

Mathematical model for controlling CO₂ concentration in greenhouses late in MATLAB

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Abstract. The article is devoted to the development of an automated control system for irradiation facilities. The system will optimize the electricity cost for supplementary lighting plants in greenhouses without economic losses. A number of scientific researches studying chlorophyll, photosynthesis and processes in the green plant leaf were analyzed as the theoretical base for the present article. On their basis, a schematic structure of the photosynthetic apparatus of plants was developed and kinetic differential equations describing the structure and functioning of the photosynthetic chlorophyll apparatus of green plants were derived. The obtained mathematical expressions describe the changes in the concentrations of the base materials that participate in the formation of the photosynthetic apparatus structure and the accumulation of photosynthesis products and allow effective controlling of the irradiation process of plants. It has been achieved by adjusting the parameters of the illumination interval and the illumination area with the aid changing the number of switched on and off sources of optical radiation and changing the spectral component in a narrow limit.

1 Introduction

The development of an automated control system of irradiation facilities will optimize the irradiation modes for growing plants in protected soil. This will help to save energy and increase crop yields.

The major task is to find the optimal distribution of radiation energy in time. This is used to obtain the maximum integral photosynthesis and the creation of an automated control system by irradiation facility based on the results.

The object of the irradiation is the green leaf. It is an extremely complex living organism. It can adapt to changing factors in the surrounding environment in particular to different levels of irradiation. Each element of the leaf can interact with radiation energy in one way or another. In optical terms it can be characterized like other physical bodies by transmittance and absorption factors in accordance with the laws of optics and photometry. The rate of biochemical reactions taking place in the plant is determined by the occurrence of growing medium, the initial substances concentration, temperature.

The leaf is a self-adjusting system unlike the inanimate physical bodies. The reaction measure of this system depends on the magnitude of the radiant effect, the presence of inhibitory factors. It is known when the irradiation value changes the chlorophyll

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concentration and the area of chloroplasts change, i.e. the characteristics that determine the optical parameters of the leaf blade. At the same time, a number of experiments indicate a correlation between the photosynthesis intensity and the chlorophyll concentration [6, 12-17]. These issues were studied by Belova A.Y., Guryanova Y.X., Lysenko V.S. In their works, there are presented their own methods and irradiation models of cultivated plants but they have a number of disadvantages. For example, Belova Y.X. does not take into account the characteristics of the photosynthetic apparatus change depending on the conditions of irradiation. Photosynthesis is not a linear function of the chlorophyll amount. Moreover, there is information indicating its dependence on the structural organization of the light- harvesting apparatus of plants.

Nowadays, the photosynthetic unit is used as an elementary photosynthetic organ in modeling the photosynthetic function of plant. It is a structure consisting of several molecules- collectors and the center of excitation energy utilization that is called the reaction center [1-3,5,7,8].

The aim of the research is to develop a mathematical model of the irradiation plants efficiency which will optimize the cost of electricity for lighting plants, without quality loss.

2 Formulation of the problem

There were studied works of Kahler V.L., Fateev V.I., Labinov V.V., Chikov V.I., Belov A.Y., Mokronosov A.T., Furbank R.T., Lichtenthaler H.K., Omasa K., Buschmann C. On their basis there have been schematically depicted the photosynthetic apparatus of plants which is presented in the form of a scheme (figure 1).

The amount of chlorophyll a associated with the enzymic complex and acting as a reaction center (according to the scheme) depends on the concentration of protochlorophyllide and irradiation value. On account the dark reaction the bound chlorophyll a becomes free and forms a conglomerate of molecules-collectors. Its concentration is determined by the intensity of irradiation and the amount of free oxygen in the tissues of the leaf because chlorophyll decay occurs in the environment of oxygen in the light. Photosynthesis is the main source of oxygen in the light. Thus, it is necessary to take into account the presence of negative feedback between the synthesis of chlorophyll and photosynthesis.

3 Theory

The formalization of photosynthesis processes made it possible to develop a system of kinetic differential equations. The equations describe the structure and functioning of the photosynthetic chlorophyll apparatus of green plants.

We obtain the following system of equations on the base of the processes scheme of chlorophyll apparatus functioning shown in figure 1, where Pchl_{id} is the protochlorophyllide;

Chl' is the chlorophyll associated with a biological membrane;

Chl is the free chlorophyll; PS is the photosynthesis;

— is the positive relation;

--- is the negative relation.

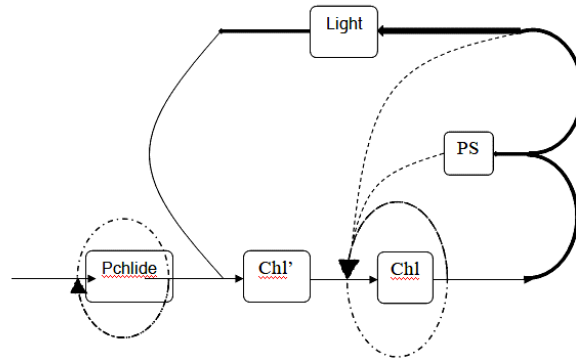


Fig.1. The scheme of chlorophyll apparatus functioning processes

The same information is shown in the work [12].

$$\begin{cases} \frac{dP}{dt} = C_1(40 - P) - C_2nP; \\ \frac{dR}{dt} = C_2nP - C_3R; \\ \frac{dH}{dt} = C_3R - C_4FH \left(n - \frac{R}{H} 3,27 - 10^4 \right); \\ \frac{dF}{dt} = C_4n - C_6A. \end{cases} \quad (1)$$

where P is the protochlorophyllide concentration, mg/g. dry basis.

n is the irradiance, W/m²;

R is concentration of reaction centers in the green leaf blade, mg/g. dry basis.

H is the chlorophyll concentration, mg/g. dry basis;

F is the photosynthetic rate, mg[CO₂]/m²;

C₁ is the rate constant of protochlorophyllide synthesis, s⁻¹.

C₂ is the rate constant, s⁻¹ W⁻¹ m².

C₃ is the rate constant of light-independent reaction of the chlorophyll a transition in the free state, s⁻¹

C₄ is the rate constant of chlorophyll photooxidation, m²mg[CO₂]⁻¹W⁻¹s⁻¹;

C₅ is the photosynthetic rate constant, (mg[CO₂]/mg/g. dry basis)⁻¹W⁻¹s⁻¹.

C₆ is the rate constant of photosynthesis inhibition own products, s⁻¹.

The mathematical expressions describe changes of the main substances' concentration involved in the formation of the photosynthetic apparatus structure and the photosynthesis products accumulation. The goal of improving the mathematical model is to achieve the maximum values of photosynthesis at an economically reasonable level of irradiance. In the process of joint solution of these equations the characteristics of photosynthetic objects in dynamic mode are obtained.

The system of equations is a dynamic model of some controllable system. It can be solved under the condition of maximum photosynthesis. If the control parameter is optical radiation the initial data will be obtained for the artificial irradiation installation design of plants. It will allow reducing the consumption of electrical energy without reducing the quality of plants grown. It should be noted that this model requires further refinement both in the accuracy of the constants included in the equation and in the reproducibility of the results based on laboratory tests.

On the basis of this model it is proposed to develop a system that could change the parameters of optical radiation based on measurements of CO₂ content, temperature, illumination in greenhouses. The automated system will adjust the parameters of the

illumination interval and of leaf illumination area. It will be achieved due to changes in the number of switched on and off sources of optical radiation and changes in the spectral component in a narrow limit for example, using LEDs. This system can be used with as the already installed lighting using lamp types of high-pressure sodium arc lamp or high-pressure sodium arc lamp mounted in a special bulb with internal mirror reflector as and FitoLED. Control methods depend on the type of lighting equipment. For example, if there are used the lamp types of HPS the principle of automated control is based on a controlled change in the brightness of the lamps by feeding them from an increased frequency source. If there is used FitoLED it is necessary to choose the optimal mode of operation through the use of LEDs and special methods of pulse width modulation.

Based on the above, a prototype was developed of the automatic control system. It is based on the optimization of growing plants process according to the criterion of minimum energy intensity by varying the irradiation parameters.

At the moment, the system contains a part of the variables obtained experimentally, as well as from the scientific literature and therefore subject to revision and optimization.

4 Experimental results

The data are collected with help the facility based on the Atmega2560 AVR microcontroller and connected sensors. Block diagram is shown in figure 2.

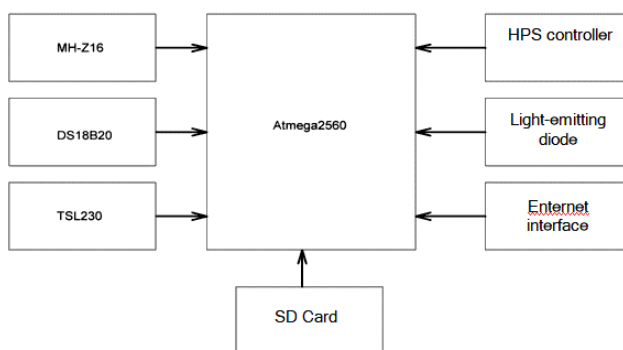


Fig. 2. Block diagram of automatic control system.

The main components of this system are:

1. MH-Z16 is CO₂ sensor. It is an industrial sensor that can measure up to 5% CO₂. An accuracy is $\pm(50\text{ppm}+5\%)$ that is about 75-100 ppm. PPM is a fraction of a million. It is a unit of measurement of any relative values equal to $1 \cdot 10^{-6}$ of the baseline. It is similar in meaning to the percentage or ppm. In the case of volume concentrations 1 ppm (1 ppm)= 1 sm³/1 m³. Thus, the volume concentration of carbon dioxide in the earth's atmosphere is about 380 ppmv which means that each cubic meter of air takes 380 ml of carbon dioxide. Temperature sensor DS18B20 allows determining the environment temperature in the range from -55°C to +125°C and it facilitates the receipt of data in the form of a digital signal with a 12-bit resolution by 1-Wire Protocol. This Protocol will allow connecting a huge number of such sensors using only 1 digital port of the controller and only 2 wires for all sensors: ground and signal. In this case, the so-called "parasite power" is used in which the sensor receives energy directly from the signal line. Each sensor has a unique 64-bit serial code that can be used by a microcontroller to communicate with a specific sensor on a common bus. The code of an individual sensor can be read by a separate command.

The permanent memory of the DS18B20 can save the boundary values of the temperature

at the outlet from which sensor will go into alarm mode. The microcontroller can at a time find out which of them switched to this mode on a common bus of many sensors. Thus, it becomes easy to identify the problem area in a controlled environment.

2. Light sensor is optical light-to-frequency converter TSL230, 300 ~ 700nm.

3. To collect statistical information for the purpose of its further analysis and processing it was possible to record all the data on the microSD-card. On the base these data dependency graphs are created to optimize the plant irradiation model.

The resulting installation is an automated system with feedback. It is able to adjust the irradiation parameters of the plant based on the input parameters obtained in real time.

5 Conclusion

It is planned to obtain data in real time and control the radiation spectrum with the help of the present installation thereby affect the process of photosynthesis and the development of the plant as a whole.

The installation takes into account the main environmental factors that directly affect the process of photosynthesis and the process of plant growth. The concentration of carbon dioxide is inversely proportional to the amount of oxygen in the air. During photosynthesis CO₂ is used and oxygen is produced. Temperature values are also important to prevent overheating and burning of plant leaves. When the maximum speed of the photosynthesis process is reached the installation suspends the irradiation system of plants thereby preventing the system from operating at idle and saving energy. According to preliminary calculations energy savings will be from 10% to 20% which is a significant indicator.

Currently, experimental studies are carried out to clarify the parameters of the model and its boundary conditions. At the same time, tests are carried out of the automated control system of a mode of additional lighting on crops to purpose of finding of optimum parameters.

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