affect the biological object (plant) and technical systems. A biological object has a law of irritability, which says that the influence of a factor depends on both the intensity of the impact and the duration of the impact. At present, studies of the mechanism of action of weak factors on biological objects make a great contribution to understanding the nature of plants. Weak long-acting factors have a more significant effect on changing the structure of a biological system.

The polynomial has variables (factors) that may turn out to be pairwise correlated, dependent on each other, so the effects corresponding to them cannot be separated.

The polynomial, which was obtained as a result of a passive multifactorial experiment, does not give an estimate of the experimental error, therefore, it is impossible to rigorously test the hypothesis about the adequacy of the representation of the experimental results by the selected mathematical model.

The article does not cover all the shortcomings of modeling systems that involve biological objects and technical systems. However, the disadvantages that are described in the article have a solution if orthogonal planning is applied, i.e. conduct an active experiment based on the experiment planning method.

The experiment requires the organization of about 6-8 levels (norms), that is, gradations of the studied factor. In this case, the experiment covers the limiting, stationary, and inhibitory regions of the curve, where it is important to establish the central point. The experiment is successfully solved from the successful choice of the main level (center of the experiment) and the unit (step) of variation of the studied trait. Thus, the traditional experiment planning strategy is modified: for the best choice of points, current information is used, which comes as a result of processing previous experiments. Such a strategy is called a sequential planning experiment or planning active experiments based on regression and variance analyses. The strategy of an active experiment requires the use of a software information product: as information is received from the object of study, the strategy of the experiment changes. It is expedient to implement this method in the form of automated systems for processing the results of the experiment.

The development of a software information product that serves to model a complex system by the method of active experiment is closely related to the visualization of scientific data. Visualization is a significant part of the numerical simulation process. Visualization will provide analysis and correct interpretation of the results for further adjustment of the experiment. Thus, the organization of a scientific experiment should include solving problems that are associated with software engineering (common to many applications); creation, storage, processing and visualization of results. Finally, the main problem relates to the perception and interpretation of visual images by the user of the system.

The light environment as part of the artificial microclimate for growing plants is a controversial issue. Experiments demonstrate a positive experience with the use of LEDs, but the practice of using LEDs reveals that the biological effect is lower than expected and is unstable and unpredictable. This fact can be explained by the fact that the mechanism of plant control does not have generally accepted patterns. Another reason is that when creating an LED lighting module, technological and engineering issues are developed separately and not deep enough. A specific experiment gives the answer for certain plants in certain conditions of an artificial microclimate.

At present, the norm is accepted as optimal for plants separately for each element of the light environment: by spectrum, by intensity, by exposure time. The choice of the norm of individual elements of the light environment is chosen empirically, according to the scientific literature based on the results of past experiments on various crops and plant varieties. There is no information about the optimal ratios (proportions) between the elements of the light environment within the whole norm. Optimal norms are not the same for different ratios (different proportions) of the parameters of the elements of the light environment. The parameters of the norm are the characteristics on which this norm depends. What does the term normal mean in this context? The norm is a state of dynamic equilibrium between the parameters of a biological object and identical parameters of its environment.

The exposure dose of illumination (EDF) during the operation of the light installation is determined as the product of the intensity E during the operation of the installation τ: H=E×t. Thus, the same exposure dose of illumination (EDL) can be obtained at different intensities and exposure times. The scientific literature does not provide an explanation of what effect the exposure dose of lighting (EDL) has on plants with different ratios of intensity and time parameters. The time of exposure to the light environment for seeds and plants is a complex indicator. The first time that characterizes the growing season during which the plant is formed. The second time, which characterizes the total daily operating time of the lighting installation (the ratio of day and night). The third time, which characterizes the short intervals into which the operating time of the lighting installation is divided and creates light impulses (dynamic lighting). This time sets the rhythm of the impact of the light environment on seeds and plants. The scientific literature does not provide an explanation of the effect on plants of the exposure dose of illumination (EDD), which was obtained from constant (continuous) illumination or from light pulses of dynamic illumination. The spectral composition of the light environment plays an important role in the growth and development of plants. The illumination spectrum is characterized as a percentage between white, red, blue, green spectra (monochromatic illumination or integral illumination). Thus, the exposure dose of illumination (EDL) in an artificial microclimate has a multivariate solution. The exposure dose of lighting (EDD) for a plant should inform about the intensity of lighting, about the time of exposure to lighting per day (for the growing season); percentage of illumination spectra (integral or monochromatic); about the parameters of exposure to constant lighting or dynamic lighting.

The criteria for effectiveness are the length of the roots, the length of the plants. An important qualitative indicator of the development of the seedling is the proportional ratio of the length of the root to the length of the seedling, thus assessing the harmony of development. The mass of seedlings provides indirect information about the area of the leaf of the seedling and the thickness of the stem. Determination of the relative increase in the parameters of the length of the roots, the length of the seedlings, the weight of the seedling compared with the control indicators. For example, the relative increase in the length of the roots for option n relative to option 0 (control).

$$L^{n}_{k.option} = \frac{L^{n}_{k}}{L^{0}_{k}} 100\% \tag{1}$$

where $L^{n}_{к}$ – the average length of the roots at the exposure dose of lighting (EDL) with a certain ratio of intensity and time of exposure to lighting (constant or dynamic); $L^{0}_{к}$ – the average length of the roots of seedlings of untreated (control) seeds.

Approximation of the obtained results for each exposure dose by third-order polynomials using, for example, MatLab mathematical software packages:

$$B = a_3 E^3 + a_2 E^2 + a_1 E + a_0 \tag{2}$$

where B – the value of the parameters of the seedlings, expressed as a percentage of the corresponding control value,%; E – intensity of optical energy with a certain exposure time t, Joule/m^2. The exposure dose of illumination (EDF) of a monochromatic LED is constant, while with an increase in the intensity of optical energy, the exposure time decreases.

The graph is formed according to the results of the experiment from a family of transfer characteristics, which are dependences of the relative increase in parameters on exposure doses, for various ratios of the elements of the light medium, taking into account the approximation. The analysis is carried out according to the graph of the family of curves. The choice is made with respect to the level of increase to determine the illumination exposure dose (EDF). The exposure rate level is determined on the basis of two conditions. The first condition is the level of impact must be significant or the relative increase in the parameter under study must be greater than the relative error of its determination. The second condition is that the significant level line should be crossed by as many transfer characteristics as possible so that the relative spectral sensitivity curve consists of a larger number of points. Determination for each monochromatic LED with a different wavelength and illumination exposure dose (EDF) that causes the same increase (increase) in germination and primary germination parameters. To do this, a horizontal line is drawn on the transfer characteristics graph for the selected increase level, and when it first intersects with the transfer characteristic for a given wavelength, the illumination exposure dose (EDL) is determined.

Conclusion. The exposure dose of illumination (EDL) for a plant solves several problems:

- Establish a relationship or lack thereof between the parameters of the exposure dose of illumination (EDI): illumination intensity, time of exposure to illumination (constant or dynamic), percentage ratio of illumination spectra (integral or monochromatic).
- The ability to use the exposure dose of illumination (EDL) as the basis of method data for compiling a database of scientific experiments; as a tool for comparing scientific experiments and testing the reproducibility of experiments.
- Use the exposure dose of lighting (ELD) to standardize and normalize artificial lighting for plants in closed systems.
- To answer the question whether it is possible to compensate for one parameter by a combination of other parameters.

The article considers an effective concept of regression analysis in modeling complex systems and processes. The purpose of the work is to modify the traditional experiment planning strategy, which uses the current information of the next level of experiments. Such a strategy is called a sequential planning experiment or planning active experiments based on regression and variance analyses. The strategy of an active experiment requires the use of a software information product: as information is received from the object of study, the strategy of the experiment changes. It is expedient to implement this method in the form of automated systems for processing the results of the experiment. In the future, the method of formalized obtaining the structure of a multifactorial regression model and stable estimation of its coefficient will be used to build high-precision statistical models of the process of growing plants under artificial lighting conditions. It is assumed that the structure of the model is unknown to the author. Approximation of initial data is carried out using polynomial mathematical models. The idea of a full factorial experiment is used as a theoretical justification for correct statistical modeling. An extended concept of orthogonality of the resulting model is proposed: the design of the experiment, the structure of the model, and the structural elements of the model are orthogonal to each other. The orthogonal structure of the multivariate statistical model allows one to obtain statistically independent estimates of the coefficients of the modeled function. Such a structure can be unambiguously determined by statistically significant coefficients. Normalization of orthogonal effects makes it possible to obtain the most stable structure of the model, and, consequently, its coefficients. The use of models will allow us to analyze the mechanisms of the occurring phenomena and determine the exposure dose of illumination (EDL) and the optimal parameters of the artificial lighting system. The results of using the extended concept of orthogonality in building models of growing plants under artificial lighting conditions should evaluate the prospects of using the considered approach, its effectiveness and expediency in building a regression-statistical model of complex systems and processes.

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