ON PROGNOSIS OF PLANT DEVELOPMENT DURING PHOTOSYNTHESIS

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ABSTRACT

In this paper we consider processes occurring in plants during photosynthesis and discusses a model of their occurrence. The model gives a possibility prognosis the above processes to control productivity of these plants. We presents an analytical approach for analysis the above model with account changing of their parameters, as well as its nonlinearity. We also discussed the possibility of changing the processes occurring in a plant when changing the conditions of photosynthesis.

KEYWORDS

photosynthesis; model; analytical approach for analysis.

1. INTRODUCTION

One of current questions is to increase the yield of agricultural plants [1-3]. One of the ways to increase the yield is selection of varieties with high efficiency of photosynthesis and create a crop structure favorable for light absorption [2-5]. In the current situation, it is important to study changes in photosynthesis and other processes of accumulation of plant biomass in a wide range of meteorological conditions. Also important is the forecast of changes in the intensity of photosynthesis in trees. This relevance is caused by an increase in the concentration of carbon dioxide in the atmosphere and an increase in its temperature. The prognosis is the basis for predicting the consequences of global climate change on the planet. This paper considers a model for prognosis of processes in plants during photosynthesis, which is more common in comparison with models in cited references. We consider a possibility of changing the processes occurring in the plant with a change in the conditions of photosynthesis. We presents an analytical approach for analysis the above model with account changing of their parameters, as well as its nonlinearity.

2. METHOD OF SOLUTION

To solve our aim we will obtain solution of the following system of equations, which describes variation in time of concentration of generated chlorophyll under influence of several factors

$$\begin{cases} \frac{d\,P(t)}{d\,t} = \alpha_1 \left[P_{\max} - P(t) \right] + \alpha_2 n(t) P(t) \\ \frac{d\,R(t)}{d\,t} = \alpha_2 n(t) P(t) - \alpha_3 R(t) \\ \frac{d\,F(t)}{d\,t} = \alpha_4 P(t) n(t) - \alpha_5 F(t) \end{cases} \tag{1}$$

where $P(t)$ is the concentration of chlorophyll being generated; α_1 and α_2 are the parameters of chlorophyll synthesis; $n(t)$ is the plant irradiation; $R(t)$ is the concentration of reaction centers in a green leaf blade; α_3 is the parameter of the dark reaction of the transition of chlorophyll to the free state; $F(t)$ is the intensity of photosynthesis; α_4 is the parameter of speed of photosynthesis; α_5 is the parameter of speed of inhibition of photosynthesis by its own products. Initial conditions for the considered functions could be written as

$$P(0)=P_0,\ R(0)=R_0,\ F(0)=F_0. \tag{2}$$

We solved the equations (1) with conditions (2) by method of averaging of functional corrections [6-8]. To determine the first-order approximations of the required functions in the framework of the method we replace these functions by their not yet known average values (i.e. $P \to \beta_{1P}$, $R \to \beta_{1R}$, $F \to \beta_{1F}$) in the right sides of equations (1). After the substitution and integration on time of the obtained relations we obtain the required first-order approximations in the following form

$$\begin{cases} P_1(t) = \alpha_1 (P_{\max} - \beta_{1P})\, t + \alpha_2\, \beta_{1P} \int\limits_0^t n(\tau)\, d\,\tau + P_0 \\ R_1(t) = \alpha_2 \beta_{1P} \int\limits_0^t n(\tau)\, d\,\tau - \alpha_3 \beta_{1R} t + R_0 \\ F_1(t) = \alpha_4 \beta_{1P} \int\limits_0^t n(\tau)\, d\,\tau - \alpha_5 \beta_{1F} t + F_0 \end{cases} \tag{3}$$

Not yet known average values β_1 were calculated by the following standard relation [6-8]

$$\beta_1 = \frac{1}{\Theta} \int\limits_0^\Theta y_1\, d\,t, \tag{4}$$

where Θ is the continuance of observation for the course of the considerate process; y_1 is the first-order approximation of the considered function. Substitution of the first-order approximations (3) into relation (4) gives a possibility to obtain the following relations to calculate the above average values in the following form

$$\begin{cases} \beta_{1P} = \alpha_1 (P_{\max} - \beta_{1P}) \frac{\Theta}{2} + \beta_{1P} \frac{\alpha_2}{\Theta} \int\limits_0^\Theta (\Theta - t) n(t)\, d\,t + P_0 \\ \beta_{1R} = \beta_{1P} \frac{\alpha_2}{\Theta} \int\limits_0^\Theta (\Theta - t) n(t)\, d\,t - \alpha_3 \beta_{1R} \frac{\Theta}{2} + R_0 \\ \beta_{1F} = \beta_{1P} \frac{\alpha_4}{\Theta} \int\limits_0^\Theta (\Theta - t) n(t)\, d\,t - \alpha_5 \beta_{1F} \frac{\Theta}{2} + F_0 \end{cases} \tag{5}$$

Solutions of the system of equations (5) could be presented in the following form

$$\beta_{1P} = \frac{\Theta\left(P_0 + \alpha_1 P_{\max}\Theta/2\right)}{\Theta - \alpha_2 \int_0^{\Theta} (\Theta - t) n(t)\, dt + \alpha_1 \Theta^2/2}$$

$$\beta_{1R} = \frac{\alpha_2 \left(P_0 + \alpha_1 P_{\max}\Theta/2\right) \int_0^{\Theta} (\Theta - t) n(t)\, dt + R_0 \left[\Theta - \alpha_2 \int_0^{\Theta} (\Theta - t) n(t)\, dt + \alpha_1 \Theta^2/2\right]}{\left(1 + \alpha_3 \Theta/2\right)\left[\Theta - \alpha_2 \int_0^{\Theta} (\Theta - t) n(t)\, dt + \alpha_1 \Theta^2/2\right]}$$

(6)

$$\beta_{1F} = \frac{\alpha_4 \left(P_0 + \alpha_1 P_{\max}\Theta/2\right) \int_0^{\Theta} (\Theta - t) n(t)\, dt + F_0 \left[\Theta - \alpha_2 \int_0^{\Theta} (\Theta - t) n(t)\, dt + \alpha_1 \Theta^2/2\right]}{\left(1 + \alpha_5 \Theta/2\right)\left[\Theta - \alpha_2 \int_0^{\Theta} (\Theta - t) n(t)\, dt + \alpha_1 \Theta^2/2\right]}$$

The second-order approximations of the required functions were obtained by replacement of these functions on the following sum $y \to \beta_2 + y_1$ in the right sides of equations (1). The replacement and integration of the obtained relations on time gives a possibility to obtain relations to calculate the considered approximations in the following final form

$$\begin{cases} P_2(t) = \alpha_1 \left[P_{\max} t - \beta_{2P} t - \int_0^t P_1(\tau)\, d\tau\right] + \alpha_2 \int_0^t n(\tau)\left[\beta_{2P} + P_1(\tau)\right] d\tau + P_0 \\ R_2(t) = \alpha_2 \int_0^t n(\tau)\left[\beta_{2P} + P_1(\tau)\right] d\tau - \alpha_3 \beta_{2R} t - \alpha_3 \int_0^t R_1(\tau)\, d\tau + R_0 \\ F_2(t) = \alpha_4 \int_0^t n(\tau)\left[\beta_{2P} + P_1(\tau)\right] d\tau - \alpha_5 \beta_{2F} t - \alpha_5 \int_0^t F_1(\tau)\, d\tau + F_0 \end{cases} \quad (7)$$

Average values β_2 were determined by the following standard relation [6-8]

$$\beta_2 = \frac{1}{\Theta} \int_0^{\Theta} \left(y_2 - y_1\right) dt. \quad (8)$$

Substitution of the first- and the second-order approximations of the considered functions into relation (8) gives a possibility to obtain the following relations to determine average values of the second-order approximations in the following form

$$\beta_{2P} = \left\{\frac{\alpha_2}{\Theta} \int_0^{\Theta} (\Theta - t) n(t)\left[P_1(t) - \beta_{1P}\right] dt - \frac{\alpha_1}{\Theta} \int_0^{\Theta} (\Theta - t) P_1(t)\, dt\right\}\left[1 - \frac{\alpha_2}{\Theta} \int_0^{\Theta} (\Theta - t) n(t)\, dt\right]^{-1}$$

$$\beta_{2R} = \left(1 + \alpha_3 \Theta^2/2\right)^{-1} \left(\frac{\alpha_2}{\Theta} \int_0^{\Theta} (\Theta - t) n(t)\left[P_1(t) - \beta_{1P}\right] dt - \frac{\alpha_3}{\Theta} \int_0^{\Theta} (\Theta - t) R_1(t)\, dt + \frac{\alpha_2}{\Theta} \int_0^{\Theta} n(t) \times\right.$$

$$\times(\Theta-t)\,dt\left\{\frac{\alpha_2}{\Theta}\int_0^\Theta(\Theta-t)n(t)[P_1(t)-\beta_{1P}]\,dt-\frac{\alpha_1}{\Theta}\int_0^\Theta(\Theta-t)P_1(t)\,dt\right\}\left[1-\frac{\alpha_2}{\Theta}\int_0^\Theta(\Theta-t)n(t)\,dt\right]^{-1}+$$

$$+\alpha_3\beta_{1R}\,\Theta^2/2\Big) \tag{9}$$

$$\beta_{2F}=\left(1+\alpha_5\Theta^2/2\right)^{-1}\left(\frac{\alpha_4}{\Theta}\int_0^\Theta(\Theta-t)n(t)[P_1(t)-\beta_{1P}]\,dt-\frac{\alpha_5}{\Theta}\int_0^\Theta(\Theta-t)F_1(t)\,dt+\alpha_5\beta_{1F}\frac{\Theta^2}{2}+\right.$$

$$+\frac{\alpha_4}{\Theta}\int_0^\Theta(\Theta-t)n(t)\,dt\left\{\frac{\alpha_2}{\Theta}\int_0^\Theta(\Theta-t)n(t)[P_1(t)-\beta_{1P}]\,dt-\frac{\alpha_1}{\Theta}\int_0^\Theta(\Theta-t)P_1(t)\,dt\right\}\times$$

$$\left.\times\left[1-\frac{\alpha_2}{\Theta}\int_0^\Theta(\Theta-t)n(t)\,dt\right]^{-1}\right).$$

In this paper we obtain the required concentrations of generated chlorophyll and reaction centers in the green leaf blade, as well as the intensity of photosynthesis as the second-order approximations in the framework of the method of averaging of function corrections. Usually the second-order approximations are enough good approximations to make qualitative analysis and to obtain quantitative results. All analytical results have been checked by numerical simulation.

3. DISCUSSION

In this section we analyzed changing concentrations of generated chlorophyll and reaction centers in the green leaf blade, as well as the intensity of photosynthesis on different parameters. Figure 1 shows typical dependences concentration of generated chlorophyll on time. Increasing of the considered concentration corresponds to increasing of parameters of synthesis of chlorophyll α_1, α_2 as well as plant irradiation. Figure 2 shows typical dependences concentration of reaction centers in the green leaf blade on time. Increasing of the considered concentration corresponds to increasing of parameter of synthesis of chlorophyll α_2, plant irradiation and concentration of generated chlorophyll as well as decreasing of parameter of dark reaction of chlorophyll transition to a free state. Figure 3 shows typical dependences concentration of intensity of photosynthesis on time. The intensity decreases with increasing of the rate of inhibition of photosynthesis by its own products and increasing of the rate of photosynthesis, as well as with increasing of concentration of the generated chlorophyll.

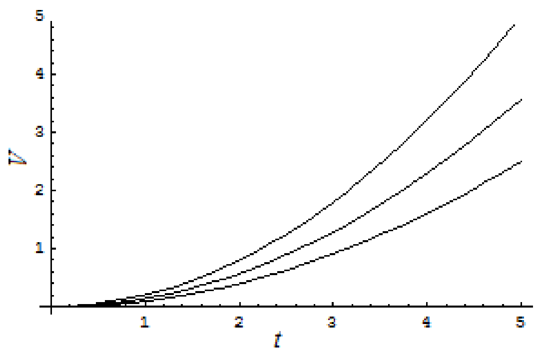

Fig. 1. Typical dependences concentration of generated chlorophyll on time.

Increasing of the considered concentration corresponds to increasing of parameters of synthesis of chlorophyll α_1, α_2 as well as plant irradiation

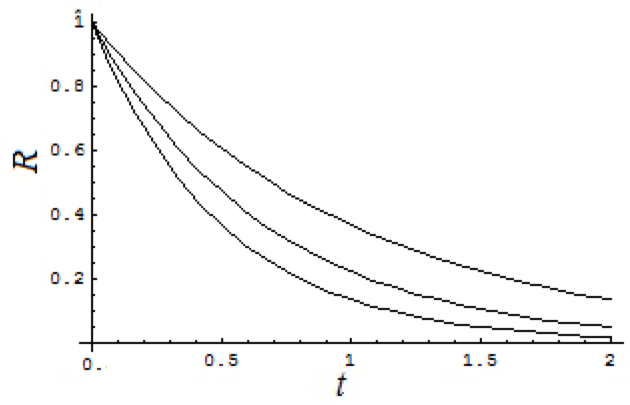

Fig. 2. typical dependences concentration of reaction centers in the green leaf blade on time.

Increasing of the considered concentration corresponds to increasing of parameter of synthesis of chlorophyll α_2, plant irradiation and concentration of generated chlorophyll as well as decreasing of parameter of dark reaction of chlorophyll transition to a free state

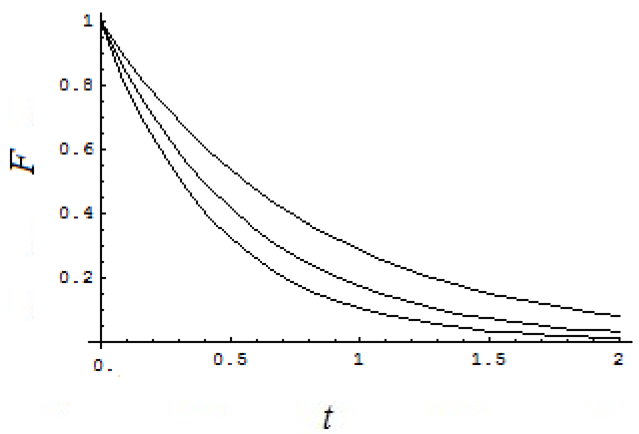

Fig. 3. Typical dependences concentration of intensity of photosynthesis on time.

The intensity decreases with increasing of the rate of inhibition of photosynthesis by its own products and increasing of the rate of photosynthesis, as well as with increasing of concentration of the generated chlorophyll

4. CONCLUSION

We consider processes occurring in plants during photosynthesis and discusses a model of their occurrence. To analyze the model it have been presented an analytical approach. The approach gives a possibility to take into account changing of their parameters, as well as its nonlinearity. We also discussed the possibility of changing the processes occurring in a plant when changing the conditions of photosynthesis.

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