МОДЕЛИРАНЕ НА ЕСЕННИЯ ПЕРИОД ЗА ВЕГЕТАЦИЯ НА ЗИМНАТА ПШЕНИЦА *(Triticum aestivum L.)*

МОДЕЛИРОВАНИЕ ОСЕННЕГО ПЕРИОДА ВЕГЕТАЦИИ ОЗИМОЙ ПШЕНИЦЫ *(Triticum aestivum L.)*

MODELLING OF THE AUTUMN VEGETATION PERIOD FOR WINTER WHEAT *(Triticum aestivum L.)*

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Резюме

Статията дава теоретично описание на динамичните фактори, които влияят върху растежа и развитието на зимната пшеница през есенния вегетационен период. Моделът се основава на агрометеорологичните условия, които въздействат на растежа, развитието и реколтата от зимна пшеница. Есенният вегетационен период е сред най-важните периоди, тъй като той определя нивото на подготовка на растенията за зимния период и тяхната способност да устояват на ниски температури. Така той спомага за получаване на по-висока реколта. Разработката на модела се основава на два подхода: първият е традиционното описание на метеорологични фактори, като се вземат под внимание въздействието на температурата и валежите върху развитието на зимната пшеница. Вторият подход предоставя количествена характеристика на есенния период за вегетация на зимната пшеница, който включва растежът на надземните и подземните части от растението, както и образуването на братя. Наблюдава се съществено пренареждане на структурата, физико-химичните свойства на протоплазмата, физиологичните и биохимичните процеси, чиято цел е приспособяване към резките промени в околната среда и поддържането на жизнено важни функции при растителните организми. С други думи, образуването на зимна устойчивост и преминаването на двете фази на закаляване.

Резюме

В данной статье приводится теоретическое описание динамической модели влияния основных факторов среды на процессы роста и развития озимой пшеницы в осенний период вегетации. Разработка модели основана на модели влияния агрометеорологических условий на рост, развитие и формирование урожая озимой пшеницы. Осенний период вегетации это один из главнейших периодов, поскольку именно он определяет степень подготовки растений к зимнему периоду и их возможность противостоять действию низких температур и, соответственно, закладывает основу для получения высоких уровней урожая. Для разработки субмодели характерны два подхода. Первый подход характерен описанием гидрометеорологических факторов, в которых учитывается, главным образом, влияние температуры и осадков на развитие озимой пшеницы. Второй подход предусматривает количественное описание периода осенней вегетации растений озимой пшеницы, который включает в себя рост надземной и подземной части растений и процессы кущения. Происходит существенная перестройка структуры, физико-химических свойств протоплазмы, физиологических и биохимических процессов, направленных на выработку приспособительных реакций к неблагоприятным факторам среды и поддержания жизнедеятельности организма, то есть формирования зимостойкости и прохождения двух фаз закаливания.

Abstract

This article provides a theoretical description of the dynamic model of influence of the main factors on the growth and development of winter wheat in the period of autumn vegetation. The development of the model is based on a model of the influence of the agrometeorological conditions on the growth, development and yield formation of winter wheat. The period of autumn vegetation is one of the most important periods, because it determines the level of plant preparation for the winter period and their ability to withstand low temperatures and thus provides a basis for obtaining high levels of crop yield. The development of the model is characterized by two approaches. The first approach is traditional description of the meteorological factors, which takes into account the impact of temperature and precipitation on the development of winter wheat. The second approach provides a quantitative description of the period of the autumn growing season of winter wheat, which involves the growth of the aboveground and underground plant parts and tillering processes. There is a substantial rearrangement of the structure, physicochemical properties of the protoplasm, physiological and biochemical processes aimed at developing adaptive responses to the environmental stress and maintaining the vital functions of the plants organism, in other words, the gain of winter hardiness and the passing of two hardening phases.

Ключови думи: зимна пшеница (Triticum aestivum L.), есенна вегетация, асимилати, закаляване.

Ключевые слова: озимая пшеница (Triticum aestivum L.), осенний период вегетации, ассимилянты, закалка.

Key words: winter wheat (Triticum aestivum L.), autumn vegetation, assimilates, hardening.

INTRODUCTION

Lifecycle of winter wheat is divided into several important stages which significantly differ from each other on the influence of agrometeorological conditions, biological processes and the type of plant's metabolism. One of such stage is the period of autumn vegetation, which is characterized by the tillering process, the formation of winter hardening and frost resistance, metabolism restructuring and passing of two phases of hardening, which determines a favorable overwintering and the formation of crops harvest, so attempts to simulate the period of autumn vegetation of the winter wheat were made.

MODEL DISCRIPTION

The emergence of the first embryonic leaf from the coleoptile covering indicates the beginning of one of the most important processes in the ontogenesis of plants – the germination process. After the first leaf unrolling over the soil surface that grew from the first embryonic leaf, the young germination seedling goes on the independent plant nutrition (Dolgiy-Trach et al., 1990; Moyseychik, 1975; Orlyuk and Goncharova, 2002; Polevoy, 2007).

First of all, modelling of the period of autumn vegetation of the winter wheat involves a quantitative description of the photosynthesis, respiration and growth processes. Photosynthesis is a basic process of organic compounds formation in plant cells. In the description of the photosynthesis process any of plants photosynthetic organs the Monsey and Saeki equation were taken as a basis (Reynolds and Tornli, 1982):

$$P_{0_i} = \frac{P_{max_i} a_{p_i} I}{a_{p_i} I^j + P_{max}}, \qquad i = l, s, \qquad (1)$$

in which P_{0_i} - photosynthetic rate of i-th organ under optimal conditions of heat and moisture availability and real lighting conditions, mg CO_2*dm^{-2}*h^{-1};

P_{max_i} - photosynthetic rate of i-th organ under the light saturation and normal concentration of CO_2, mg CO_2*dm^{-2}*h^{-1};

a_{p_i} - the initial tilt of the light curve of photosynthesis, mg CO_2*dm^{-2}*h^{-1} /(W*m^{-2});

I - the intensity of PAR, W*m^{-2};

l, s – leafs, stems;

j - day number of the calculated period.

Using the equation (1) calculation of the rate of photosynthesis in biologically optimal environmental conditions is carried out. To determine the rate of photosynthesis in the real conditions should take into account the impact of external factors and the phases of plant growth, therefore, in light of the foregoing, the equation (1) takes the following form:

$$P^j_{\tau_i} = P^j_{0_i} a^j_{p_i} \psi^j_p \gamma^j_p, \qquad (2)$$

in which P_{τ_i} - the photosynthesis rate in the real environment, mg CO_2*dm^{-2}*h^{-1};

a_p - ontogenetic curve of photosynthesis;

$\psi_p \gamma_p$ - the influence functions of temperature and soil moisture respectively.

In dynamic models, designed for the solving of applied problems is preferable to calculate the rate of photosynthesis organ to the relative area of assimilating surface for the daylight (Polevoy, 1988; 2007):

$$P^j_i = \varepsilon P^j_{\tau_i} L^j_i \tau^j_d , \qquad (3)$$

in which P_i – the photosynthetic rate i-th organ, g*m^{-2} day^{-1};

ε - the coefficient for recalculation to the dry solid matter units, g*mg^{-1} CO_2;

L_i - the relative area of assimilating surface of the i-th organ; m^2*m^{-2};

τ_d – the duration of daylight, h.

Part of the assimilated carbon during photosynthesis is spent on plant respiration, including the breathing growth and breathing support structures:

$$\frac{dR}{dt} = a_R\,(c_1M + c_2P), \qquad (4)$$

in which $\frac{dR}{dt}$ – the breathing expenditure, g*m^2 day;

a_R - the ontogenetic curve of breathing;

c_1, c_2 - the coefficients of breathing expenditure for maintaining the structures and growth;

M – plants mass, g* m^2.

In the description of the rate of change of the dry biomass of individual organs on the basis of the proposed the growth equation by Ross (1975) and taking into account the modifications by Galyamina and Tooming (1984) adopted the following equation (Polevoy, 1988):

$$\frac{dm_i^j}{dt} = \frac{\beta_i^j\,p^j}{1+C_{G_i}} - \frac{(a_{R_i}^j C_{m_i}\varphi_R^i + v_i^j)\overline{m}_i^j}{1+C_{G_i}}, \qquad (5)$$

in which $\frac{dm_i}{dt}$ - the growth rate of i-th vegetative organ, g*m^{-2}day^{-1};

$\overline{m}_i$ – the functioning biomass of i-th vegetative organ, g*m^{-2};

β_i,- the growth function of vegetative period;

v_i – the growth function of reproductive period, °C^{-1}.

When the first green leaf appears the second and third embryonic leaves appear too. Under sufficient moistening the growth of the first and second pairs of embryonic roots is continued, coleoptile roots are appeared, i.e. the primary root system is formed.

At the same time, the part of the stem the former embryonic shoot turns into the tillering node of the main (parent) shoot. Tillering phase of the main shoot of wheat begins from the appearance under the soil surface of the first side shoot. The process of shoot formation and tillering occurs almost simultaneously. Side shoots of the1st order form shoots 2nd order and shoots 2nd order form shoots the 3rd, etc. With the coming of tillering phase the secondary (nodal) roots are developed, growing out from the tillering nodes of the main shoot, and then from the side shoots (Orlyuk and Goncharova, 2002; Satorre Emilio et al., 1999).

Water and air regimes of the soil, the level of mineral nutrition significantly affect the tillering rate. Formation of the side tillering shoots require the necessary amount of effective temperatures, total solar radiation and must be provided reserve of nutrients that necessary for the development of the main and side shoots of the first order. Consequently, the equation of the rate of formation of side tillering shoots is:

$$\frac{dN_{sts}}{dt} = \begin{cases} rgr * N_{sts}^{max} * \sqrt{FTK^j * FWK^j} \\ when\ W_{0-20} > W_{0-20}^{crit};\ \sum T_{ef} > \sum \mathrm{T}_{ef}^{t} \\ 0,\ when\ W_{0-20} \le W_{0-20}^{crit};\ \sum T_{ef} \le \sum \mathrm{T}_{ef}^{t} \end{cases} \qquad (6)$$

in which $\frac{dN_{sts}}{dt}$ - the formation rate of the side tillering shoots;

N_{sts}^{max} - the maximum possible quantity of shoots in given conditions;

FTK, FWK – the influence functions of temperature and moisture content on the side shoots rate;

W_{0-20}^{crit}; – the critical moisture content in the topsoil in which the tillering doesn't occur, mm;

$\sum \mathrm{T}_{ef}^{t}$ - the required amount of effective temperatures for the tillering start, °C;

rgr - relative growth rate of the side shoots.

The maximum possible quantity of shoots in given conditions, which will be provided with assimilates is determined by the formula:

$$N_{sts}^{max} = \frac{dm_{sts}^{res}/dt}{G_{sts}^{max}}, \qquad (7)$$

in which N_{sts}^{max} - the maximum possible quantity of shoots in given conditions;

$\frac{dm_{sts}^{res}}{dt}$ - the assimilates reserve remaining after the needs of the main shoot.

The reserve of assimilates count as difference between the amount of assimilates directed to overground part of the plant and the amount of assimilates received by the main shoot:

$$\frac{dm_{sts}^{res}}{dt} = \frac{dm_{og}}{dt} - \frac{dm_{ms}}{dt}, \qquad (8)$$

in which $\frac{dm_{og}}{dt} - \frac{dm_{ms}}{dt}$ – the biomass buildup of the overground part of the plant and the main shoot respectively, g/m^2*day;

G_{sts}^{max} – the maximum possible the biomass buildup of side shoots in given conditions is determined as:

$$G_{sts}^{max} = m_{sts}\,G_{sts}^{abs}\,\sqrt{FTK^j * FWK^j}, \qquad (9)$$

in which m_{sts} – the biomass of side shoots, g/m^2;

G_{sts}^{abs} – the absolute relative biomass buildup of side shoots, g/m^2*day.

The biomass of main shoot is determined as:

$$m_{ms} = FRGL_j * (m_l + m_s), \qquad (10)$$

in which $FRGL_j$ – the distribution function of overground biomass in the main shoot;

m_l, m_s – the biomass of leaves and stems, respectively, g/m^2.

Accordingly, the biomass of side shoots is calculated as:

$$m_{sts} = (1 - FRGL_j) * (m_l + m_s)\,, \quad (11)$$

Dynamics of overground and underground biomass of winter wheat plants described by next equations (Curry, 1971; Reynolds and Thornley, 1982):

$$\frac{dm_{og}}{dt} = \left(P^j - \frac{dR}{dt}\right)\gamma_{og}, \quad (12)$$

$$\frac{dm_{nug}}{dt} = \left(P^j - \frac{dR}{dt}\right) * (1 - \gamma_{og}), \quad (13)$$

in which $\frac{dm_{og}}{dt}, \frac{dm_{ug}}{dt}$ – the biomass buildup of the overground and underground parts of plants, respectively, g/m^2 * day;

γ_{og} – the growth function of the overground plant parts.

Buildup of the overground mass is distributed initially to the main shoot, then to the side shoots of the 1st, 2nd and subsequent orders:

$$\frac{dm_{ms}}{dt} = \gamma_{ms} * \frac{dm_{og}}{dt}, \quad (14)$$

$$\frac{dm_{sts1}}{dt} = \gamma_{sts1} * \left(\frac{dm_{og}}{dt} - \frac{dm_{ms}}{dt}\right), \quad (15)$$

$$\frac{dm_{stsn}}{dt} = \gamma_{stsn} * \left(\frac{dm_{og}}{dt} - \frac{dm_{ms}}{dt} - \sum_i^{n-1}\frac{dm_{stsi}}{dt}\right), \quad (16)$$

in which $\frac{dm_{sts1}}{dt}, \frac{dm_{stsi}}{dt}, \frac{dm_{stsn}}{dt}$ – the biomass buildup of side shoots 1 st, i-th, n-th orders, g/m^2 * day;

$\gamma_{ms}, \gamma_{sts1}, \gamma_{stsn}$ – the distribution function of assimilates for the main and side shoots.

Assimilating surface area is described by the equation:

$$L^{j+1} = L^j + \frac{\Delta m_i^j}{\sigma}, \quad (17)$$

in which L^{j+1}– the relative leaf area, m^2/m^2;

Δm_i – the buildup of the dry biomass of leaves, g/m^2;

σ - the specific surface density of the leaves, g/m^2.

The flow of nutrients to the underground part of the plant is directed to the formation of primary, secondary root systems and the tillering node:

$$\frac{dm_{r1}}{dt} = \gamma_{r1} * \frac{dm_{ug}}{dt}, \quad (18)$$

$$\frac{dm_{r2}}{dt} = \gamma_{r2} * \frac{dm_{ug}}{dt}, \quad (19)$$

$$\frac{dm_{\text{у.к}}}{dt} = \gamma_{tn} * \frac{dm_{ug}}{dt}, \quad (20)$$

in which $\frac{dm_{r1}}{dt}, \frac{dm_{r2}}{dt}, \frac{dm_{\text{у.к}}}{dt}$ the biomass buildup of the primary, secondary root systems and the tillering node, respectively, g/m^2*day;

$\gamma_{r1}, \gamma_{r2}, \gamma_{tn}$ – the growth function of primary, secondary root systems and the tillering node, respectively.

In the second half of autumn the decline of the average daily air temperature causes inhibition of growth processes. Due to the lack of heat plants grow poorly, and the resulting excess products of photosynthesis that is not used for growth processes, leading to the formation of sugars in the overground parts and tillering nodes that perform the function as protective substances that ensuring the preparation of plants for the winter, that is, the process of hardening of plants is took place. The process of hardening occurs in two phases: a favorable conditions for the passage of the first phase of hardening created on sunny clear days and high daily temperature amplitude (+5 ... +10°C at daytime, +2 ... +3°C at night), and the second phase begins after the transition temperature air through 0°C towards the negative temperatures (Guy et al., 2008; Major et al., 2010; Tumanov, 1979).

Changing of the mechanism of distribution of assimilates between the continuing growth retardation by plant organs and creating a reserve of assimilates, which is converted into sugars, after a steady transition of air temperature through 6°C is simulated. The quantity of products of photosynthesis is compared with the maximum possible amount of buildup of overground and underground biomass of plants that are defined similarly to above mentioned equation (Polevoy, 2007). The biomass buildup of the overground and underground parts of plants is determined as:

$$\frac{dm_{og}}{dt} = \begin{cases} G_{og}^{max}, when \;\; P^j > G_{og}^{max} + G_{ug}^{max} \\ \left(\frac{G_{og}^{max}}{G_{og}^{max} + G_{ug}^{max}}\right) * P^j - \frac{dR_{ug}}{dt}, \; when \;\; P^j < G_{og}^{max} + G_{ug}^{max}, \end{cases} \quad (21)$$

$$\frac{dm_{ug}}{dt} = \begin{cases} G_{ug}^{max}, when \;\; P^j > G_{og}^{max} + G_{ug}^{max} \\ \left(\frac{G_{ug}^{max}}{G_{og}^{max} + G_{ug}^{max}}\right) * P^j - \frac{dR_{ug}}{dt}, when \;\; P^j < G_{og}^{max} + G_{ug}^{max}, \end{cases} \quad (22)$$

The excess of photosynthesis products is defined as the difference:

$$\frac{dm_{res}}{dt} = P^j - (G_{og}^{max} + G_{ug}^{max}), \quad (23)$$

in which $\frac{dm_{res}}{dt}$ – the reserve of photosynthesis products, which is formed after the needs in assimilates of underground and overground parts of the plants, g*m^2.

The concentration of the occurring reserve products of photosynthesis is determined as the ratio:

$$mc_{res} = \frac{m_{res}}{M}, \qquad (24)$$

in which mc_{res} – the concentration of excess products of photosynthesis in plants;

M – the mass of plant, g*m^2.

CONCLUSIONS

The model of the period of autumn vegetation of the winter wheat includes the modeling of the processes of photosynthesis and respiration of plants, described the formation of overground part of plants, which includes the formation of the main shoot and side shoots of the 1st, i-th, n-th orders and the dynamics of leaf area. Also, the flow of nutrients is directed into the formation of underground part of the plants, namely, into primary, secondary root systems and tillering node.

The equations of the formation of reserves of the photosynthesis products of plants, which are formed when the growth processes of plants is declined, and after satisfying of the needs in assimilates of overground and underground parts of plants is described.

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