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Studies on crop growth modelling and simulation models in China*

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Abstract—There is a close relationship between agricultural production and environmental meteorological conditions. In the study of the correlation between them, the simulation models are paid more attention to the crop growth. In this paper the development of the studies on the crop growth dynamic simulation model in China is briefly reviewed. The relationships between meteorological conditions and each process of crop growth (such as photosynthesis, respiration, accumulation and distribution of assimilation products and growth of leaf area) are studied and simulated basing on the results from field experiments. Preliminary models for rice, wheat, maize and soybean have been developed, and some investigations about modelling methods, procedures and parameters in simulation models are made.

Keywords: simulation model; crop growth modelling.

INTRODUCTION

There is a close relationship between agricultural production and meteorological condition. In the study of correlation between meteorological conditions and crop growth, not only empirical statistical models are often used, but also crop growth simulation models are paid more attention to. As is well known, crop growth modelling and simulation models have been studied for several years in the Netherlands, USSR and US. And begun in China since 80's. At present preliminary models for rice, wheat, maize and soybean have been developed and some investigations about modelling method, parameters, procedures in simulation model are made. Here the studies on crop growth modelling and simulation models in China are briefly reviewed.

MODELS AND PARAMETERS

Plants transform solar energy into chemical energy to form dry matter through photosynthesis. During this process CO_2 is assimilated to form carbohydrates, which is partly consumed in respiration, on the other hand, the net accumulation formed is storage of dry matter. At the same time the dry matter formed is partitioned into each organ of plants according to certain biological rule. This is the process of growth, development and yield formation of

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plants. According to this concept the submodels of the above-mentioned processes are studied and developed correspondingly. Based on experimental data and research in China some correlations between meteorological conditions and physiological processes are established, some parameters in model are adjusted. Here part of the results are presented as follows.

Photosynthesis

The modelling of photosynthesis is a key to crop growth modelling. At present most researchers use the Monsi equation (1953) or equation derived from it:

$$P = BI \;/\; (1 + AI), \tag{1}$$

where P is the photosynthesis intensity. I is radiation, B is the initial slope of P-I curve, A is the ratio of B to maximum photosynthesis intensity. Usually the parameters A and B are established in laboratory. In view of the difference in climate between laboratory and field, which would result in the errors in calculation of dry matter production in field, some researchers of China define the value of A in laboratory firstly, and then in turn iterate and calculate the parameter B using a model of photosynthesis based on the measurements of canopy photosynthesis. They have got the value of B and A at different development stages for each variety of rice. Some authors use the Hesketh equation

$$P = P_{max} \times B \times I \;/\; (1 + BI), \tag{2}$$

the P_{max} and parameter B are expressed as functions of nitrogen content of leaves:

$$P_{max} = 3.2\ LNC; \qquad B = 0.031 \exp\,(-1.2\ LNC)\ , \tag{3}$$

where LNC is the nitrogen content of leaves. It is correlated with crop development days.

$$LNC = SLW \times PNC, \qquad SLW = f(t), \qquad PNC = f(t). \tag{4}$$

The photosynthesis intensity is influenced by temperature. According to actual experimental data, Chinese researchers use many functions or empirical expressions to describe and fit this effect. For example,

$$P = P_o \times TF\ , \tag{5}$$

where P_o is the photosynthesis intensity at optimal temperature, TF is the temperature effect function, which is expressed as linear or nonlinear functions

$$TF = -0.434 + 0.1027T - 0.00184T^2\ , \tag{6}$$

where T is temperature. Some researchers suggest that the maximum photosynthesis intensity is controlled by leaf temperature, so they suppose the A in Equation (1) is a function of three threshold temperatures and give the following equation:

$$A(T) = A(T_o)\exp\ [(T-T_o)^2\ /\ (T-Tm)(TM-T)], \tag{7}$$

where T is temperature, T_o is optimal temperature, Tm is minimum temperature, and TM is maximum temperature, thus Equation (1) becomes

$$P = BI\ /\ (1 + A(T) \times I)\ . \tag{8}$$

In addition some researchers establish a direct relation between P_{max} and temperature.

The distinction coefficient K is used in calculating the distribution of light in canopy. In some models it is assumed that the variation of K with the heights within a canopy and development stages of crops can be neglected. In other models Ko at different heights, development stages for some varieties of rice is obtained from experimental data.

Respiration

The photosynthetic products are partly consumed by respiration, that is, growth respiration and maintenance respiration. The values of growth respiration coefficient and maintenance respiration rate are mainly drawn from literature.

The growth of leaf area

Green leaf is a main photosynthesis organ of plants, the capacity of photosynthesis depends on the area of green leaves. Field experiments show that in general before earing green leaves grow slow in beginning, then fast afterwards, and finally relatively slow again, so in some models the growth process of leaves is simulated by the logistic growth function, for example:

$$LAI = LAIM\ /\ (1 + (LAIM - LAIo)\ /\ LAIo \times \exp\ (-K \times Kt \times t))\ , \tag{9}$$

where $LAIo$ and $LAIM$ are LAI at transplanting and earing of rice, respectively, K is an empirical constant, and Kt is the temperature coefficient; after heading the leaf area decreases rapidly, the appropriate empirical functions are chosen by measurement, for example:

$$LAI = LAIM\ /\ (1 + at^2)\ , \tag{10}$$

where a is constant. In other models the following equation is used:

$$LAI = WL\ /\ SLW \tag{11}$$

where WL is the dry weight of leaves, SLW is the specific leaf weight. The SLW is expressed as a function of development stages or days.

Because of the limited life-span of green leaf, the weight of yellowing-death leaves must be estimated and deducted. In some references of Netherlands the senility of leaf is taken into account only after flowering, and the death rate is assumed as a constant. In our simulation model of spring wheat the beginning time of yellowing-death leaves and its variation with development stages, temperature and soil moisture (Fig. 1), have been studied respectively through the experimental results.

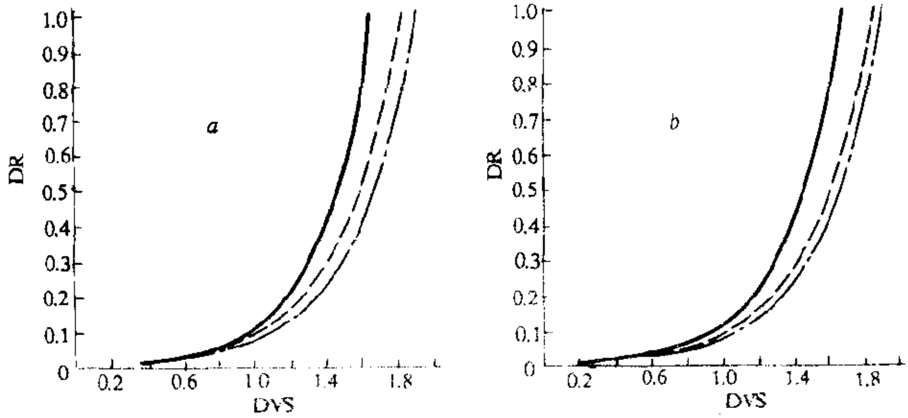

Fig. 1 Relationship between DVS and DR with different treatments of seeding days and irrigation

a: --* – seeding 10 days later b: – • – irrigating once
–** – seeding timely – • • – irrigating twice
--*** – seeding 10 days earlier – • • • – irrigating 3 times

Disitribution of dry matter

The growth of plant organs is based on the distribution and transference of assimilation products. Both of these processes are considered in our rice models:

$$\alpha i=\Delta Wi^{+} / (P-R) \cdot \Delta t; \qquad \beta i=\Delta Wi^{-} / Wi \cdot \Delta t. \ (i=1, 2, 3);$$

$$\alpha 4=(W4+\beta 4\times\sum_{i=1}^{3}\Delta Wi^{-}) / (P-R) \cdot \Delta t; \quad \beta 4=\Delta W4 / W4 \cdot \Delta t, \qquad (12)$$

where i stand for leaf, stem and root, respectively; 4 represents ear; αi is the distribution coefficient; βi is the transference coefficient; ΔWi^{+} means the increase of dry matter in someone organ and ΔWi^{-} is the decrease of dry matter.

Here the Fig. 2 presents the distribution curve of dry matter for spring wheat.

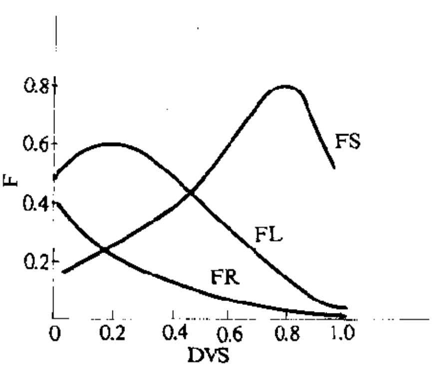

Fig. 2 The distribution function of dry matter of organs FR: root, FL: leaf, FS: stem

CONCLUSION

As a result, it is shown that the parameters in these models are basically correct, and the model can dynamically represent the trend of dry matter accumulation with time (Fig. 3 and Fig. 4). The results of comparison and verification are satisfactory. But the correlation between crop growth and meteorological conditions is much more complex, thus there are lots of modifications to be advanced and studied in future due to less sufficient fine instruments and the sampling errors in field experiments, especially the simulation model under actual water and nutrient conditions should be studied and developed. Furthermore we have also done and verified some works for U. S. crop simulation models of IBSNAT CERES based on the field experimental data in China.

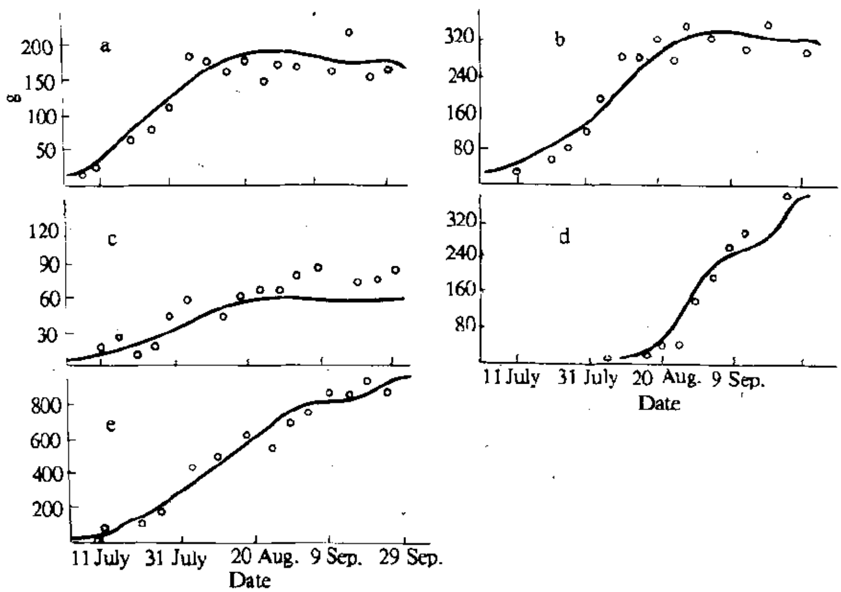

Fig. 3 The modelling curves (dashed) and measured values (dots) of the rice growth (in 1984)

a: the dry weight of leaf b: the dry weight of root

c: the dry weight of stem d: the dry weight of ear

e: the gross dry weight

It is obvious that crop growth modelling and simulation model have both theoretical significance and potential (operational) in application. By means of simulation model we can not only study and interpret the relationship between crop growth and meteorological condition, but also advance crop yield forecasting and assess better the impacts of climate changes on agriculture.

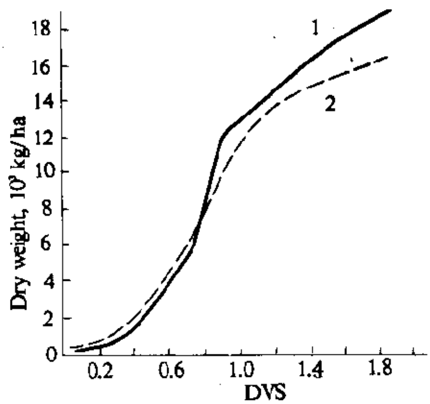

Fig. 4 The modelling, curve of gross dry matter weight of spring wheat
1 Measured 2 Simulated

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