# MATHEMATICAL MODEL OF CONTROL OF THE TEMPERATURE REGIME OF GREEN MASS GROWTH IN GREENHOUSE CONDITIONS

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***Abstract.*** *The article discusses the issues of automation and modeling of technological processes for growing green mass in a greenhouse complex with a controlled microclimate. A mathematical model of the behavior of such a complex is presented, which makes it possible to control the growth of green fodder. To simulate the behavior of the greenhouse, a computer model of the temperature control system was used, and the components of its object level are carried out.The article discusses the problem of assessing the influence of factors, in particular, ambient temperature on the growth of green fodder on the basis of a temperature control model. A comparative study of the morphophysiological parameters of green mass seedlings was carried out, in greenhouse conditions, depending on the intensity of the ambient temperature, the optimal temperature regime for the growth of green mass was revealed.*

***Keywords:*** *modeling, management, control, temperature regime, microclimate, growth of green mass, greenhouse farming.*

**Introduction.** Greenhouse farming today is one of the important areas that requires automation of production processes. For these purposes, various robotic systems are widely used by cyber-physical systems for such important tasks as: sowing, growing, watering, controlling humidity and ambient temperature, as well as pest control [1].

To solve these problems, it is necessary to develop various models, methods and systems of management and control, which can be attributed to the field of "smart greenhouse" [2]. The structural diagram of a "smart" greenhouse is shown in Figure 1.

All this requires the use of automation systems for technological processes in greenhouses, all this is aimed at the use of autonomous software installations, where it will be implemented for growing crops, monitoring such parameters as: temperature, humidity, water level and flow, irrigation and filtration, aeration of nutrient solutions. As a result, a large amount of time and costs for growing plants will be reduced, and as a result, it will lead to a decrease in the influence of the human factor, such factors as: mistakes that can lead to the death of plants, and ultimately to significant damage to the enterprise [3].

To solve these problems, it is necessary to simulate the behavior of autonomous plants so that the entire cultivation system can be controlled and deviations of these factors can be detected in a timely manner [4].

In this article, we will consider mathematical models of microclimate control (environmental model).

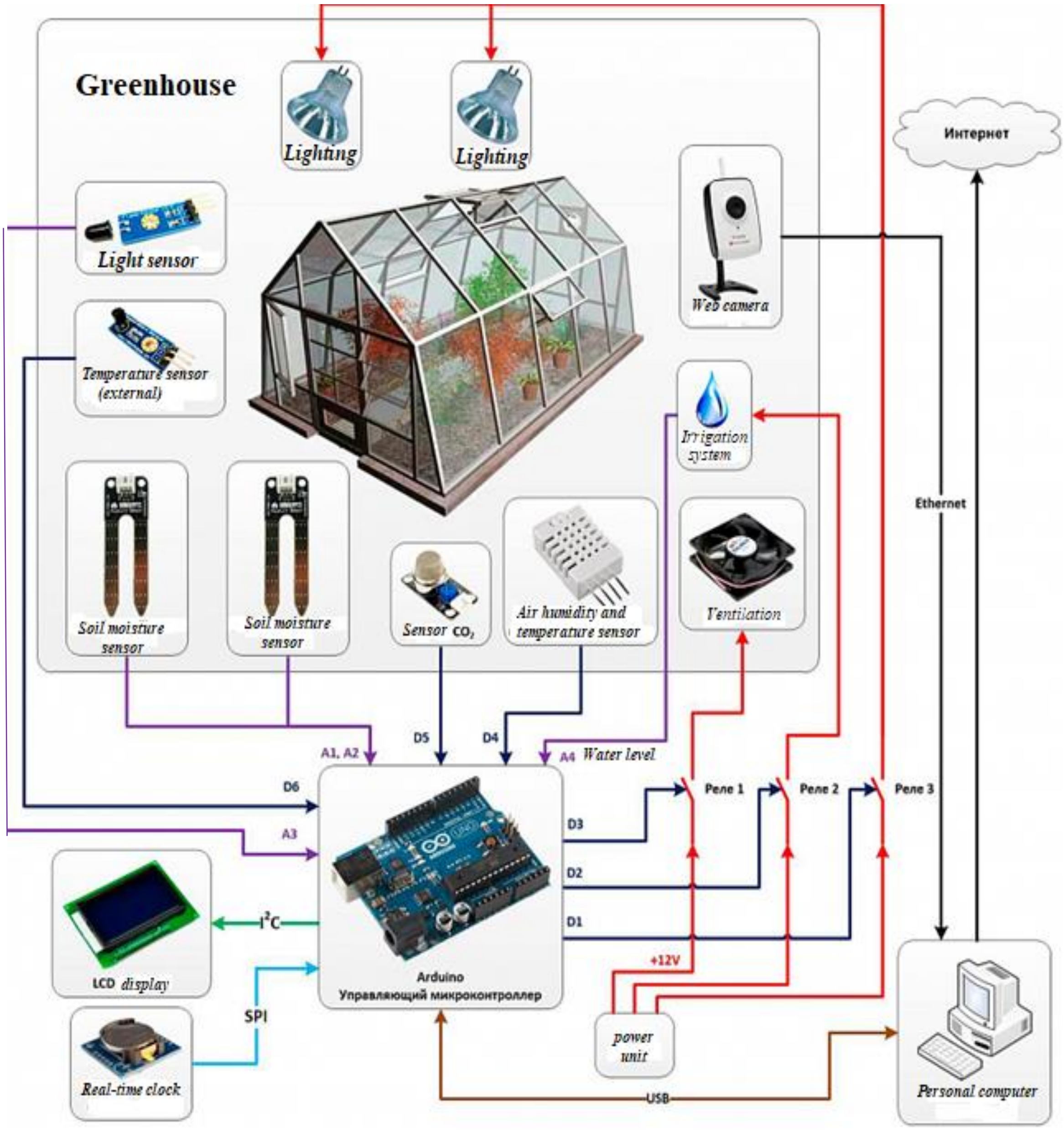



***Fig.1. Structural diagram of a "smart greenhouse"***

## 2. Material and Method

There are many models, methods, algorithms and architectures for automating the technological process of growing crops in closed greenhouse complexes. For example, [5] offers an automatic monitoring system for a greenhouse complex using temperature sensors, monitoring is carried out using Google Cloud, and information is provided via SMS.

However, the protocols used do not contribute to the reliability and scalability of the solution, and there is no way to control the parameters.

There are also methods of temperature control using Arduino and Raspberry Pi and offer a corresponding cloud architecture.

Methods using modern technology, or otherwise we call them automated greenhouses for growing crops, in particular, vegetables and fruits, require constant maintenance of an appropriate microclimate in closed ground systems, the operation of modern microclimate control systems is based on various control principles.

The method of use to maintain a certain temperature in the closed ground consists of the parameters of the greenhouse design, which provides natural heat accumulation, and the capacity of the heating equipment used [6].

Nutrients are most intensively consumed by plants at a temperature of 25-30°C. At a temperature above 35°C, the inactivation of enzymes involved in the absorption of nutrients begins. At temperatures below 15°C, all physiological processes slow down. The methods used to control the air temperature are important for plants, but it is expensive to regulate it for certain species, which is an important factor for greenhouses.

**2.1. Temperature control model**

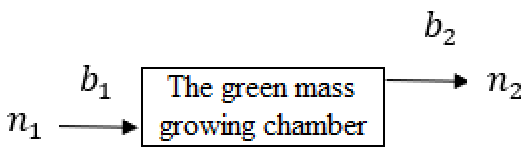
The main task of the management system for the cultivation of green fodder is to maintain the temperature regime in accordance with the crops grown. Its current temperature T is measured by the temperature sensor at regular intervals and transmitted to the control device.

If (where is the maximum possible temperature in the room), then the cooling system is switched on to ventilate the greenhouse room.$T > T_{max} T_{max}$

As soon as the temperature drops below the current temperature, the cooling system shuts down. When (is the minimum permissible room temperature), the heater fan is switched on, which heats the air in the room, and a control signal is also generated to the warning system, which warns the operator of an emergency situation in the room. If the minimum temperature value increases, the heater fan is switched $T < T_{min} T_{min} T > T_{min}$off.

**2.2. Temperature Management Model**

A computer model of the thermal control system, the following components of its object level are carried out.




***Rice. 2. "Grow Chamber" Component***

1. The "Grow Chamber" (Fig. 2) contains components with three heterogeneous vector connections [7]:

$S_1 = (b_1 \eta n_1) \rightarrow \{\{P_{1,} G_1\}, \{T_{1,} Q_1\}\}$ - for growing plants, air enters the chamber, where, is the air pressure; - speed of admission; - Incoming air temperature - the amount of heat carried by the air;$P_{1,} G_{1,} T_{1,} Q_{1,}$

$S_2 = (b_2 \eta n_2) \rightarrow \{\{P_{2,} G_2\}, \{T_{2,} Q_2\}\}$ - The air under the pressure created in the chamber and the current temperature of the air in the chamber is discharged from the chamber. $P_{2,} T_{2,}$

The mathematical model of a grow chamber includes the following equations:

$$P_1 = 0; \ \frac{dP_2}{dt} = \frac{1}{\pi d_1^2} G_1 - \frac{1}{\pi d_2^2} G_2; \ \frac{dT_2}{dt} = \frac{1}{\rho V c} Q_1; Q_1 - Q_2 = 0. \qquad (1)$$

Where is the diameter of the air inlet into the grow chamber;$d_1$ $d_2$ - diameter of the air outlet from the chamber; $\rho$ is the density of the air; $V$ *is* the volume of the chamber; c is the heat capacity of the air.

**3. Results and Discussions**

Regulation of the microclimate in greenhouses has its own peculiarities, which differ significantly from the maintenance of specified environmental parameters in residential and industrial premises. For this purpose, we have studied a number of factors influencing the growth of green mass in greenhouse conditions [7]. Let's discuss their features.

**3.1. Influence of ambient temperature on plant growth**

Thermal conditions regulate the intensity of photosynthetic processes and therefore directly affect the growth and development of plants. Photosynthesis reaches its maximum at a temperature of about 20…25 °C, and as the temperature rises further, it slows down [8].℃

When analyzing the temperature dependence of plant growth, three main points are distinguished: minimum (growth is just beginning), optimal (the most favorable period for growth) and maximum (growth arrest). Cardinal points are not the same for all plants. For example, green fodder (lettuce) belongs to the category of heat-loving plants, all points are shifted towards high temperatures. The minimum temperature for average height is 5+15℃ optimal 25+35 ℃; maximum 37+44 ℃. During the growing season, the state of the cardinal temperature points changes, as individual tissues and organs have their own significance. Thus, seed germination begins at 0, leaf growth at 6, and staminate filaments at 15℃.

At temperatures of 40-50 ℃, the rate of photosynthesis drops dramatically, while the rate of respiration is still high. Under such conditions, growth not only stops, but in some cases the dry weight of the plant may even decrease [9].

For example, the optimal temperature for the growth and development of wheat ranges from 10-24℃ degrees. Temperature deviations in one direction or another negatively affect the growth, development and productivity of the plant. With a relatively slow accumulation of the required amount of active temperature in the above temperature range, green forages will be large, with good shoots, broad leaves and a large ear, provided that they are provided with moisture, light and nutrients.

Our experiments for growing green fodder in greenhouse conditions showed that the optimal temperature during the period of seed formation at the time of the experiments was about 16... 24°C [10].

The results of the tests carried out in greenhouse conditions, the effect of temperature on the growth of green fodder are given in the table.

***Table***

| Day | Temperature, green mass growth | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20...24℃ control | Height cm | 5...15 ℃ | Height cm | 16...24 ℃ | Growth cm | 25...35 ℃ | Growth cm | 36...44 ℃ | Height cm |
| | | control | Minimum | | Optimal | | Higher than optimal | | Maximum | |
| 3 | | 1-3 | 4 | 1-2 | 16 | 2-3 | 23 | 1-2 | 33 | 1-2 |
| 4 | | 4-6 | 5 | 3-4 | 17 | 3-4 | 26 | 2-3 | 35 | 2-3 |
| 5 | | 7-9 | 7 | 4-5 | 18 | 5-6 | 27 | 4-5 | 37 | 3-4 |
| 6 | | 10-11 | 9 | 5-6 | 19 | 7-10 | 29 | 5-6 | 39 | 5-6 |
| 7 | | 12-14 | 10 | 7-8 | 20 | 11-13 | 31 | 7-8 | 40 | 6-7 |
| 8 | | 15-16 | 12 | 9-10 | 22 | 14-16 | 32 | 9-10 | 41 | 7-8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | | 17-18 | 14 | 11-12 | 23 | 17-18 | 33 | 11-13 | 42 | 9-10 |
| 10 | | 17-19 | 15 | 12-13 | 24 | 19-22 | 34 | 13-15 | 43 | 11-13 |

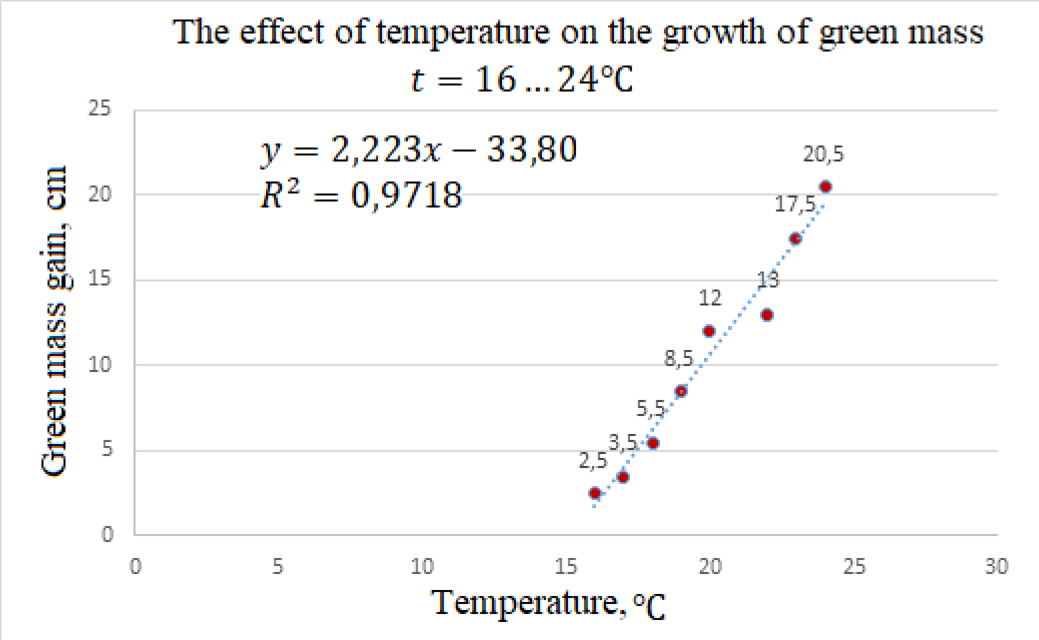



*Fig.3. Graph of the dependence of the growth of green fodder at a temperature of 16 ... 24* ℃.

Thus, a comparative study of the morphophysiological parameters of green mass seedlings showed that depending on the intensity of the ambient temperature in greenhouse conditions, the optimal regime is a temperature of power 16... 24℃.

**Findings**

The results presented in the article allow us to talk about the consistency of the main modules of the system, the architecture of which together is a simulation model of managing "smart" greenhouses using currently used hardware and software systems. This model allows us to draw the following conclusions about the operation of the greenhouse and the control of the ambient temperature in greenhouse conditions.

- A mathematical model of climate control was developed for the purpose of designing and testing hardware and software complexes for growing green fodder in greenhouse conditions.

- The algorithm for the growth of green fodder is aimed at technical regulation and automatic control of technological parameters (temperature), which affects the development and cultivation.

- In the cultivation of green fodder and the ratio of factors influencing its growth (temperature), determined by the method, are estimated and expressed by a graph of temperature dependence on growth.

The given mathematical model of the control system for monitoring the maintenance of the temperature regime in the automatic mode includes a large number of parameters, for these purposes and the complex of the automated system, it is also necessary to take into account humidity and artificial lighting in the greenhouse.

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