



# AGROPHYSICAL AND ECOLOGICAL PROBLEMS OF AGRICULTURE IN THE 21<sup>st</sup> CENTURY

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## PARAMETER ESTIMATION OF SOIL-PLANT- ATMOSPHERE MODEL

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### **Abstract**

Dynamic model of the system soil-plant-atmosphere includes a set of unknown parameters, which must be estimated in the process of model identification. Paper is devoted to the problem of parameter estimation of the model developed by the authors in the Agrophysical Research Institute. Model is included into simulation system AGROTOOL.

### **Introduction**

Agroecosystems play an essential role in the turnover of water, energy, organic and mineral matter on the Earth. Existing models (Diepen et al., 1988; Hanks & Rietche, 1991; Poluektov, 1991) describe a set of essential processes taking place in the soil, agricultural crops and the atmosphere. Model considering as a software product includes a set of unknown parameters connected with the conditions of plan cultivation. Some of these parameters reflect physical and chemical soil properties. Another parameter group is related with climate and weather conditions of the site of crop cultivation. Plant culture and cultivar determine the third group. At the final stage of model development these parameters must obtain their concrete numeric values. It denotes that model identification is an essential part of this job.

A number of parameters in some models can reach several tens and the use of various experimental data is needed for their estimation. So the special technique has to be developed in order to solve this problem. One of possible approaches to model identification on the example of model family AGROTOOL (Poluektov, et al. 2002) is considered in the paper.

### **Model structure**

Model family **AGROTOOL** is intended for estimation of agrometeorological crop state, calculation of soil water storage, forecast of the rates of plant development, yield forecast (starting from flowering stage), as well as the irrigation control (Poluektov et al. 2002). It comprises such cultures as winter and spring wheat, barley, maize, alfalfa and some others. **AGROTOOL** system shell permits to organize an active dialogue with the user for design of computer test, model run and visualization of their results in the form of tables and graphics. Besides the system includes programs for model parameter identification. It permits to adapt model for new soil climate and weather conditions.

Dynamic model of an agroecosystem consists of several units (Poluektov, 1991; Poluektov et al. 1997; Poluektov & Zakharova 2000; Poluektov et al. 2000):

- Agrometeorological unit connected with meteorological database, which contains daily weather data of a region to be simulated. Besides the unit carries out the weather forecast which is used for prediction of phenological development and an expected yield. The algorithm of weather forecast uses weather data for some years (20-30 years) and the correction after analyze the difference between the current year and climatically average one.
- Radiation and photosynthesis unit which calculates dally sum of incoming and absorbed by crop solar radiation and PAR as well as a sum of accumulated assimilates. This unit works with hour time step.
- The unit of turbulent gas exchange in the atmosphere, which permits to calculate the wind speed profile above and inside the crop and aerodynamic resistances for heat, water vapor and carbon dioxide fluxes.
- The unit of soil water dynamics. It calculates the soil water balance in one meter soil layer and water availability to plants which is determined by precipitation intensity, plant transpiration, soil evaporation and water exchange on the lower soil boundary. For these purposes the water retention curve is used, because the intensity of all the processes of water transport are determined by soil water potential. The dependency of soil water potential on soil moisture is estimated approximately on the base of soil hydraulic constants such as permanent wilting point, saturation point and field capacity.
- The unit of plant growth and development which realises the calculation of the increment in dry matter of several plant organs by means of dry matter distribution functions and the physiological time which is determined by the sum of effective temperatures (in degree-days) corrected by water stress.
- The unit of the forecast of the rate of phenological development. This unit estimates the date of the next development stage during the current vegetation using the algorithm of the weather forecast.
- The unit of grain yield forecast (starting from the date of flowering). The algorithm of the forecast is based on the integral (accumulated up to the date of forecast) leaf area index and water stress function.

### **Model identification**

The technique of model identification will be described on the example of spring wheat model cultivated in Saratov region. The results of laboratory experiments and long-time field research were used for problem solution. The experiments were carried out on an experimental plot of the Research Production Association "Elite Povolzh'ya (51.5 ° N.L.) for 12 years: 1972-1979 and 1987-1990 (Kumakov, Berezin & Evdokomova, 1994). The following characteristics were used to identify the model:

- Daily meteorological data for respective years;
- sowing dates and plant development stages onset dates;
- leaf area index (LAI) and above ground dry mass on different plant development stages;
- grain yield;
- water capacity measured in the 0-100 cm layer on these dates;
- physical properties of the soil such as bulk density, maximum and field water capacity, wilting point.

The site of experiment is situated in arid zone where the droughts occur regularly. So the main attention when model development was paid to take into account the influence of water stress on plant growth and development. Note, that experimental information for 5 years only was used for model validation. The data for the remaining 7 years were used for model verification as independent information.

The set of model parameters can be divided into three groups. Physical values, which can be measured directly, compose the first group. These parameters mainly relate to soil characteristics such as soil bulk density, general porosity, field capacity and wilting point. Parameters that can be chosen in the literature compose the second group. Some biological constants, for example, respiration and conversion coefficients, parameters of growth functions and so on form the second group. Many authors determine numeric values of these constants and thus they characterize an "average plant" of this type. Finally, there are parameters making the group of so called "calibration coefficients" of the model. They are the key values, which characterize the features of concrete culture and are responsible for plant reactions on environment conditions. In this model the set of parameters controlling the rate of plant development (Poluektov et al., 2000) and coefficients of water stress function concern to this group.

Model identification was fulfilled in three steps. It is the reason to call this procedure "stepwise identification". The unit of soil water dynamics was identified on the first step. For this aim a special method of simulation of real evapotranspiration was developed (Poluektov et al., 1997). The method is based on the fact that evapotranspiration (the sum of plant transpiration and soil evaporation) is slowly sensitive to the values of LAI changing during the vegetation. As a result the parameters of lower boundary conditions of the equations of soil water dynamics were determined. Coefficients controlling the rate of plant development were estimated on the second stage. It was possible because the rate of plant development depends on weather conditions and soil moisture and does not depend on the dynamics of plant organs. The submodel, which does not include a majority of biological units was developed. Besides the special program realizing the algorithm of automated finding of a goal function was elaborated.

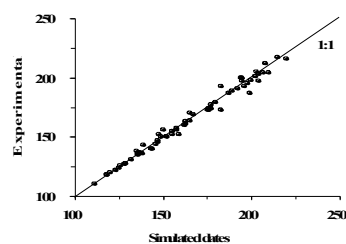


Fig. 1. The comparison of real and simulated dates of plant development.

The parameters of water stress function were estimated on the third step. The complete model, which includes the whole set of model units was used at this step.

## **Results**

Some results of model identification are presented on Figs 1-3 and in Table 1. The comparison of real and simulated dates of plant development stages is shown on Fig. 1. On the axes are placed the day numbers according to Julian calendar. The following stages of wheat development were observed and simulated: emergence, 3-rd leaf, tillering, stem formation, ear formation, milk and wax ripening. The points correspond to all these stages for 12 years of vegetation.

The correlation of calculated and measured values of leaf area index (Fig. 2) shows satisfactory agreement between them. Note that there was a great variability between LAI values in different years of vegetation.

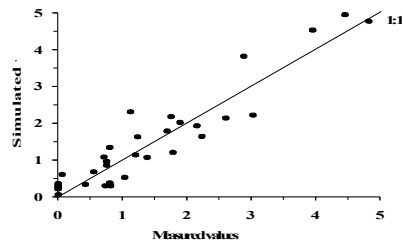


Fig. 2. Comparison of measured and simulated LAI values

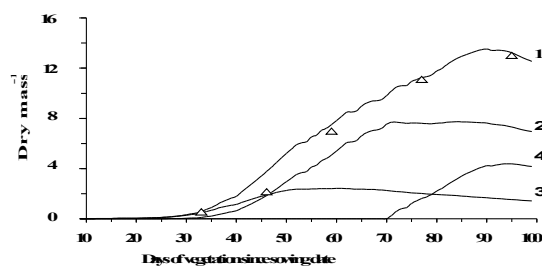


Рис 74. Динамика роста биомассы крапивницы 1973г.  
 1 - суммарная биомасса  
 2 - биомасса стебля  
 3 - биомасса листа  
 4 - биомасса уха  
 Δ - экспериментальные данные

Fig.3. Dynamics of plant organs during the vegetation season 1983.  
 1 – shoot d.m., 2 – stems d.m., 3 – leaves d.m., 4 – ear d.m, Δ – experimental data.

Table 1. Simulated and measured values of grain d. m.

Years of vegetation	Grain d.m., t ha <sup>-1</sup>	
	Simulated	Experimental
1972	1,15	1,64
1973	4,17	4,98
1974	4,63	3,99
1975	2,09	2,30
1976	4,07	3,46
1977	1,88	2,20
1979	1,88	1,49
1987	2,74	2,63
1988	1,98	2,06
1989	5,11	3,47
1990	2,77	3,12

Maximum LAI in 1983 reached, for example, the value 4.65, while the same variable in 1972 was equal only 1.21. It is connected with the variation of weather conditions, mainly with the sum of precipitation during the vegetation season.

Finally, the time course of plant production process is presented on Fig. 3. Dry matter (d.m.) of plant organs, such as leaves, stems, roots and ears were calculated, but only summary above ground d.m. was measured in the field test. It would be better, if d.m. of all plant organs will be measured in the future experiments directed to model validation.

### **Discussion**

The method of stepwise identification of soil-plant-atmosphere model is proposed. It is based on the different sensitivity of the model to the parameters of a separate unit. For example, summary crop evaporation e.g. evapotranspiration slowly depends on leaf area index and crop height. So it is possible to use a special method for identification of the parameters of the unit of soil water dynamics (Poluektov et al. 1998). The specially developed structure, so called “single-layer soil water balance model” can be used for the identification of this unit. It does include biological units at all, but only simulate their dynamics approximately. Analogous idea works at the second identification step devoted to the estimation of parameters of plant development unit, which connect astronomic and biological time during vegetation period. As for biological submodel, the numeric values of its parameters primarily are used going from literature data (see, for example, Diepen et al. 1988). They characterize, of course, “average plant”. So on the third identification stage they can be corrected when the other model parameters are yet known.

Identification procedure described above requires running model repeatedly in order to minimize the difference between the experimental and simulated data. A

special program **IDENT** is developed, which permits to make this procedure automatically. This program is included in the simulation system **AGROTOOL**.

The new model possibilities have to be taken into account in the design of new schemes of field experiment. From the modern position, field test must be closely connected with model development and application. One of the main problems is model validation and adaptation. The situation was discussed in (Acock & Acock, 1991). The main author's conclusion was that it would be advantageous to link the explanatory power of crop simulators and the data from long-term field experiments. In this process we cannot use the data collected in earlier years for developing crop simulators. However, we can collect additional types of data in the future, to use in parameter adjustment and validation. So, there are two possibilities to use field research for model development and validation. First of them is a collection of necessary dynamic data for 5-7 years of vegetation, or more. This possibility was used in the paper. Another way is connected with the carrying out of many test variants in one year. It must lead to reduction of the years necessary to model validation. (Poluektov, 2000). Nevertheless, the coordination of dynamic plant production models with the design of field experiments is of great importance now.

### **Acknowledgements**

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### **Резюме**

Динамическая модель системы почва-растение-атмосфера как программный продукт включает в себя набор заранее неизвестных параметров, которые должны быть оценены в процессе ее калибровки (параметрической идентификации). Работа посвящена решению задачи идентификации динамической модели, разработанной авторами. Предложенный метод получил название пошаговой идентификации. Модель входит в качестве подсистемы в имитационную систему AGOTOOL, позволяющую выполнять компьютерные эксперименты в режиме диалога.