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Estimation of Predictability of Agrophytocenoses Productivity on the Basis of Mathematical Modeling, Field Experiments and Satellite Measurements

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ABSTRACT

Estimation of predictability of agrophytocenoses productivity was made by comparing the results of investigation of a mathematical model, field experiments and satellite measurements. The mathematical model of the seasonal dynamics of agrophytocenoses productivity was built with account of air temperature. For model investigation the coefficients were used that were calculated on the basis of the results of field experiments conducted in the Republic of Khakassia. The objects of the research were agricultural crops (wheat, oats). The results of satellite measurements (NDVI dynamics), and theoretical and experimental results of the seasonal dynamics of plant total biomass proved to be quantitatively consistent.

Key words: mathematical model, agrophytocenoses productivity, satellite measurements.

INTRODUCTION

Satellite sensing techniques are becoming more and more important for optimization of land use, rehabilitation of degraded territories, and prediction of changes in agrophytocenoses (Savin, 2003). These techniques make it possible to cover large territories at a time and possess an information value, reliability and periodicity necessary to solve the above mentioned tasks. For a reliable interpretation of the images, it is necessary to use ground-based observation data on the state of crops for referencing satellite images to the territory. However, in the process of comparison of ground-based and satellite data there can be uncertainty because of agrophytocenoses pollution, changes in climatic conditions etc. A mathematical model of seasonal dynamics of agrophytocenoses production was built and investigated, and the modeling results were compared with ground-based and satellite data, with the aim of searching for the method of estimation of phytocenoses productivity.

MATERIALS and METHODS

Ground-truth observations of agricultural land vegetation were made for interpretation of satellite images. The objects of investigation were the agricultural crops and fallow lands in Krasnoyarsk Territory (Minusinsk Region) (Shevyrnogov et al., 2007)

During the vegetation season of 2006, the agrophytocenoses of wheat, oat and buckwheat (with a total area of 5.3. thousands of hectares) were studied using standard geobotanical methods, on permanent plots, on such days (or several days before or after) when the Modis/Terra satellite was passing (Shevyrnogov et al., 2007). The coordinates of the plots were registered using a GPS-navigator.

Samples for weighing aboveground raw biomass were taken during the vegetation season from 1×1 m^2 plots, number of replications being 3-5.

To estimate the photosynthetic active biomass we used the Normalized Difference Vegetation Index (NDVI) which is calculated by the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}, \qquad (1)$$

where NIR is reflection in the near infrared region;

RED – reflection in the red region.

According to this formula, NDVI in a certain image point is equal to a difference between the reflected light intensities in the red and near infrared bands divided by the sum of the intensities.

RESULTS and DISCUSSION

Figure 1 shows the results of field investigations – the results of the seasonal dynamics of wheat total aboveground raw biomass, including weeds, and net phytomass (the sum of vegetative and generative parts); the values of phytomass vegetative and generative parts are given separately.

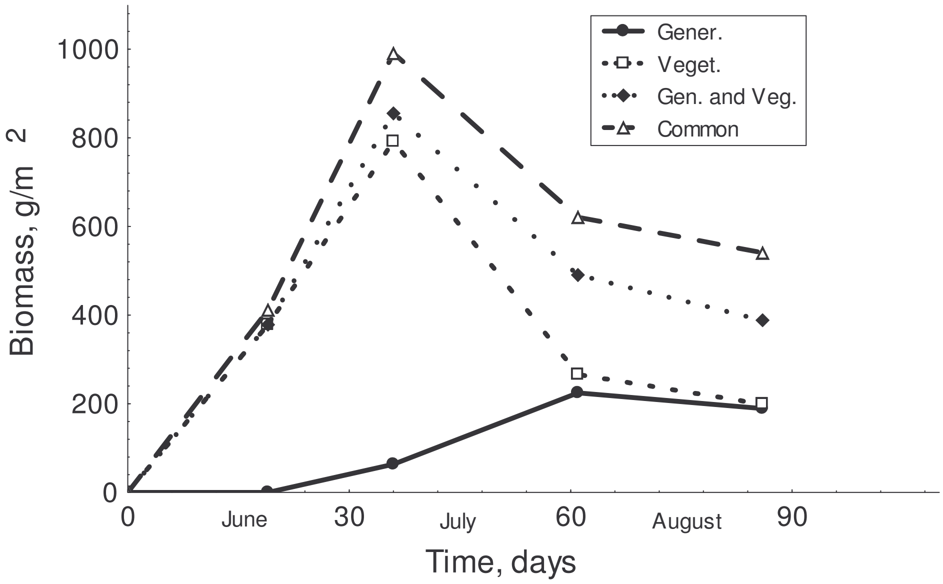

Fig.1. Dynamics of wheat aboveground raw phytomass in 2006.

The data of satellite images are presented on Fig. 2. The dynamics of NDVI values during the field season (June - August) allows one to fully trace the dynamics of the seasonal production of aboveground raw phytomass of wheat agrophytocenosis, that is, its total biomass. However, it is rather difficult to study the production dynamics of vegetative and reproductive phytocenosis parts separately. Scientists are trying to isolate these growth stages by calculation of vegetation rates (based on NDVI changes) according to satellite data (Pugacheva, 2007). It is necessary to find connection between the total phytocenosis phytomass and its components (biomass of vegetative and reproductive organs) to predict phytocenoses productivity.

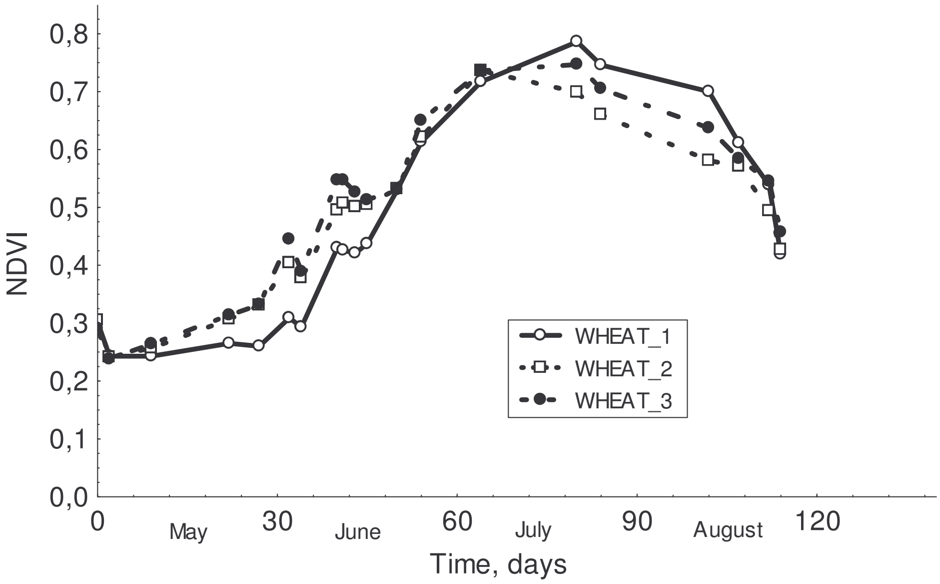

Fig. 2. Dynamics of NDVI values at the territory of Minusinsk Region sown with wheat, in 2006.

The mathematical model of phytocenosis production seasonal dynamics is based on a common differential equation limited in terms of growth in the end of field season.

$$dX/dt = \mu(T, W, N)\, X - \mu(T, W, N)\, X^2 / X_{max} \text{, where} \qquad (2)$$

X is the biomass of the sum of agrophytocenosis vegetative and reproductive parts;

$\mu(T, W, N)$ – phytocenosis specific growth rate;

X_{max} – the maximum biomass of the sum of agrophytocenosis vegetative and reproductive parts;

Since the phytocenosis seasonal growth was observed for one year, the limitation of phytocenosis growth was simplified: it was supposed that the limiting factor is the biogenous element nitrogen.

The solved equation demonstrates a quantitative coincidence with the results of full-scale experiments and data calculated on the basis of satellite images. The maximum total production of phytocenosis falls on July. NDVI dynamics has a more smoothed form, as there are more points than in case of field investigations, which is connected with the difficulty to measure the production of aboveground raw biomass in the field.

Modeling of the production of phytomass reproductive part has its characteristic features – delay in new production of reproductive organs as compared to the new production of vegetative organs. In this case, apparently, it is necessary to use delay time or the dependence of the production rate of the phytocenosis reproductive part on the biomass of the vegetative part according to Mono. Then the equation for calculation of the specific rate of reproduction will look as follows:

$$\mu_{repr.} = \mu_{max\ repr.}\ X_{veg.} / (K_{X\ veg.} + X_{veg.}) \qquad (3)$$

Fig. 3 shows the results obtained during the investigation of the model of wheat phytocenosis seasonal growth: production of total (vegetative and reproductive) biomass and production of reproductive organs biomass. Once the delay time was introduced, a more complete coincidence with the results of field investigations was obtained. In June the total biomass of phytocenosis increased due to the new production of vegetative organs, and in June it decreased as a result of vegetative organs drying.

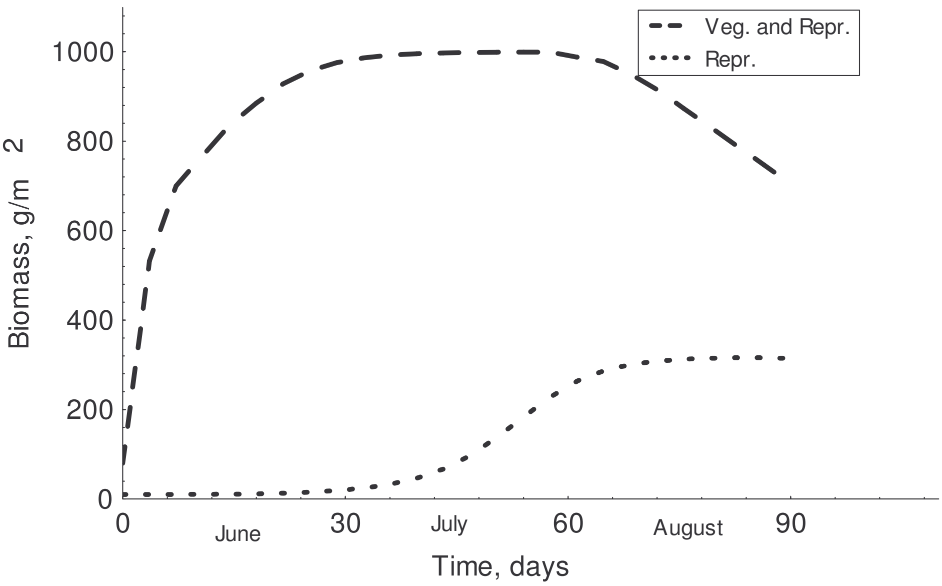

Fig. 3. Dynamics of the seasonal growth of wheat phytocenosis (results of model investigations).

Thus, investigation of the mathematical model of wheat phytocenosis seasonal growth showed that it is possible to make satellite measurements more complete and precise. Combination of the results of mathematical modeling, satellite sensing and field experiments will allow scientists to obtain complete information on the state of crops and their productivity more quickly.

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REFERENCES

Pugacheva I.Yu., Shevyrnogov A.P. 2007. Investigation of NDVI dynamics of agricultural crops in Krasnoyarsk Territory and the Republic of Khakassia/The Fifth Anniversary Open All-Russian Conference "Present-Day Problems of Remote Sensing of Earth" Moscow, Russian Academy of Sciences, November 12-16, (in print).

Savin I.Yu. 2003. On the new approach to NDVI application in monitoring of the state of agricultural crops. Earth exploration from space. No 4: 91- 96.

Shevyrnogov A.P, Zorkina T.M., Zhukova V.M., Zhukova E.Yu., Zhidkaya M.V. 2007. Investigation of the seasonal dynamics of agricultural crops at the territory of Khakassia by Terra Modis images. Sibirskiy vestnik selskokhozyaystvennoi nauki (Siberian Reporter of Agricultural Science). No 5 (173): 29 – 35.