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ABIOTIC FACTORS IN CROP MODELS

CZYNNIKI ABIOTYCZNE W MODELACH ROŚLINNYCH

Abstract: Dynamic development of models describing growth, development and yielding of plants was observed in the last quarter of the 20th century. Explanatory models interpreting the phenomena constitute a specific group. Modeling of biomass accumulation is most frequently presented on three levels of productivity: potential, limited by the access to water and minerals and obtainable (reduced by the presence of weeds, diseases and pests). Modeling provides plenty of valuable information for proper interpretation and better understanding of the investigated process. Knowledge obtained in this way may be used to conduct so called simulation experiments using models, which can be of particular importance for research on the protection of the natural environment (eg migration and transformation of pesticides, biogens or heavy metals in soil).

Keywords: crop models, abiotic factors

The quantity of biomass accumulated by the canopy is the effect of a complex of meteorological and soil factors, ecophysiological plant properties of various degrees of importance and differently interconnected. It is an exceptionally complicated process and difficult to quantify. Still, owing to the development of electronic computational techniques in the last quarter of the 20th century, a dynamic evolution of models describing plant growth, development and yielding occurred. Explanatory (mechanistic) models interpreting the mechanisms of the phenomenon constitute a particular group. Determining the formula of the function describing a model requires theoretical knowledge about the course of a phenomenon usually using the laws of physics, chemistry or physiology [1, 2].

Due to universal applications of simulation models in agricultural sciences they may be divided into:

– models of physical, chemical and biological processes (eg water flow in a soil profile or erosion process modeling, etc.)

– models describing comprehensively a single plant species growth and development (eg Oryza, Ceres-Maize),

– models describing comprehensively the growth and development of many plant species (SUCROS, WOFOST, DSSAT, APSIM, EuroACCES and others),

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– systems of models analysing the situation on various levels of production system organization and in different time and space scales – ALMANAC, MARS-CGMS, IMPEL [1–4].

It should be stated that the impact of abiotic factors on plants may be regarded on different levels. Field research (canopy) and pot experiments (single plant) try to estimate the quantitative and qualitative effect of abiotic and biotic factors on the amount of accumulated biomass and usable yield. Currently, interdisciplinary research aimed at the identification of the mechanism or plant response to stressors on cell levels has been frequently conducted by plant physiologists, geneticists and biochemists [5].

The role of abiotic factors on an example of selected crop models

Modeling of biomass accumulation is most frequently presented on three levels of productivity:

1. potential production – with determining factors, such as solar radiation, temperature, CO_2 concentration and plant genetic traits,
2. attainable production – with limiting factors – water and mineral supply,
3. actual (reduced) production with reducing factors – weeds, diseases, pests and pollution [6].

The WOFOST model was developed as part of studies on food safety and potential world food production conducted by the Centre for World Food Studies (CWFS) in cooperation with the Wageningen Agricultural University. WOFOST belongs to the group of models developed in Wageningen by De Wit school, which also comprises such models as SUCROS, ARID CROP, MARCOS or ORYZA [7, 8]. There is a group of several models of plant growth and development considering the impact of diseases and weeds on the amount of production (eg DSSAT or INTERCOM).

In field conditions radiation and temperature are the basic factors determining the amount of potential production of cultivated crops. *Photosynthetically active radiation* (PAR) – wavelength λ = 400–700 nm is useful for plants. Other radiation ranges have diversified influence on the course of physiological processes in plants (Table 1). For computations of potential production it is most frequently assumed that PAR constitutes half of total radiation which reaches the canopy.

Table 1

The radiation effect upon plants [9]

Wave length	Effect on plants
< 280	Fast plant death
280–315	Harmful for most plants
315–400	Shortening of plants, leaf thickening
400–510	Large absorption by chlorophyll and xantophylls
510–610	Low photosynthetic activity
610–720	Strong absorption by chlorophyll
720–1000	Lengthening of plants
> 1000	No specific physiological effect

Explanatory (mechanistic) models are based on determining canopy gross photosynthesis depending on photosythetically active radiation reaching the canopy, temperature, water availability, leaf area, carbon dioxide concentration, photosynthetic output of single leaves and many stressors. The number of assimilates produced (gross photosynthesis) is diminished by the value of maintenance and growth respiration. These models work according to daily or even shorter time-step. This type of computations is included in many models developed at the Wageningen Agricultural University (Fig. 1).

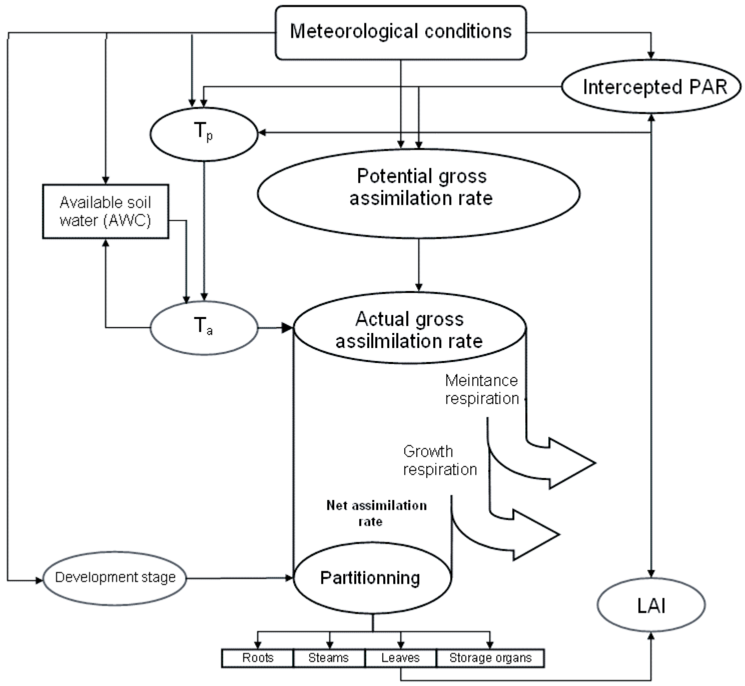

Fig. 1. The general diagram of the WOFOST model (Ta, Tp – actual and potential transpiration rate), Boogaard et al [10] modified

In another approach the estimation of biomass production is based on the coefficient of *light use efficiency* (LUE) or radiation use efficiency (RUE). The amount of radiation reaching the canopy is converted directly into the amount of produced carbohydrates using a conversion coefficient. This method has been applied in many models, such as CropSyst, DSSAT, APSIM, LINTUL and others [4].

Simulation of plant development in deterministic models is conducted with daily or longer time-step. Plant development in the models is determined by the increment of the effective temperature sum and the length of day, whereas in some models it is based also on the vernalization process. The temperature influences not only the speed of plant development but also the intensity of photosynthesis, evapotranspiration and respiration, which has been described by appropriate equations [4, 10–12].

In many plant growth and development models (including WOFOST), production limited by water deficit is computed through multiplication of potential output by actual to potential transpiration (evapotranspiration) ratio. It may be assumed with great probability that *potential assimilation* (Ap) and *actual assimilation* (Ar), *potential yield* (Qp) and *actual yield* (Qr) correspond to *potential* (ETp) and *actual evapotranspiration* (ETa). This statement may assume the following form:

$$\frac{Q_r}{Q_p} = \frac{A_r}{A_p} = \frac{ET_a}{ET_p}$$

Passioura [13] introduced a formula to compute the usable yield (Y) in conditions limited by water deficit:

$$Y = WUE \cdot T \cdot HI$$

where: WUE – coefficient of water utilization (g d.m./kg H_2O),
T – transpiration (g H_2O/g d.m. $\cdot$ m^2),
HI – harvest index.

The majority of plant growth and development models calculate the production limited by nutrient (most often nitrogen) availability and in a limited number also the other microelements. Moreover, some models consider also the effect of aluminium ions, connected with soil environment acidification and soil salinity on the amount of production (Table 2). These issues were discussed in detail in the papers by de Baros [14], Kulig [4] and others. The Daisy model has a "pesticides" module which considers pesticide dispersion in the environment: uptake by leaves, volatilization, absorption by the root system, pesticide decomposition in the soil environment or leaching [15].

Table 2

Comparison of selected plant growth and development models considering yield determinants [14]

Name of model	Weather	Soil water	Nutrient availability	Toxic substances
SUCROS	+	+	—	—
CENTURY	+	+	N, P, S	—
WOFOST	+	+	N, P, K	—
CANDY	+	+	N	—
Daisy	+	+	N	—
N-SIM	+	+	N	—
EPIC	+	+	N, P	Al, salinity
CROPGRO	+	+	N	—
EPICSEAR	+	+	N, P, K	Al, Na

The DSSAT packet (including CERES model family) belongs to a small group of models simulating, beside quantitative, also qualitative features of yield, eg protein concentrations in cereal grains. The amount of protein accumulated in grain depends, among others, on the temperature, water and nitrogen deficit stress [16].

Conclusion

Modeling plant growth and development is a specific synthesis of interdisciplinary knowledge in the field of yield physiology, agroclimatology, agronomy and soil science. Therefore it provides plenty of useful information for proper interpretation and better understanding of the researched process. Knowledge gained in this way may be used for conducting the so-called simulation experiment using models, which may be of crucial importance for research on the agricultural environment protection (eg pesticide, biogens or heavy metal migration and transformation in soil).

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Abstrakt: W ostatnim ćwierćwieczu XX w. nastąpił dynamiczny rozwój modeli opisujących wzrost, rozwój i plonowanie roślin. Szczególną grupę stanowią modele wyjaśniające (mechanistyczne) mechanizmy zjawiska (ang. *explanatory model*). Modelowanie akumulacji biomasy przedstawiane jest najczęściej na trzech poziomach produkcyjności: potencjalnej, limitowanej dostępnością wody i składników pokarmowych oraz osiągalnej (redukowanej przez obecność chwastów, chorób i szkodników). Modelowanie dostarcza wielu cennych informacji służących właściwej interpretacji i lepszemu zrozumieniu badanego procesu. Uzyskana w ten sposób wiedza może służyć do przeprowadzania za pomocą modeli tzw. eksperymentów symulacyjnych, co może mieć szczególne znaczenie w badaniach związanych z ochroną środowiska rolniczego (np. przemieszczanie się i przemiany pestycydów, biogenów lub metali ciężkich w glebie).

Słowa kluczowe: matematyczne modele roślin, czynniki abiotyczne