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Smart greenhouse and plant growth control

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ABSTRACT

Since the development of agriculture is an important problem for every state, huge funds are allocated to this industry. However, the problem of lack of fresh fruits/vegetables, that is, the problem of import substitution remains a pressing issue in many countries. The aim of the study was to inspect the growth of plants in a home-based mini-greenhouse, for which reason the following tasks were set: conduct a biological experiment; search for dependence of the influence of environmental conditions (microclimate) on growth. The paper highlights the problem of import substitution of vegetables in Kazakhstan, and suggests the best way to solve this issue. The proposed solution offers the development of mini-greenhouse that meets the criteria of price and quality. The developed system differs from other smart greenhouses, firstly, by its availability to a wide range of users (price criterion), and secondly, by ensuring agrotechnical, energy, and design requirements (quality criterion). These requirements are implemented through the use of promising technologies: phytomonitoring, intelligent technologies and open source software, the use of available construction materials and water saving technologies such as drip irrigation. The economic effect from the use of the proposed technology has amounted to 10,000 tenge, the payback period was 4 seasons.

Keywords: Home-based mini-greenhouse, Phytomonitoring, Drip irrigation, Optimum, Plant growth dynamics, Open source software

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1. Introduction

Throughout human history, agriculture has remained the most conservative branch of the economy. Low margins, high risks, an acute dependence on fluctuations in the prices of fertilisers, fuel, finished products (highly fragmented supply chain) impede the infusion of private investment. Up to 30% of the total budget of the European Union is spent on supporting European farmers [1]. Greenhouse industry is one of the leading branches of agriculture. The health of the population directly depends on the development of this sector of the economy. For the full development of the human body, 80-100 kg of fresh vegetables (not counting potatoes) are needed for one person a year. For a family of 5, it is necessary to consume vegetables (kg): tomatoes (50), cabbage (50), onions (50), carrots (50), cucumbers (25), beans (25 kg), etc. [2; 3].
Since the development of agriculture is an important problem for every state, huge funds are allocated to this industry. However, the problem of lack of fresh fruits/vegetables, that is, the problem of import substitution remains a pressing issue in many countries [4-7]. The authors of the paper suggest the following solution. It is necessary to build a mini-greenhouse, which, although cannot give a large harvest, can provide for one family. The main advantage of mini-greenhouses from industrial ones is an affordable price for building materials, relatively low prices for household appliances and components, low costs for resources (electricity, water, etc.). It is assumed that if every citizen himself provides his family with fresh vegetables/fruits (growing in his own garden), then the state problem of import substitution will eventually fix itself [8]. There is also a problem of lack of personnel in the countryside due to the outflow of rural youth to the city. The training of rural personnel

in the field of smart and precision farming, energy-saving technologies, as well as the widespread introduction of mini-greenhouses in the village will solve the last problem.
It is known that the key requirement for the development and implementation of technical systems is the price/quality criterion. Obviously, the higher the quality, the higher the development cost and vice versa. But how to assemble a system that provides both the required quality and low price at the same time? One of the key problems in the development of modern greenhouses is the construction of a system that meets the criterion of price/quality [4; 6]: 1 – improving the quality of service (accuracy and high speed of control); 2 – reducing the cost of construction and equipment (availability to the general user) of the greenhouse.
Phytomonitoring is one of the leading advances in the greenhouse industry, which performs direct and continuous monitoring of the plant growth process, aimed at improving the controllable yield factors. According to experts, in the near future, it is the use of phytomonitoring that will become the world standard for developed agriculture and change the approach of farmers to their work [4; 9; 10]. This technology includes three components: 1 – recurrent visual inspection by specialists, sampling of plants, evaluation of the general condition; 2 – systematic laboratory analyses of plants, soil, irrigation water; 3 – continuous processing of information coming from phytomonitoring stations (monitoring sensors). But, however, the widespread adoption of the latest technology is limited by several reasons. A plant is a living organism that implements several functions – maintaining a stationary inner state (immunity), on the one hand, and adaptation to external conditions (survival) [3; 11]. Therefore, there is still a problem of the complexity of analysing the state of the plant (biological problem), and the complexity of developing equipment for monitoring the state of the plant (technical problem) (Table 1).

Table 1. New technologies in the greenhouse industry

Technology	IT functions	Advantages and disadvantages (in terms of price-quality)	Accessibility to the general population
Phytomonitoring [10]	TP control	The quality is increased due to continuous monitoring of all stages of plant growth and development. The price is relatively high.	There is no mass production and widespread use of this technology yet.
Drip irrigation [12, 13]	TP management	The accuracy of water regime control is increased and the loss of water resources is reduced (by about 30-60%). Affordable price.	Yes.
Smart greenhouses [14, 15, 16]	TP management and control	Labour automation, accuracy and speed of data processing. Complexity of development. Requires special knowledge. The development cost is relatively high, requires an order to a specialist.	No.
AIoT platforms / AIoT applications	TP control	Control of data coming from sensors, equipment, and other devices.	Yes.
Agricultural robots	TP management and control	Unmanned aerial vehicles, drones for monitoring the state of fields and harvesting, smart sensors.	No.
Hydroponics / Aeroponics [17, 18]	*	Improves the quality of harvesting by growing plants in water/air. Requires special knowledge in the field of biology and special equipment. The price is relatively high.	Yes.
Genetic engineering [4]	*	Improves the quality of obtaining crop varieties. Requires special knowledge in the field of biology and special equipment. The price is relatively high.	No.

*Note: * These technologies do not belong to IT technologies.*

For these reasons, most inexpensive greenhouses use control schemes without taking into account the state of the object of research – plants. This is a big drawback of such systems [5; 12; 14; 17; 18]. How to get out of the situation, is it possible to find an alternative solution that replaces the use of sensors for monitoring plant health? The authors propose to use intellectual technology instead of a phytosensor as part of the system, that is, two expert systems were used throughout the study. The first is used for control (phytomonitoring), the second – for object management.

The aim of the study is to inspect the growth of a plant in a mini-greenhouse. Research tasks: conduct a biological experiment; find the dependence of growth on the influence of environmental conditions (microclimate).

2. Materials and methods

In the life cycle (ontogeny) of the plant, four stages are distinguished: embryonic (seed development), juvenile (youth), reproductive (maturity), old age. Growth dynamics is determined by a growth curve that obeys a logarithmic law (Figure 1a) [3; 19]. The productivity of vegetable crops is largely determined by external conditions, that is, by microclimate conditions:

– climatic – temperature (day and night, total temperature), light (illumination, spectrum, photoperiod), air (composition, movement, humidity), magnetic field, mechanical impact (wind, etc.);
– soil (physical and chemical properties, soil air and moisture).

The level of plant response to exposure is determined by three values: optimum (most favourable), minimum and maximum (extreme) values of the factor at which plant life is possible. Closer to the optimum, the normal growth is observed, and closer to the minimum and maximum, the growth of individual organs slows down or accelerates, and as a result, the growth is defective. The closer to the optimum, the shorter the lag and the steeper the logarithmic part of the curve (Figure 1b).

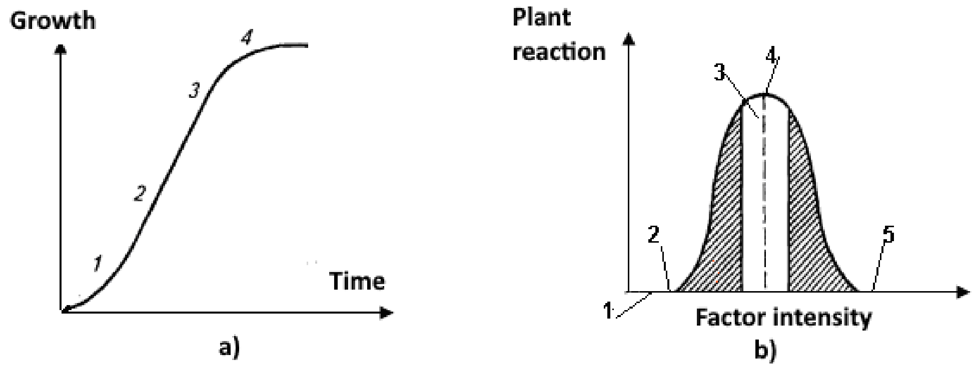


Figure 1. Plant growth dynamics: a) logistic curve: 1 – lag period, 2 – intensive growth phase, 3 – slow growth phase, 4 – steady state phase; b) the plant's response to environmental factors: 1 – minimum, 2 – pessimum zone, 3 – optimum zone, 4 – optimum, 5 – maximum.

Optimisation of conditions for growing vegetable crops in sheltered ground depends on the level of technical equipment that provides heating, lighting, maintaining a gaseous regime, watering, feeding and caring for plants, phytomonitoring.

The purpose of the experiment is to investigate the dynamics of plant growth in a home mini-greenhouse. The tasks of the experiment: to determine the dependence of growth on the influence of three factors of the microclimate environment: temperature, watering and illumination. Experiment characteristics:

1. Experiment site: home-based mini-greenhouse.
2. Time of the experiments: spring-summer season.
3. Period of the experiments: the full growing season.
4. Biological characteristics of the plant: tomato variety “Pink giant”. Mid-season variety (harvest in 110-120 days). The plant is semi-determinate. The normal height of the stem is 45 cm. Planting of seedlings in 40-45 days. Fruits are flat and round, fleshy, low-seeded, very large, weighing 350-500 g, good taste. Productivity 20-24 kg/m^2. Recommended for open and sheltered ground.
5. Cultivation technologies: greenhouse soil, composition – biohumus; drip irrigation.
6. Growing scheme: plot area – pot with of area 1 m^2, total area – 2 m^2. Each pot contains 4 plants (total planted 8).

The agrotechnical work plan is presented in the Table 2.

Table 2. The agrotechnical work plan

No.	Designation of the works	Implementation date
1	Sowing seeds	April
2	Lining-out	April
3	Seedling hardening	April
4	Planting seedlings	April
5	Installation of supports and trellises	May
6	Manual plant care (loosening the soil, weeding, hilling, watering)	the entire growing season
7	– visual inspection, measurement, processing of measurement data; – analysis of the work of the expert system and adjustment, if necessary	every 7 days during the growing season
8	Control and management of plant growth using the “Microclimate GH” mobile application	the entire growing season
9	Combatting plant diseases	May-July
10	Removal of side shoots	May-July
11	Harvest	August

The 7th and 8th stages of the work plan represent the use of intelligent technology. In the course of the 7th stage, the following indicators of plant growth are measured: number and length, colour of leaves, length and thickness of the main stem. The 7th stage is the training mode, and the 8th stage is the usage mode of the expert system.
The figure below provides the process flow diagram of the mini-greenhouse (Fig. 2). The system implements three technological processes (TP): cooling, watering and lighting.

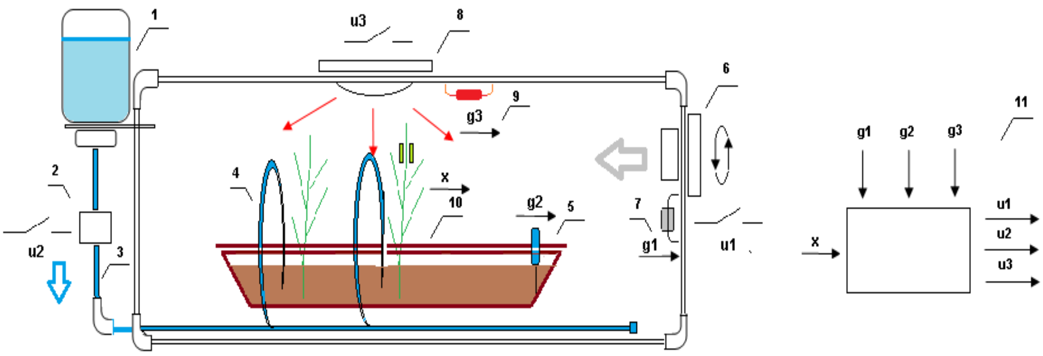


Figure 2. Technological processes in the mini-greenhouse

The drip irrigation system works in the following way. Water is filled into the tank (1). The control unit (CU) (11) regulates the water supply (control action *u2*), that is, opens/closes the water valve (2) by turning on/off the controller relay. When the valve is open, water flows downward (blue arrow), passing the main pipeline (3) and the drip chamber (4), and watering the plant in the pot (brown vessel). Information about the state of the soil *g2* is measured by the moisture sensor (5) and transmitted to the controller by the control unit. The cooling system is described as follows. The control unit regulates the air supply to the greenhouse, forming a control action *u1*, by turning on/off the fan (6) through a relay. The air supply is indicated by a grey arrow. The temperature sensor (7) measures the greenhouse air temperature *g1* and transmits the data to the CU controller. The lighting system controls the light conditions in the greenhouse. The control unit generates a control action *u3*, which turns on/off the lamp (8) via the controller relay. The light intensity data *g3* is measured by the light sensor (9) and transmitted to the CU controller.
Data on the state of the object *x* is measured by a phytosensor (10) and transmitted to the CU controller. Based on these data, the CU makes a decision on the management of the object. Let us consider in more detail the connection of the Control Unit with the technological processes of the greenhouse (Figure 3).

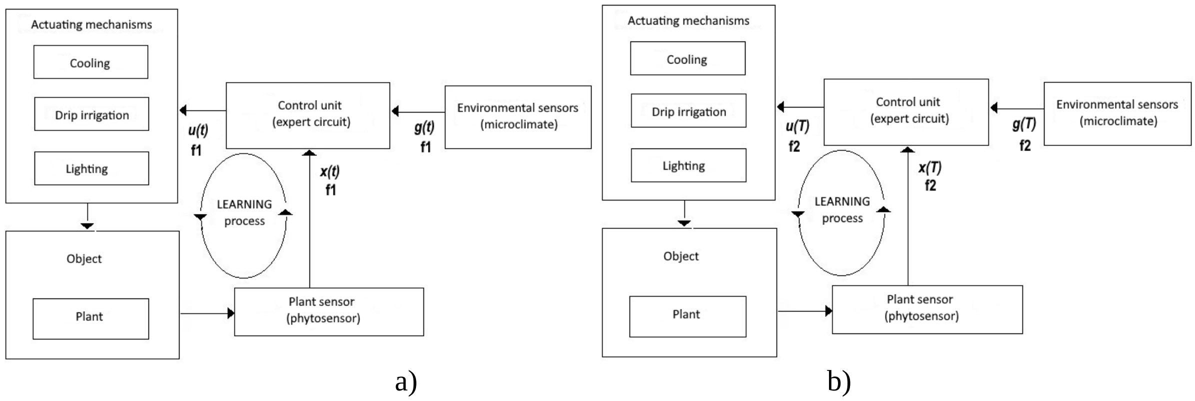


Figure 3. Control unit and data processing: a) in usage mode (*f1*); b) in training mode (*f*2)

The signals *g1(t), g2(t), g3(t)* from the sensors of the greenhouse environment (5), (7), (9), the signal *x(t)* of the plant sensor (10) are received at the input of the control unit. The frequency of reception of these signals and the frequency of processing by the microcontroller are different – the growth rate of a plant is much slower than the speed of reaction to environmental factors. This is due to biological and physiological processes in plants [3; 19]. The frequency of receiving environmental signals is assumed to be *f1=1* min (this is the frequency of updating the Database). The frequency of receiving signals from the plant sensor (10), describing the growth rate, is taken equal to *f2=7* days (7*24*60=10080 min). This is the frequency of updating the Knowledge Base. The developed model "Plant-Environment-Situation-Control" allows solving two types of problems: assessment of the state of an object (environment and plants) and the choice of a control mode for NLC. To assess the state of an object, the Environment block and the Plant block are used. The regulator (NLC) implements the function of selecting technological control depending on the situation in the Situation-Control block. The circuit that functionally implements the described model is shown in Fig. 4. It consists of the main blocks: a) Control object, in the centre of which the Plant is located; b) Information and measuring system; c) Actuating mechanisms; d) Control devices (CD) based on NLC. The system is controlled by the CD, which generates a control action based on the rules of the expert (the law of optimum) and based on the assessment of the current situation, calculated on the basis of information received from the measuring sensors and sends it to the appropriate actuating mechanism. Data exchange also occurs through the CD, which sends data to the Cloud Data Storage. Data from cloud storage for machine processing goes to the Matlab script, after processing it goes back to the CD through the Cloud storage. Monitoring data are stored in the storage for the entire growing season.

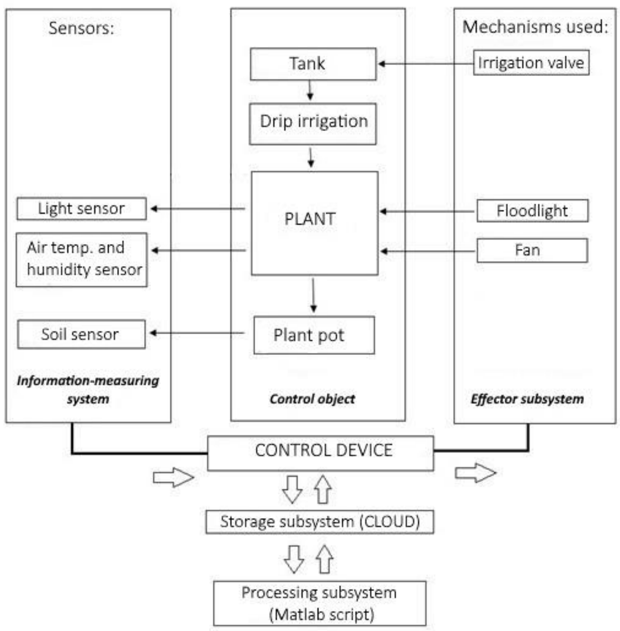


Figure 4. Functional diagram of an intelligent system

An experiment was carried out on a small scale, that is, in a home-based mini-greenhouse. This paper also presents an experiment on a large scale in a greenhouse for scientific research. For the purpose of the experiment, a diagram of the third block of the research greenhouse of the Al-Farabi Kazakh National University (Fig. 5). The block area is 3 hectares (length 60 m, width 5 m, height 3.6 m). The growing area contains 4 rows, each row contains 3 blocks. The total number of blocks is 4x2 = 8. One block is one plot, 3 plants can be planted in it. Each of the 8 blocks has its own watering valve (shown as a white open square). Water supply can be controlled by opening/closing the corresponding irrigation valve. Through each valve, through three irrigation droppers, water flows to an 8x3 = 24 plants. To monitor the state of the plant, each plant in the vicinity of the soil zone has its own transmitter with built-in sensors: temperature and humidity, illumination and soil moisture.

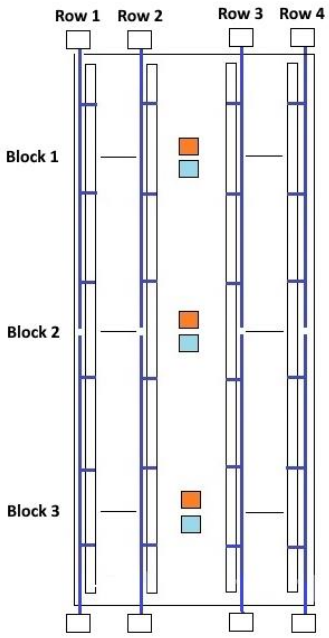


Figure 5. Arrangement of the third block of the greenhouse of the Al-Farabi KazNU

In the centre of the greenhouse, between the second and third rows, there are floodlights (highlighted in orange) and fans (highlighted in blue). There is free space between the rows for the possibility of performing agrotechnical manipulations, for example, visual inspection, etc. The total number of transmitter boards is 24. The total number of receiver boards with relays is 5. Of these, three are for turning on/off fans and floodlights. And the other two are for turning on/off the irrigation valves.

Characteristics of the biological experiment: the goal and objectives – to conduct a laboratory-vegetation experiment to study the dynamics of growth and assess the environmental conditions for optimum; place of the experiment – research greenhouse of the Al-Farabi KazNU; the time of the experiment is the spring-summer season; the period of the experiments is the entire growing season, including the initial phase, the phase of vegetative growth, flowering and the reproductive phase (fruiting).

Experiment configuration:

1. Growing scheme: the size of the plots – 1 m^2 (2 pots), the number of replications is 5-6.
2. Cultivation technologies: greenhouse soil, composition – biohumus.
3. To regulate the microclimate processes, three modes are implemented: a) cooling/heating mode: ventilation; b) lighting modes: natural and artificial; c) irrigation mode: drip irrigation.

Biological characteristics of the plant: hybrid cucumber variety “Junior Lieutenant”. High-yielding early maturing parthenocarpic bundle gherkin hybrid with a female flowering type. It is characterised by intensive growth, good regrowth of lateral shoots in combination with the second type of self-regulation of branching. In the nodes, from 2-3 to 5-7 or more ovaries are formed. Buttons are bright green, lumpy, with white-thorns, 9-12 cm long. High taste and canning qualities. The hybrid is resistant to mildew, cucumber scab, mosaic virus, tolerant to downy mildew. Recommended for open and sheltered ground. The agrotechnical work plan is presented in the Table 3.

Table 3. The agrotechnical work plan

No.	Designation of the works	Implementation date
1	Sowing seeds	April
2	Lining-out	April
3	Seedling hardening	April
4	Planting seedlings	April
5	Installation of supports and trellises	May
6	Manual plant care (loosening the soil, weeding, hilling, watering)	Initial and All stages
7	– visual inspection, measurement, processing of measurement data; – analysis of the work of the expert system and adjustment, if necessary	every 7 days during the growing season
8	Control and management of plant growth using the "Smart Greenhouse" mobile application	All stages
9	Combatting plant diseases	May
10	Removal of side shoots	May
11	Harvest	Fruiting stage

The experimental data was obtained on specially designed equipment of the "Home Smart Greenhouse" system (the system configuration is given in the Table 4).

Table 4. Technological equipment, materials and programmes

Equipment and materials	Model	Characteristics
Communication device		
Mobile phone	Samsung (1 pce)	Model SM-T239. Operating system Android 4.4.4
Control unit with built-in transmitter and receiver		
Microcontroller + Transmitter	ESP32 WiFi&Bluetooth CP2104 DHT11 Soil (24 pcs)	ESP32 WiFi&Bluetooth development board, support Nodumcu / Arduino DHT11 temperature and humidity sensor CP2104 communication chip Micro USB port Soil probe (long) soil temperature and humidity detection module LM393 based photosensor
Microcontroller + Receiver	ESP 32 WiFi + Bluetooth + battery (5 pcs)	ESP32 WiFi&Bluetooth development board, support Nodumcu / Arduino CP2104 communication chip USB to TTL Micro USB port 18650 Lithium Battery Holder Powered (Battery is not included)
MK programming environment	Arduino IDE (1 pce)	version 1.8.10
Mobile coding environment	Blynk (1 pce)	version 2.27.6

Figures 6 and 7 show experimental data on the environment and plants for 75 days. This is the daily average of the environment and the average of each plant. The average yield was 3-4 kg/plant. By maintaining optimal conditions in the greenhouse, several yields can be obtained in 2-3 months.

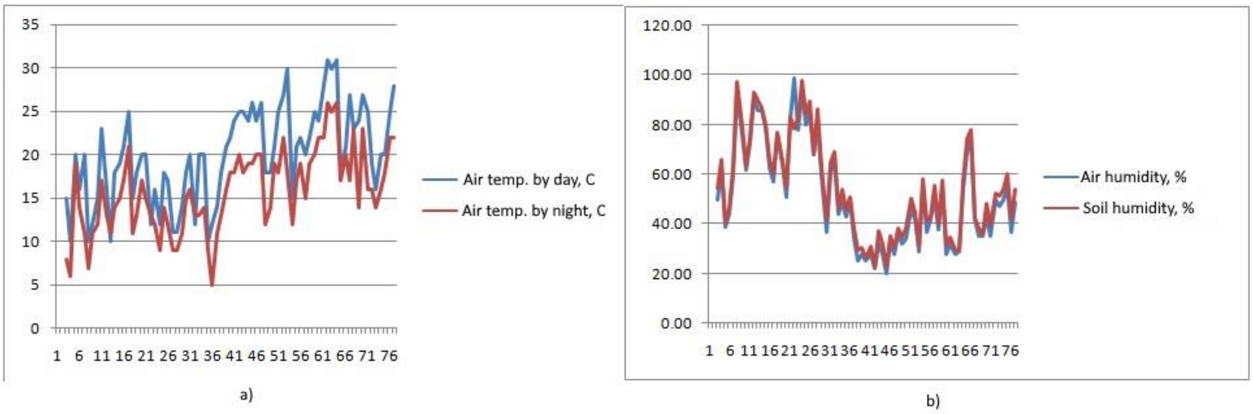


Figure 6. Data from monitoring air temperature (a) and humidity (b)

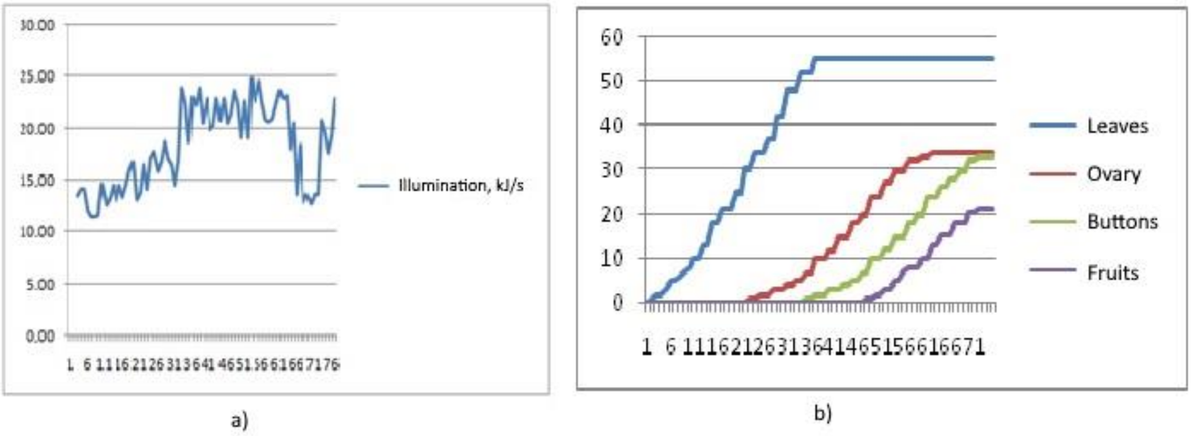


Figure 7. Data from monitoring illumination (a) and growth dynamics (b)

3. Results and discussion

A mathematical model of the "Plant-Environment-Situation-Control" system is proposed. It consists of blocks: Environment, Plant, Situation, and Control:

1 – Block Environment characterises the state of the microclimate on a daily basis (Atmosphere – air temperature, relative air humidity; Soil – relative soil humidity; Light – illumination). The state of the environment is described by the vector F.

2 – The Plant block is the main block of the system (Control object) and characterises the state of the plant and is described by the vector X.

3 – The Situation-Control block characterises the state variables of the system and the choice of the control mode (ventilation, lighting, drip irrigation) depending on the specific situation S. In this block, the integral indicators of Environment and Plants are calculated.

The mathematical model of the system belongs to the class of continuous-discrete (hybrid) systems. This suggests that the system is characterised by both continuous and discrete behaviour. Despite the fact that in any physical system the time t is continuous, we can speak of discrete times $t\ (i,j)$ as a subset of continuous time values. The developed model of the "Plant-Environment-Situation-Control" system and the process of regime control in accordance with a specific situation are shown in Figure 8. Before starting the simulation, the operation of converting continuous time into discrete time is performed: $t \rightarrow t\ (i,j)$. For example, the processes in the Environment Block are described in the diurnal time scale $t\ (i)$, that is, they have the Day and Night states. And the processes of the Plant Block on a biological time scale $t\ (j)$, this means that during the growing process, the plant passes through four phases (phenophases): initial (Sprout-Seedling), growth of the vegetative part, flowering and fruiting.

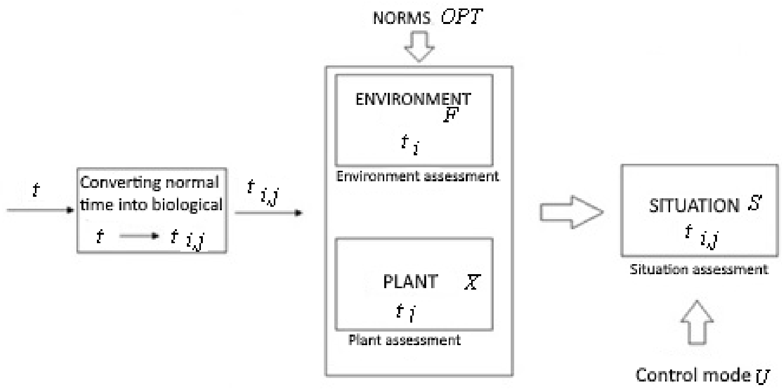


Figure 8. Model of the "Plant-Environment-Situation-Control" system and regime control

Depending on the specific state of the environment and the state of the plant, the system transitions from one mode to another. These specific states are situations (events). They define the control modes. There are two types of modes: a) biological, which describe the transition of a plant from one phase to another; and b) technological, describing the transition from one technological process to another. The conditions for the transition from one mode to another are determined by the corresponding biological and technological standards [20-24].

The "Plant-Environment-Situation-Control" model is described in [2; 4] and is implemented as an expert system (ES). Its core is the Knowledge Base (KB), it is built on the basis of an expert's knowledge and formalised in the form of rules. In our case, knowledge base replaces the mathematical model of the control object [25-48]. At the same time, the success of solving the problem largely depends on the structure and content of knowledge bases, as well as algorithms for their processing [49-67]. At the disposal of the expert, with whose participation the biotechnological (biological and technological) control is formed, there is a database in which the state of plants $X(t)$, the state of the environment (climate) $F(t)$, operating parameters of technological operations $u_k(t)$, $_k$=0,1,2,3 (norm, ventilation, lighting and watering). The knowledge of the expert in assessing the situation $S(X, F)$ will be used to select the control mode u_k.

The model of the "Plant-Environment-Situation-Control" system is specified as a sequence (Eqs. 1-6):

$$\langle X, F, S, OPT, U\rangle \tag{1}$$

$$X = \langle X_m(t_i), X_m(t_j)\rangle \tag{2}$$

$$F = \langle F_r(t_i), F_l(t_j)\rangle \tag{3}$$

$$S = \langle S_i(0, F_r), S_j(0, F_l), S_j(X_m, 0, t^*, t^{**}, t^{***}), S_j(X_m, F_l, t^*, t^{**}, t^{***})\rangle \tag{4}$$

$$OPT = \left\langle OPT_i(0, F_r), OPT_j(0, F_l), OPT_j(X_m, 0, t^*, t^{**}, t^{***}), OPT_j(X_m, F_l, t^*, t^{**}, t^{***})\right\rangle \tag{5}$$

$$U = \langle U_k(S_i), U_k(S_j)\rangle, \tag{6}$$

where:

– X_m (t_i) – daily plant state – input parameter (data);
– X_m (t_j) – biological state of the plant – input parameter (data);
– F_r (t_i) – daily state of the environment – input parameter (data);
– F_l (t_j) – biological state of the environment – input parameter (data);
– S_i – assessment of the current situation (daily) – calculation;
– S_j – assessment of the current integral situation (biological) – calculation;
– $U_k(S_i)$ – control mode in the current situation (daily) – calculation;

– $U_k(S_j)$ – control mode in the current situation (biological) – calculation;
– OPT_i – optimal conditions and norms (daily) – task;
– OPT_j – optimal conditions and norms (biological) – task.
– $t \in [0;T]$ – period.
Discrete moments of time t (i,j) are Boolean functions $D(t)$, $J(t)$ (Eqs. 7-8):

$$D(t) = \begin{cases} 1, t = t^{восх} \\ 0, t = t^{зах} \end{cases} \tag{7}$$

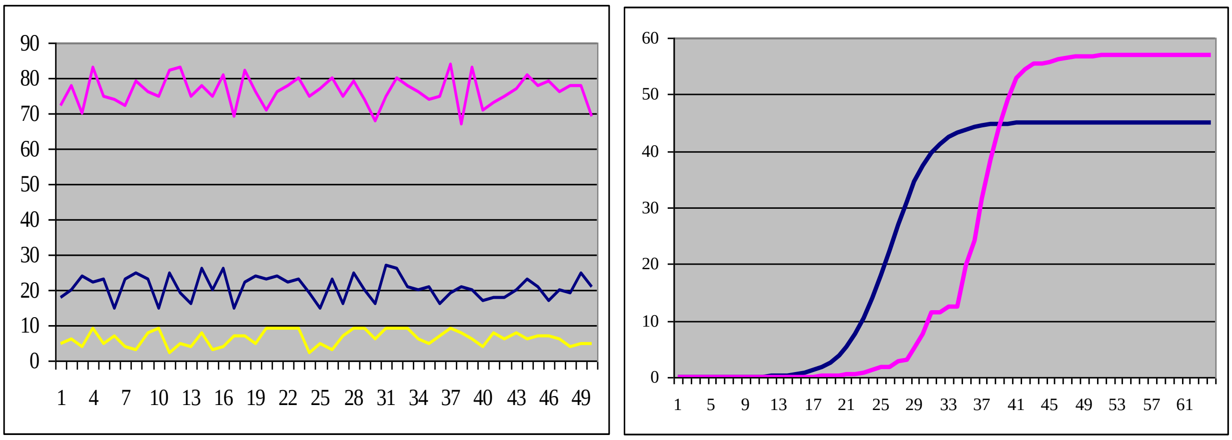
$$J(t) = \begin{cases} 1, t = t^{*} \\ 2, t = t^{**} \\ 3, t = t^{***} \end{cases} \tag{8}$$

where: t^*, t^{**}, t^{***} – moments of the onset of the 1st, 2nd, 3rd phases of plant development; t^{srise}, t^{sset}- the moments of sunrise and sunset; t – normal continuous time; $D(t)$ – discrete time (daily); i = 0, 1, 2; n – day number; $J(t)$ – discrete time (biological); J = 0, 1, 2, 3 – plant phenophase number [68-85].
The state of the plant $X_m(t_i)$ and $X_m(t_j)$ is defined through the variable m = 1, 2, 3, 4 – the number of agrotechnical indicator; where the specified variable expresses, respectively, the number of true leaves, the number of ovaries, the number of buttons, the number of ripe fruits in the daily t_i and in the biological time scale t_i. The state of the environment $F_r(t_i)$ and $F_l(t_j)$ is defined through the variables r = 1, 2, 3, 4, 5 – the number of the microclimate parameter and l = 1, 2, 3, 4, 5 – the number of the integral indicator; where $F_r(t_i)$ expresses, respectively, the daytime air temperature, night-time air temperature, air humidity, illumination, soil moisture in the daytime t_i; and the variable $F_l(t_j)$ expresses the daytime total effective temperature, night-time total effective temperature, total effective illumination, light period, and heat period in biological time t_j.
Control modes (technological solutions) $U_k(S_i)$ and $U_k(S_j)$ are defined, respectively, through the variable k = 0, 1, 2, 3 – control mode number: norm, ventilation, lighting, watering; where the variable $U_k(S_i)$ expresses the choice of the k-th mode in the current situation on a daily time scale; and $U_k(S_j)$ expresses the choice of the k-th mode in the current situation on a biological time scale for the j-th phase [86-102].
Mini-greenhouse is located in the apartment, under the window. The drawings were removed in the evening. It can be seen that the apartment is dark, although it was light outside and there is a lack of light. Therefore, most of the time the floodlight is switched on (Fig. 9).

a) b) c)

Figure 9. Home mini-greenhouse: a) irrigation valve; b) control unit; c) plants in the greenhouse

Figure 10 illustrates the readings of the sensors for air temperature, soil moisture and light. These data reflect the law of variation of a random variable (temperature 20 ± 2 ºC, soil moisture 76 ± 6%, illumination 5 ± 2 lm).



a) b)

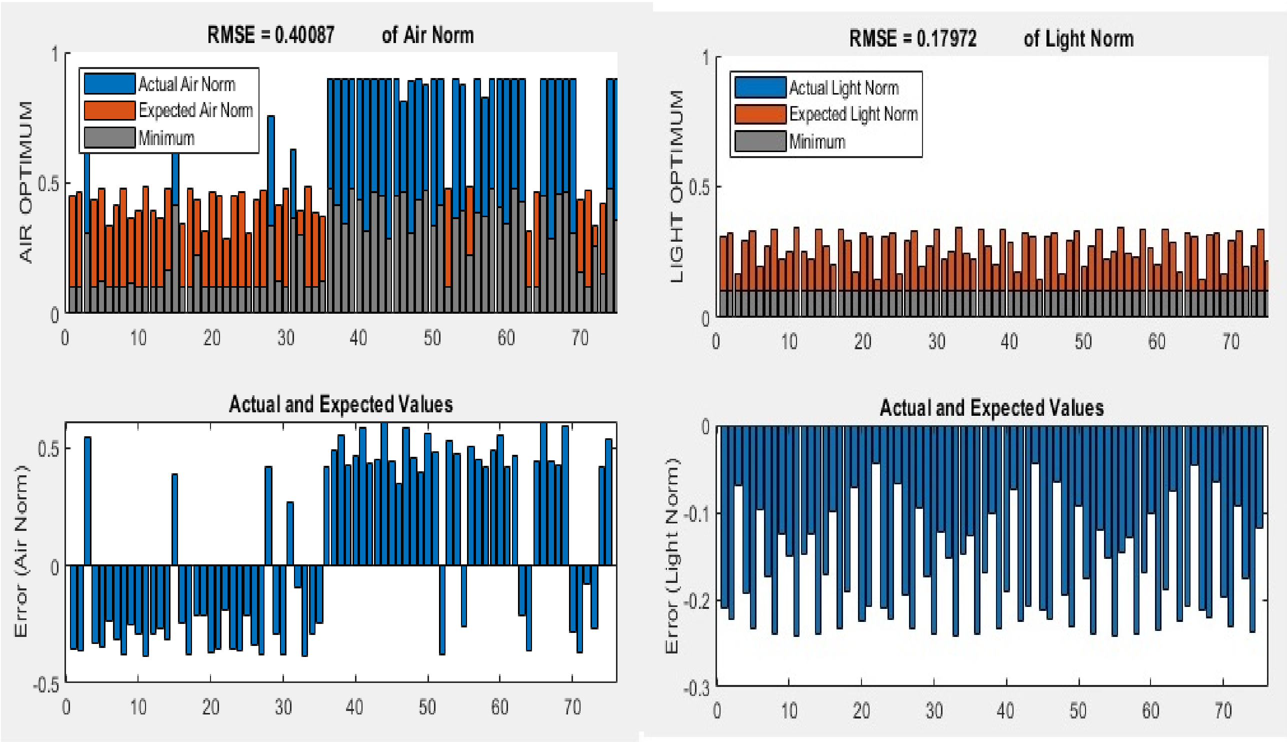
Figure 10. Influence of environmental factors (microclimate) on plant growth: a) measurement data of microclimate parameters (pink line – soil moisture, blue line – temperature, yellow line – lighting); b) plant growth depending on the microclimate condition (blue line – growth under normal environmental conditions, pink line – growth under deviations of environmental conditions and control modes)

The results of the biological experiment are shown in the Table 5.

Table 5. The results of the biological experiment (average)

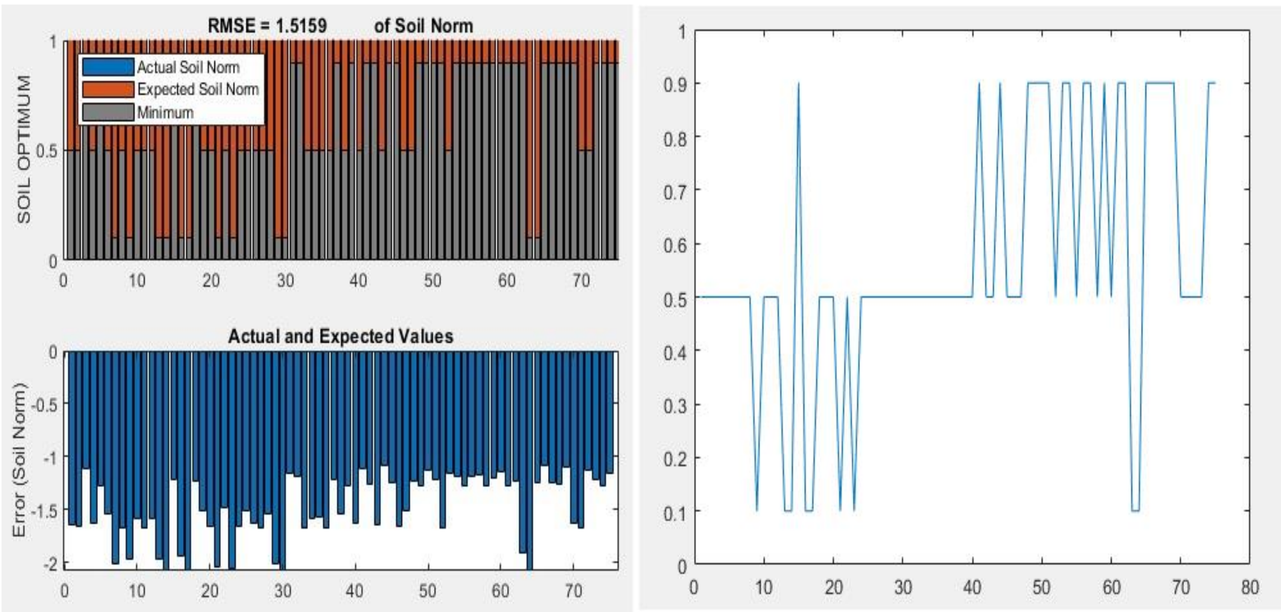
Control modes	Deviation of microclimate conditions		Zone	Growth quality
{1,1,1}	All three conditions are not met (3 deviations)	2%	Pessimum	Deviation 1
{1,1,0} or {1,0,1} or {0,1,1}	Two conditions are not met (2 deviations)	5%	Suboptimum 2	Deviation 2
{1,0,0} or {0,1,0} or {0,0,1}	One condition is not met (1 deviation)	26%	Suboptimum 1	Deviation 3
{0,0,0}	All conditions are met	22%	Optimum	Normal

From the biological characteristics of the plant, we know that normal growth is 45 cm, planting of seedlings in 40-45 days. The growth graph in Figure 10b shows the plant growth function with deviations from Table 5. Plant growth in a home-based greenhouse with deviations from Table 6 was: stem height 56.93 cm (1.26 times higher), time delay about 10 days.
The calculated conditions for the onset of phases $t^{*}= 9$; $t^{**}= 31$; $t^{***}= 57$ and real moments of plant phases are correspondingly equal to $t^{*}= 11$; $t^{**}= 38$; $t^{***}= 65$. In Figs. 11-14 are histograms showing the values of the standard deviations from the optima for air, light, soil and plants. The values of the estimates are respectively equal to $O1$ = 0.4008, $O2$ = 0.1797, $O3$ = 1.5159 (Fig. 8a, 9b, 10a). The overall cumulative estimate is O = 2.1105 (Fig. 9a). Fuzzy inference graphs of the knowledge base FIS_OPTIM in Fig. 11b show that the integral state of the environment and the plant is located near the optimum zone, thereby providing favourable conditions for plants. The results confirm that the observed states correspond to the law of optimum throughout the entire period of plant growth and development [103-120].



a) b)

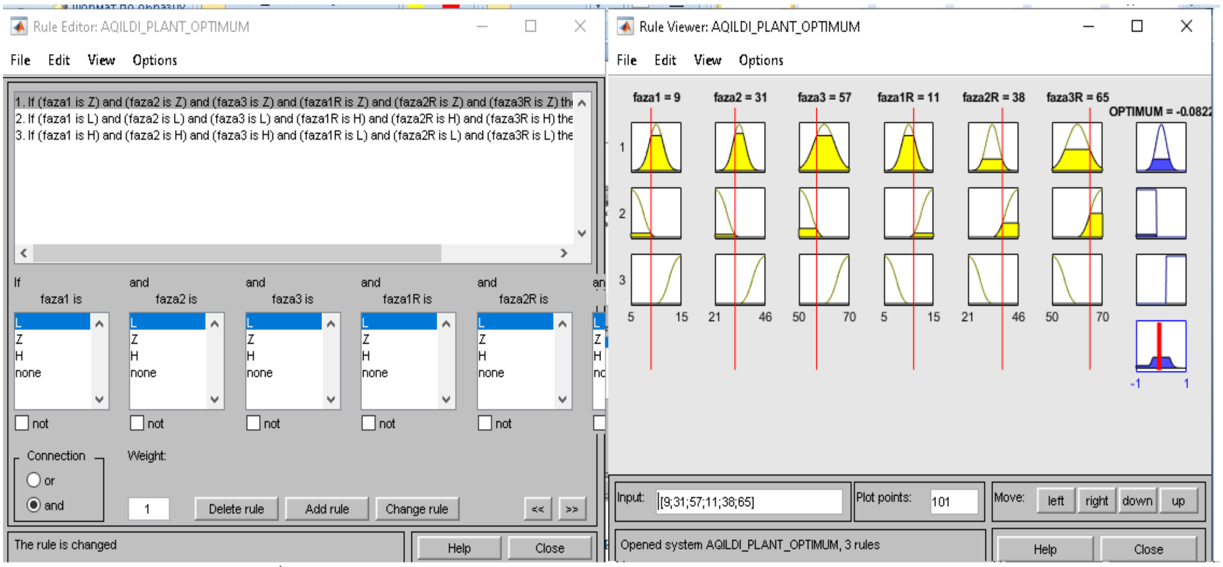
Figure 11. Optimum assessment: a) air environment; b) illumination



a) b)

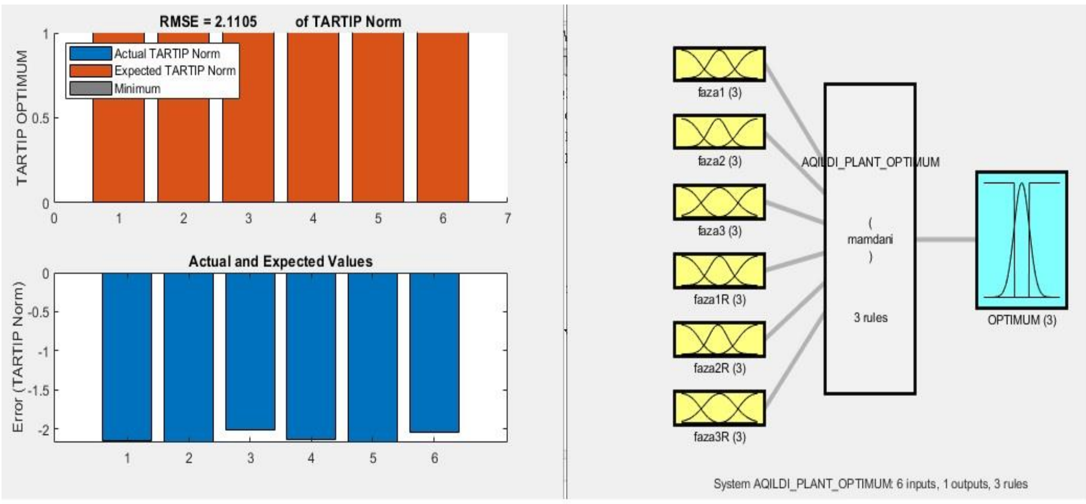
Figure 12. Optimum assessment: a) soil environment; b) fuzzy inference of the soil environment FIS_OPT3

Figures 13 and 14 also show the structure and rules of the knowledge bases of the fuzzy systems FIS_OPT3 and FIS_OPTIM, which are part of the "Plant-Environment-Optimum" expert system. Figure 10b shows the dynamics of plant growth and development, its graph clearly resembles the logistic growth curve (Fig. 2).



a) b)

Figure 13. The knowledge base of the integral estimation of the optimum FIS_OPTIM: a) Knowledge base rules; b) derivation of KB rules



a) b)

Figure 14. Knowledge base FIS_OPTIM: a) integral assessment b) structure of the FIS_OPTIM system

Figure 15 shows the greenhouse of the Al-Farabi Kazakh National University during the growing season of cucumber crops.

Figure 15. Greenhouse of the Al-Farabi KazNU during the growing season of cucumber crops

4. Conclusions

The task of developing mathematical models of complex agrotechnical and biological systems is an urgent problem for engineers and developers of software systems. This paper considers the model of the "Plant-Environment-Situation-Control" systems, proposed by the authors as an alternative version of the "Soil-Plant-Atmosphere" system. Unlike the Soil-Plant-Atmosphere system, which is a white box type model, the latest models are grey box type models, that is, based on the identification of experimental data. A feature of the system is its availability and simple operation, allowing the use of simpler methods than special allometric measurements to account for plant growth and development. It should be noted that the central place in the control of the state of the object and the management of agrotechnical systems will remain with the Man. The developed system is also a man-machine system with a rational separation of the functions of data preparation (computer) and decision-making (man).

In the course of the study, the following estimates were obtained: the state of the air environment to the optimum (process 1), the state of illumination to the optimum (process 2), the state of the soil environment to the optimum (process 3), and the overall integral assessment of the environment and plants to the optimum (process 4). The results obtained confirm that only at optimal values of the factor (in the optimum zone) are the best indicators of plant vital activity observed: they actively grow, feed, and multiply. The greater the deviation of the factor from these indicators, the less favourable it is for plants. As a result of the study, the authors came to the conclusion that:

a) under optimal environmental conditions, the process of normal, balanced growth and development of the plant is observed;

b) with non-optimum, that is, with a lack of certain factors (heat, air, light, water), a slowdown of plant growth and development is observed.

In the course of the study, the following was performed: a biological experiment was carried out; the dependence of growth on the conditions of microclimate parameters were determined.

The following conclusions were also made:

1. Vegetable plants react very sharply to changes in environmental factors, these factors are not interrelated, none can be replaced by another. The lack of illumination cannot be replaced by an increase in temperature or an improvement in root nutrition.
2. The full development of plants, and, consequently, a high yield is achieved while maintaining a complex of environmental factors within the optimum range.

When receiving a crop yield of 20 kg/m^2, at a price of 500 tenge/kg, the economic effect has amounted to 10,000 tenge.

References

[1] B. A. Belgibaev, A. A. Umarov, Utility Model Patent No. 2019/1162.2. "Smart Home Greenhouse", Nur-Sultan: The "National Institute of Intellectual Property" RSE, 2019.

[2] B. A. Belgibaev, V. V. Nikulin, A. A. Umarov, "Designing smart greenhouses, satisfactory price-quality", *Journal of Mathematics, Mechanics, Computer Science*, no. 1(105), pp. 174-190, 2020.

[3] S.S. Medvedev, Plant Physiology, St. Petersburg: BHV-Petersburg, 2012.

[4] N. A. Voinov, Modern problems and methods of biotechnology, Krasnoyarsk: IPK SFU, 2019.

[5] V. Petin, Projects using the Arduino controller, St. Petersburg: BHV-Petersburg, 2014.

[6] Irrigation solutions & climate control [Online], Available: www.naandanjain.com, 2014.

[7] H. A. Manisha Bhangea, "Hingoliwalab. Smart farming: pomegranate disease detection using image processing. second international symposium on computer vision and the internet (VisionNet'15)", *Procedia Computer Science*, no. 58, pp. 280-288, 2015.

[8] S. D. Shtovba, Design of fuzzy systems by means of Matlab, Moscow: Gor liniya – Telekom, 2007.

[9] Ch. S. Jao, Efficient decision support systems – practice and challenges in multidisciplinary domains, London: IntechOpen Limited, 2011.

[10] A. A. Umarov, B. A. Belgibaev, M. E. Mansurova, Zh. N. Eripkhan, Copyright certificate "Agyldy zhylyzhai". Computer program No. 7578, Nur-Sultan: The "National Institute of Intellectual Property" RSE, 2020.

[11] S. I. Savosin, Intelligent system for controlling humidity and air temperature in the greenhouse, Moscow: RGAZU, 2009.

[12] A. Umarov, M. Kunelbayev, M. Satymbekov, G. Turken, B. Alimbayeva, K. Imanzhanova, L. Duisembayeva, "Micro climate monitoring system for a home greenhouse as part of ESP32", *Test Engineering and Management*, no. 82, pp. 4564-4573, 2020.

[13] D. Klapwijk, Kasklimaat plantengroei en groeibeheersing onder glas, Amsterdam: Agon Elsevier, 1971.

[14] V. A. Kozhukhov, A. F. Semenov, N. V. Zuglenok, "Neural network temperature control in a greenhouse with a heat accumulator", *Bulletin of KRASGAU*, no. 8, pp. 125-130, 2010.

[15] Auroras S.r.l [Online], Available: www.auroras.eu, 2015.

[16] U. Ahmad, D. Made Subrata, Ch. Arif, "Speaking plant approach for automatic fertigation system in greenhouse", *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 4, no. 3, pp. 95-106, 2011.

[17] D. Li, L. Xu, Ch. Tan, E. D. Goodman, D. Fu, L. Xin, "Digitization and visualization of greenhouse tomato plants in indoor environments", *Sensors*, vol. 15, no. 2, pp. 4019-4051, 2015.

[18] U. Schuch, D. Dannehl, Microclimate control in greenhouses based on phytomonitoring data, Berlin: Humboldt University of Berlin, Biosystem Engineering division, 2013.

[19] G. N. Zaitsev, Optimum and norm in plant introduction, Moscow: Nauka, 1983.

[20] Association of greenhouses of Kazakhstan [Online], Available: http://greenhouses.kz/, 2020.

[21] Microclimate control and management system in the "Agroterm" vegetable store, [Online], Available: https://docplayer.ru/38758326-Sistema-kontrolya-i-upravleniya-mikroklimatom-v-ovoshchehranilishche-agroterm.html, 2017.

[22] "Smart farming": Overview of leading manufacturers and technologies, [Online], Available: https://geoline-tech.com/smartfarm/, 2018.

[23] Y. I. Zhuravlev, A. E. Dyusembaev, "Neural network construction for recognition problems with standard information on the basis of a model of algorithms with piecewise linear surfaces and parameters", *Doklady Mathematics*, vol. 100, no. 2, pp. 411-415, 2019.

[24] A. E. Dyusembaev, M. V. Grishko, "Construction of a correct algorithm and spatial neural network for recognition problems with binary data", *Computational Mathematics and Mathematical Physics*, vol. 58, no. 10, pp. 1673–1686, 2018.

[25] M. Kuprikov, L. N. Rabinskiy, "Influence of infrastructure constraints on the geometrical layout of a long-haul aircraft," *Journal of Mechanical Engineering Research and Developments*, vol. 41, no. 4, pp. 40-45, 2018.

[26] N. Aralbayev, F. Dikhanbayeva, A. Serikbayeva, Y. A. Yusof, Y. N. Abdul Manaf, "Comparative study of amino acid composition of raw and dry camel milk and shubat (Camelus dromedaries)," *EurAsian Journal of BioSciences*, vol. 13, no. 2, pp. 1489-1493, 2019.

[27] S. Kalchenko, N. Trusova, D. Hrybova, B. Serhii, "The small and large business interaction within national economy's gross added value reproduction in Ukraine," *Oeconomia Copernicana*, vol. 9, no. 3, pp. 403-417, 2018.

[28] E. Barbotkina, I. E. Dunaieva, V. Popovych, V. Pashtetsky, "Review of methods and approaches of abandoned lands identification," *E3S Web of Conferences*, vol. 224, 04004, 2020.

[29] M. Kuprikov, L. N. Rabinskiy, "Cross-polar routes as a factor that changed the geometric layout of long-haul aircrafts flying over long distances," *Journal of Mechanical Engineering Research and Developments*, vol. 41, no. 4, pp. 53-57, 2018.

[30] T. Sladkovska, M. Ostapchuk, S. Gorbatyuk, "Seed productivity formation of common ryegrass varieties," *Scientific Horizons*, vol. 11, no. 84, pp. 86-91, 2019.

[31] R. A. Baizholova, Y. D. Orynbassarova, A. N. Ramashova, Z. A. Abylkassimova, "Interactions between human capital and innovation," *International Journal of Economic Perspectives*, vol. 11, no. 2, pp. 36-39, 2017.

[32] O. V. Egorova, Y. K. Kyaw, "Solution of inverse non-stationary boundary value problems of diffraction of plane pressure wave on convex surfaces based on analytical solution," *Journal of Applied Engineering Science*, vol. 18, no. 4, pp. 676-680, 2020.

[33] M. Y. Kuprikov, N. M. Kuprikov, L. N. Rabinskiy, "The dependence of the appearance of the aircraft on the conditions of the arctic basing," *INCAS Bulletin,* vol. 11, pp. 115-123, 2019.
[34] A. G. Getmanov, L. N. Rabinskiy, "Assessment of durability of coatings in difficult stress conditions," *Periodico Tche Quimica,* vol. 16, no. 33, pp. 490-497, 2019.
[35] O. Nykolyuk, P. Pyvovar, L. Zherybor, "The level of flexibility of agricultural enterprises in the Zhytomyr region," *Scientific Horizons,* vol. 12, no. 85, pp. 3-14, 2019.
[36] L. M. Gaisina, M. L. Belonozhko, V. V. Maier, N. K. Abdrakhmanov, E. A. Sultanova, "Deliberate reorganization of the system of social relations in oil and gas companies in the period of changes in economics," *Espacios,* vol. 38, no. 48, pp. 1-12, 2017.
[37] A. Shoman, A. Serikbayeva, L. Mamayeva, B. Faye, T. Tultabayeva, "A biological analysis of endocrine-disturbing chemicals in camel meat sector in Kazakhstan," *EurAsian Journal of BioSciences,* vol. 12, no. 2, pp. 473-479, 2018.
[38] A. O. Zhupysheva, S. B. Makysh, R. R. Beisenova, L. Z. Beisenova, R. M. Tazitdinova, "Criteria for auditing the efficiency of natural resource use. Example of the Karaganda region," *Journal of Environmental Management and Tourism,* vol. 10, no. 7, pp. 1466-1477, 2019.
[39] B. K. Khusain, A. R. Brodskiy, V. I. Yaskevich, M. Z. Zhurinov, A. Z. Abilmagzhanov, "Investigation of the influence of the thermal effects on the fecral alloys KH15YU5 and KH23YU5," *EurAsian Journal of BioSciences,* vol. 13, no. 2, pp. 687-694, 2019.
[40] V. A. Zagovorchev, O. V. Tushavina, "The use of jet penetrators for movement in the lunar soil," *INCAS Bulletin,* vol. 11, pp. 121-130, 2019.
[41] V. A. Zagovorchev, O. V. Tushavina, "Selection of temperature and power parameters for multi-modular lunar jet penetrator," INCAS Bulletin, vol. 11, pp. 231-241, 2019.
[42] S. Vakhneev, E. Starovoitov, "Damping of circular composite viscoelastic plate vibration under neutron irradiation," *Journal of Applied Engineering Science,* vol. 18, no. 4, pp. 699-704, 2020.
[43] Y. Sun, M. Y. Kuprikov, E. L. Kuznetsova, "Effect of Flight range on the dimension of the main aircraft," *INCAS Bulletin,* vol. 12, pp. 201-209, 2020.
[44] A. M. Taufiq, Y. A. Yusof, N. L. Chin, S. H. Othman, A. Serikbaeva, M. G. Aziz, "Physicochemical properties of tamarind and pineapple fruit pulps and powders," *International Food Research Journal,* vol. 22, no. 2, pp. 707-712, 2015.
[45] O. M. Barbakov, M. L. Belonozhko, S. S. Siteva, A. L. Koltunov, L. N. Belonozhko, "The virtual space simulation of the regional governance system," *International Journal of Economics and Financial Issues,* vol. 6, no. 5, pp. 72-79, 2016.
[46] M. L. Belonozhko, L. N. Belonozhko, S. S. Siteva, "Digital tourism in the development of the Arctic Region," *Journal of Environmental Management and Tourism,* vol. 9, no. 6, pp. 1154-1164, 2018.
[47] I. D. Bobruskin, S. M. Shaĭkhin, M. V. Muratova, L. A. Baranova, E. S. Severin, "Allosteric regulation of Ca2+-calmodulin-dependent phosphodiesterase activity from the bovine brain," *Biokhimiya,* vol. 52, no. 8, pp. 1344-1352, 1987.
[48] Y. Li, A. M. Arutiunian, E. L. Kuznetsova, G. V. Fedotenkov, "Method for solving plane unsteady contact problems for rigid stamp and elastic half-space with a cavity of arbitrary geometry and location," *INCAS Bulletin,* vol. 12, pp. 99-113, 2020.
[49] E. L. Kuznetsova, G. V. Fedotenkov, E. I. Starovoitov, "Methods of diagnostic of pipe mechanical damage using functional analysis, neural networks and method of finite elements," *INCAS Bulletin,* vol. 12, pp. 79-90, 2020.
[50] D. A. Kozorez, E. A. Dolgova, A. V. Korneenkova, A. V. Rumakina, M. Sha, "Higher education institutions educational process digitalization in the context of the necessity to provide a model for students' choice of training areas and academic specialties," *International Journal of Criminology and Sociology,* vol. 9, pp. 3033-3039, 2020.
[51] R. R. Anamova, L. V. Bykov, D. A. Kozorez, "Algorithm for designing professional retraining programs based on a competency approach," *Education Sciences,* vol. 10, no. 8, pp. 1-9, 2020.
[52] M. K. Alimardanova, D. A. Tlevlesova, Z. Simov, D. Dimitrov, A. I. Matibayeva, "Incorporating allium odorum as a vegetable ingredient of processed cheeses," *Research Journal of Pharmaceutical, Biological and Chemical Sciences,* vol. 6, no. 3, pp. 330-338, 2015.
[53] E. V. Akimov, D. A. Kozorez, D. M. Kruzhkov, "Navigation solution concept and its practical approach development for lunar missions," *Russian Engineering Research,* vol. 40, no. 7, pp. 605-607, 2020.

[54] N. S. Kudryavtseva, A. E. Sorokin, "Comparative reliability assessment and costing of life support systems for extended interplanetary missions," *Aviakosmicheskaya i Ekologicheskaya Meditsina*, vol. 54, no. 2, pp. 30-37, 2020.
[55] O. Skydan, B. Sheludchenko, S. Kukharets, O. Medvedskyi, Y. Yarosh, "Analytical study of multifractal invariant attributes of traffic flows," *Eastern-European Journal of Enterprise Technologies*, vol. 3, no. 3-99, pp. 22-29, 2019.
[56] A. Issimov, D. B. Taylor, K. Zhugunissov, L. Kutumbetov, A. Zhanabayev, N. Kazhgaliyev, A. Akhmetaliyeva, B. Nurgaliyev, M. Shalmenov, G. Absatirov, L. Dushayeva, P. J. White, "The combined effects of temperature and relative humidity parameters on the reproduction of Stomoxys species in a laboratory setting," *PLoS ONE*, vol. 15, e0242794, 2021.
[57] B. K. Khusain, I. A. Shlygina, A. R. Brodsky, M. Z. Zhurinov, "Quantum chemical modeling of regents and products in the process of siloxane airgel formation," *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, vol. 7, no. 5, pp. 3073-3082, 2016.
[58] A. Issimov, D. B. Taylor, M. Shalmenov, B. Nurgaliyev, I. Zhubantayev, N. Abekeshev, K. Kushaliyev, A. Kereyev, L. Kutumbetov, A. Zhanabayev, Y. Zhakiyanova, P. J. White, "Retention of lumpy skin disease virus in Stomoxys SPP (Stomoxys calcitrans, Stomoxys sitiens, Stomoxys indica) following intrathoracic inoculation, Diptera: Muscidae," *PLoS ONE*, vol. 16, no. 2, e0238210, 2021.
[59] E. E. Galkina, A. E. Sorokin, "Quality management and sustainable economic development," *Russian Engineering Research*, vol. 40, no. 7, pp. 577-578, 2020.
[60] V. V. Bodryshev, L. G. Nartova, L. N. Rabinskiy, "Digital interpretation of gas dynamics problems as a means of optimizing fundamental general engineering education," *Asia Life Sciences*, vol. 2, pp. 759-774, 2019.
[61] V. V. Bodryshev, A. A. Larin, L. N. Rabinsky, "Flaw detection method for radomes in weakly anechoic conditions," *TEM Journal*, vol. 9, no. 1, pp. 169-176, 2020.
[62] V. V. Bodryshev, N. P. Korzhov, L. N. Rabinskiy, "Grapho-analytical analysis of video frames of supersonic flow around two solid revolutions using the digital image processing method," *TEM Journal*, vol. 9, no. 2, pp. 449-459, 2020.
[63] V. S. Terentieva, A. N. Astapov, "Conceptual protection model for especially heat-proof materials in hypersonic oxidizing gas flows," *Russian Journal of Non-Ferrous Metals*, vol. 59, no. 6, pp. 709-718, 2018.
[64] G. Chen, L. Wang, M. M. Kamruzzaman, "Spectral classification of ecological spatial polarization SAR image based on target decomposition algorithm and machine learning," *Neural Computing and Applications*, vol. 32, no. 10, pp. 5449-5460, 2020.
[65] R. S. Alibekov, G. S. Kenzhibayeva, A. A. Utebaeva, K. A. Urazbayeva, L. M. Tursynbay, D. A. Kulanova, "Enriched plum filling for the confectionery," *Food Research*, vol. 4, Suppl. 6, pp. 26-34, 2020.
[66] M. L. Belonozhko, O. M. Barbakov, A. L. Abramovsky, "Development of tourism in the arctic zone and its impact on environment," *Journal of Environmental Management and Tourism*, vol. 9, no. 8, pp. 1642-1650, 2018.
[67] L. Akbayeva, N. Mamytova, R. Beisenova, R. Tazitdinova, A. Abzhalelov, A. Akhayeva, "Studying the self-cleaning ability of water bodies and watercounts of Arshalyn district of Akmola region," *Journal of Environmental Management and Tourism*, vol. 11, no. 5, pp. 1095-1104, 2020.
[68] V. S. Terentieva, A. N. Astapov, L. N. Rabinskiy, "State in the field of heat-resistant coatings for heat-proof nickel alloys and steels," *Periodico Tche Quimica*, vol. 16, no. 33, pp. 561-572, 2019.
[69] V. A. Pogodin, A. N. Astapov, L. N. Rabinskiy, "CCCM specific surface estimation in process of low-temperature oxidation," *Periodico Tche Quimica*, vol. 17, no. 34, pp. 793-802, 2020.
[70] V. A. Pogodin, L. N. Rabinskii, S. A. Sitnikov, "3D printing of components for the gas-discharge chamber of electric rocket engines," *Russian Engineering Research*, vol. 39, no. 9, pp. 797-799, 2019.
[71] N. S. Severina, "Software complex for solving the different tasks of physical gas dynamics," *Periodico Tche Quimica*, vol. 16, no. 32, pp. 424-436, 2019.
[72] A. V. Babaytsev, L. N. Rabinskiy, K. T. Aung, "Investigation of the contact zone of a cylindrical shell located between two parallel rigid plates with a gap," *INCAS Bulletin*, vol. 12, pp. 43-52, 2020.
[73] I. Dunaieva, E. Barbotkina, V. Vecherkov, V. Popovych, V. Pashtetsky, V. Terleev, A. Nikonorov, L. Akimov, "Spatial and temporal databases for decision making and forecasting," *Advances in Intelligent Systems and Computing*, vol. 1259, pp. 198-205, 2021.

[74] R. Tazitdinova, R. Beisenova, G. Saspugayeva, B. Aubakirova, Z. Nurgalieva, A. Zandybai, I. Fakhrudenova, A. Kurmanbayeva, “Changes in the biochemical parameters of rat blood under the combined effect of chronic intoxication with such heavy metals as copper, zinc, arsenic,” *Advances in Animal and Veterinary Sciences,* vol. 6, no. 11, pp. 492-498, 2018.
[75] N. V. Trusova, I. A. Kohut, S. A. Osypenko, N. G. Radchenko, N. N. Rubtsova, “Implementation of the results of fiscal decentralization of Ukraine and the countries of the European union,” *Journal of Advanced Research in Law and Economics,* vol. 10, no. 6, pp. 1649-1663, 2019.
[76] G. Raiymbek, B. Faye, I. T. Kadim, A. Serikbaeva, G. Konuspayeva, “Comparative fatty acids composition and cholesterol content in Bactrian (Camelus bactrianus) and dromedary camel (Camelus dromedarius) meat,” *Tropical Animal Health and Production,* vol. 51, no. 7, pp. 2025-2035, 2019.
[77] A. V. Babaytsev, L. N. Rabinskiy, “Design calculation technique for thick-walled composite constructions operating under high-speed loading,” *Periodico Tche Quimica,* vol. 16, no. 33, pp. 480-489, 2019.
[78] G. Golub, O. Skydan, V. Kukharets, Y. Yarosh, S. Kukharets, “The estimation of energetically self-sufficient agroecosystem’s model,” *Journal of Central European Agriculture,* vol. 21, no. 1, pp. 168-175, 2020.
[79] A. V. Babaytsev, Y. K. Kyaw, S. N. Vakhneev, T. Zin Hein, “Study of the influence of spherical inclusions on mechanical characteristics,” *Periodico Tche Quimica,* vol. 17, no. 35, pp. 654-662, 2020.
[80] A. V. Babaytsev, A. A. Zotov, “Designing and calculation of extruded sections of an inhomogeneous composition,” *Russian Metallurgy (Metally),* vol. 2019, no. 13, pp. 1452-1455, 2019.
[81] R. Baizholova, Z. Abylkassimova, A. Ramashova, “Problems of staffing for innovation sector,” *Actual Problems of Economics,* vol. 178, no. 4, pp. 232-245, 2016.
[82] R. Beisenova, Z. Rakhymzhan, R. Tazitdinova, A. Auyelbekova, M. Khussainov, “Comparative characteristics of germination of some halophyte plants in Saline soils of Pavlodar region,” *Journal of Environmental Management and Tourism,* vol. 11, no. 5, pp. 1132-1142, 2020.
[83] B. Kalimbetov, B. Kalymbetov, G. Kenzhibayeva, D. Karmanov, A. Tukhtakuziyev, B. Kablan, “Justification parameters of the ripper tooth of combined unit for minimum tillage,” *EurAsian Journal of BioSciences,* vol. 13, no. 1, pp. 341-347, 2019.
[84] A. V. Babaytsev, A. A. Orekhov, L. N. Rabinskiy, “Properties and microstructure of $alsi_{10}mg$ samples obtained by selective laser melting,” *Nanoscience and Technology,* vol. 11, no. 3, pp. 213-222, 2020.
[85] V. V. Bodryshev, A. V. Babaytsev, L. N. Rabinskiy, “Investigation of processes of deformation of plastic materials with the help of digital image processing,” *Periodico Tche Quimica,* vol. 16, no. 33, pp. 865-876, 2019.
[86] G. Golub, S. Kukharets, O. Skydan, Y. Yarosh, V. Chuba, V. Golub, “The optimization of the gasifier recovery zone height when working on straw pellets,” *International Journal of Renewable Energy Research,* vol. 10, no. 2, pp. 529-536, 2020.
[87] V. A. Korolenko, Y. Li, V. N. Dobryanskiy, Y. O. Solyaev, “Experimental studies and modelling of fracture toughness of the epoxy samples with eccentric cracks,” *Journal of Applied Engineering Science,* vol. 18, no. 4, pp. 719-723, 2020.
[88] M. Sha, O. A. Prokudin, Y. O. Solyaev, S. N. Vakhneev, “Dependence of glare destruction mechanisms on the elongation of samples in tests to three-point flexural,” *Periodico Tche Quimica,* vol. 17, no. 35, pp. 549-558, 2020.
[89] S. Shamshedenova, R. Beisenova, Z. Rakhymzhan, Z. Zhaznaeva, N. Syzdykova, R. Tazitdinova, M. Khanturin, “Ecological characteristics of groundwater in rural areas of the Karaganda region,” *Journal of Ecological Engineering,* vol. 20, no. 11, pp. 67-75, 2019.
[90] V. S. Pashtetsky, V. V. Khomenko, N. P. Demchenko, N. Y. Poliakova, R. V. Kashbrasiev, “Sustainable and competitive agricultural development of a water-deficient region (Case of the Crimean Peninsula),” *Geography, Environment, Sustainability,* vol. 13, no. 2, pp. 65-72, 2020.
[91] N. V. Trusova, T. A. Cherniavska, S. R. Pasieka, V. H. Hranovska, O. S. Prystemskyi, V. S. Demko, “Innovative clustering of the region in the context of increasing competitive positions of the enterprises of the tourist-recreational destination,” *Geojournal of Tourism and Geosites,* vol. 31, no. 3, pp. 1126-1134, 2020.
[92] A. Babaytsev, V. Dobryanskiy, Y. Solyaev, “Optimization of thermal protection panels subjected to intense heating and mechanical loading,” *Lobachevskii Journal of Mathematics,* vol. 40, no. 7, pp. 887-895, 2019.

[93] S. A. Lurie, P. A. Belov, Y. O. Solyaev, E. C. Aifantis, "On one class of applied gradient models with simplified boundary problems," *Materials Physics and Mechanics*, vol. 32, no. 3, pp. 353-369, 2017
[94] S. Kukharets, G. Golub, O. Skydan, Y. Yarosh, M. Kukharets, "Justification of air flow speed in the oxidation area of a gasifier in case of straw pellets using," *INMATEH – Agricultural Engineering,* vol. 60, no. 1, pp. 37-44, 2020.
[95] Yu. G. Evtushenko, V. I. Zubov, S. A. Lurie, Yu. O. Solyaev, "Identification of kinetic parameters of the model of interphase layer growth in a fibrous composite," *Composites: Mechanics, Computations, Applications,* vol. 7, no. 3, pp. 175-187, 2016.
[96] N. V. Nevkrytaya, V. S. Pashtetskiy, I. A. Novikov, I. N. Korotkikh, R. R. Tkhaganov, "Variability of component composition of Melissa officinalis l. essential oil depending on the climatic conditions of the region of cultivation," *Khimiya Rastitel'nogo Syr'ya,* vol. 1, pp. 257-263, 2020.
[97] T. N. Melnichuk, S. F. Abdurashytov, E. E. Andronov, E. R. Abdurashytova, A. Y. Egovtseva, A. A. Gongalo, E. N. Turin, V. S. Pashtetskiy, "The taxonomic structure of southern chernozem at the genus level influenced by microbial preparations and farming systems," *IOP Conference Series: Earth and Environmental Science,* vol. 422, no. 1, 012101, 2020.
[98] R. Beisenova, S. Tulegenova, R. Tazitdinova, O. Kovalenko, G. Turlybekova, "Purification by ketoconazole adsorption from sewage," *Systematic Reviews in Pharmacy,* vol. 11, no. 6, pp. 550-554, 2020.
[99] V. S. Pashtetskiy, E. N. Turin, A. M. Izotov, S. F. Abdurashytov, A. A. Gongalo, K. G. Zhenchenko, "Effect of Pisum sativum L. seed treatment with the complex of microbiological preparation on the plants' growth and development under direct sowing," *IOP Conference Series: Earth and Environmental Science,* vol. 422, no. 1, 012012, 2020.
[100] E. L. Kuznetsova, A. V. Makarenko, "Mathematic simulation of energy-efficient power supply sources for mechatronic modules of promising mobile objects," *Periodico Tche Quimica,* vol. 15, no 1, pp. 330-338, 2018.
[101] Y. K. Kyaw, E. L. Kuznetsova, A. V. Makarenko, "Complex mathematical modelling of mechatronic modules of promising mobile objects," *INCAS Bulletin,* vol. 12, pp. 91-98, 2020.
[102] B. K. Khussain, K. K. Vinnikova, Y. Y. Kumarov, Z. D. Meirbek, A. B. Khussain, "Import substitution of software for digitalization of industry in the Republic of Kazakhstan," *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences,* vol. 3, no. 441, pp. 204-207, 2020.
[103] G. A. Golub, O. V. Skydan, S. M. Kukharets, O. A. Marus, "Substantiation of motion parameters of the substrate particles in the rotating digesters," *INMATEH - Agricultural Engineering,* vol. 57, no. 1, pp. 179-186, 2019.
[104] I. Sultangaliyeva, R. Beisenova, R. Tazitdinova, A. Abzhalelov, M. Khanturin, "The influence of electromagnetic radiation of cell phones on the behavior of animals," *Veterinary World,* vol. 13, no. 3, pp. 549-555, 2020.
[105] Z. Sarmurzina, G. Bissenova, K. Zakarya, R. Dospaeva, S. Shaikhin, A. Abzhalelov, "Characterization of probiotic strains of Lactobacillus candidates for development of synbiotic product for Kazakh population," *Journal of Pure and Applied Microbiology,* vol. 11, no. 1, pp. 151-161, 2017.
[106] N. V. Trusova, N. S. Tanklevska, T. A. Cherniavska, O. S. Prystemskyi, D. V. Yeremenko, V. S. Demko, "Financial provision of investment activities of the subjects of the world industry of tourist services," *Journal of Environmental Management and Tourism,* vol. 11, no. 4, pp. 890-902, 2020.
[107] B. S. Omirbayeva, R. A. Baizholova, D. M. Nurkhaliyeva, "Health care system in transition: Some aspects of financing," *Journal of Advanced Research in Law and Economics,* vol. 8, no. 4, pp. 1260-1275, 2017.
[108] R. S. Zhussupov, R. A. Baizholova, I. N. Dubina, G. T. Sadykova, "Methodology for assessing the competitive advantages of agriculture in the Northern regions of Kazakhstan," *Espacios*, vol. 39, no. 16, pp. 1-10, 2018.
[109] S. Shaikhin, A. Sobkiewicz, J. Barciszewski, T. Twardowski, "Evidence for plant ribosomal 5S RNA involvement in elongation of polypeptide chain biosynthesis," *Acta biochimica Polonica,* vol. 41, no. 1, pp. 57-62, 1994.
[110] E. Nagyzbekkyzy, G. Abitayeva, S. Anuarbekova, D. Shaikhina, K. Li, S. Shaikhin, K. Almagambetov, A. Abzhalelov, S. Saduakhassova, A. Kushugulova, F. Marotta, "Investigation of acid and bile tolerance,

antimicrobial activity and antibiotic resistance of lactobacillus strains isolated from Kazakh dairy foods," *Asian Journal of Applied Sciences,* vol. 9, no. 4, pp. 143-158, 2016.
[111] A. B. Maydirova, R. A. Baizholova, L. K. Sanalieva, G. T. Akhmetova, A. A. Kocherbaeva, "Strategic priorities of Kazakhstan innovative economy development," *Opción*, vol. 36, Special Edition 27, pp. 779-793, 2020.
[112] N. S. Salikova, Z. O. Tleuova, A. S. Kurmanbayeva, R. K. Khussainova, A. A. Kakabayev, "Distribution of radionuclides in natural waters of Northern Kazakhstan and assessment of waterborne doses irradiation of population," *Periodico Tche Quimica*, vol. 17, no. 36, pp. 1016-1037, 2020.
[113] V. D. Nazarova, N. S. Salikova, A. U. Bektemissova, B. E. Begenova, G. B. Aubakirova, "Isolation of miricetine-containing fractions from linosyris villosa plant and their application as antianemic agent," *Periodico Tche Quimica*, vol. 17, no. 35, pp. 998-1012, 2020.
[114] N. Vikhrova, E. Eliseeva, E. Sidorova, L. Korshunova, "Economic rationale for the operation of the circulation system of water use in nhermal power plants," *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM,* vol. 5, pp. 203-208, 2020.
[115] N. S. Salikova, A. U. Bektemissova, V. D. Nazarova, B. E. Begenova, N. V. Ostafeichuk, "Preparation of mixed hydrogels based on biopolymers and the study of their rheological properties," *Periodico Tche Quimica,* vol. 17, no. 35, pp. 23-40, 2020.
[116] L. Igaliyeva, S. Yegemberdiyeva, K. Utepkaliyeva, A. Bakirbekova, "Development of economic mechanism for ensuring ecological security in Kazakhstan," *International Journal of Energy Economics and Policy,* vol. 10, no. 4, pp. 240-250, 2020.
[117] Z. M. Orynkanova, R. A. Baizholova, A. Z. Zeinullina, "Improving the energy efficiency of Kazakhstan's economy," *Journal of Environmental Management and Tourism*, vol. 11, no. 1, pp. 44-53, 2020.
[118] S. Veremeenko, S. Tkachuk, S. Trusheva, "The influence of microfertilizers and plant growth regulators on the yield and grain quality of spring barley," *Scientific Horizons,* vol. 1, no. 86, pp. 14-21, 2020.
[119] E. Sidorova, "Modern strategic decisions in the field of waste as a basis of development of circular economy and greening of industrial production," *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM,* vol. 19, no. 5, pp. 531-538, 2019.
[120] N. V. Zakharchenko, S. L. Hasanov, A. V. Yumashev, O. I. Admakin, S. A. Lintser, M. I. Antipina, "Legal rationale of biodiversity regulation as a basis of stable ecological policy," *Journal of Environmental Management and Tourism,* vol. 9, no. 3, pp. 510-523, 2018.