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AGROTOOL software as an intellectual core of decision support systems in computer aided agriculture

VLADIMIR Badenko[1,a*], VITALY Terleev[1,b] and ALEXANDER Topaj[2,c]

[1]St.Petersburg State Polytechnical University,

Polytechnicheskaya, 29, St.Petersburg, 195251, Russia

[2]Agrophysical Research Institute, Grazhdansky pr. 14, St.-Petersburg, 195220, Russia

[a]vbadenko@gmail.com, [b]vitaly_terleev@mail.ru, [c]alex.topaj@gmail.com

* corresponding author

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Abstract. Some problems of decision support systems in computer aided agriculture are discussed. The main focus is made on collaborative model development, including model decomposition issues and implementation of generic frameworks for polyvariant model use. A current state and prospective ideas for improvement of modeling infrastructure suitable to perform multi-factor computer experiments with existing crop simulation models are presented.

Introduction

A scope of decision support systems in computer aided agriculture is not associated with any particular method of farming. The appearance of dynamic models in computer aided agriculture has led to a new understanding of the processes taking place in the soil-plant-atmosphere system. AGROTOOL is the dynamic model of agroecosystem. AGROTOOL is developed to estimate the agrometeorologial crop state, to forecast crop yield, as well as to support agricultural decision making and analyze the sowing, irrigation, fertilization and harvesting management [1]. Plant growth imitation algorithm in AGROTOOL is invariant, so the model itself is generic crop simulator applicable for modeling many different crops such as: barley, winter and spring wheat, alfalfa, maize and others.

Model AGROTOOL

AGROTOOL consists of several rather independent, scalable and replaceable modules, interacting each other every time step.

1) The agrometeorological module is connected with hydro-meteorological database that consists of all needed daily weather data (minimum and maximum temperature, air humidity, precipitation and solar radiation characteristics).

2) The module of radiation and photosynthesis calculates the daily sum of solar radiation intercepted and absorbed by plants, as well as the daily sum of accumulated assimilates due to photosynthesis and dark metabolism.

3) The module of turbulent gas exchange in the atmosphere calculates the wind speed profile above and inside the vegetation as well as the aerodynamic resistances for fluxes of carbon dioxide, heat and water vapor.

4) The module of soil water dynamics calculates the moisture balance in frames of multi-layer presentation of one meter soil profile. The available water content is determined taking into account rainfall intensity, plant transpiration, water evaporation from soil, percolation and moisture exchange within soil layers. The intensity of all the processes caused by the water transport are determined by water potential in soil, so the soil water retention curve is used for simulating these processes [2]. The dependency of volumetric moisture content on water potential in soil is approximately estimated on

the base of soil-hydraulic constants such as field capacity, permanent wilting point, saturation capacity and maximum hygroscopy [3,4].

5) The module of plant growth and development uses some specific "growth distribution" functions for performing the calculation of the dry matter increase for different plant organs. The original concept of adaptive distribution key is used to define the shoot-root balanced growth during vegetative development stage. In turn, the physiological time is determined as the sum of effective temperatures that is corrected by effect of plant water-stress.

6) The module of nitrogen transfer and transformations in soil takes into consideration main processes determining the soil nitrogen status: litter humification, ammonification, nitrification and denitrification, root nitrogen uptake etc.

7) Special module has been developed to provide the model control of principal agronomical treatments: sowing, irrigation, nitrogen fertilizing and top dressing, harvesting. All these human impacts can be imitated both in declarative (predetermined dates and rates of actions) and reactive mode (as a formal rules based on the feedback of internal model variables).

Applications

The scope of possible applications of crop models is really broad and ever increasing. One can enumerate many various problems in theoretical agroecology as well as in practical agriculture which can be solved by means of model analysis. Problems can differ principally by settings of target. But problems have the common feature. For example to solve a particular task the user must start the model many times. Indeed, single model run with given set of input datasets has rather narrow benefit. But sometimes slightly more complicated investigation always requires multiple executions with varied inputs and opportunities for comparison of results. Below there are some typical problems requiring multiple model runs and reveal a particular source of polyvariance for each of them.

For analysis and optimization of concurrent agro-technologies one needs to investigate the relative efficiency (in yield units or economic terms) for selected variants of technological impact (irrigation, fertilization, tillage etc.). Usually the difference in variants can be expressed in dates and quotas of corresponding actions. We deal with operative control if time span is current vegetation season, the source of polyvariance here is the set of checked variants (levels of factor of computer experiment). More complicated case is the determination of longstanding technological strategy. The sought technological variant must demonstrate the best average efficiency on the set of possible weather scenarios for the region under investigation. In this instance one has a supplementary source of multiple model computations – the set of typical weather realizations.

For assessment of climate change influence on agroecosystem the computer experiment is, probably, the only way to forecast how possible changes of global climate may affect crop productivity and ecosystem stability. The problem, however, is that crop or forest dynamic model must have not climate, but the weather as an input dataset. So, typical research scheme requires execution of rather big number of model runs with alternative “futuristic” weather inputs and statistical treatments of results obtained. A way to prepare such kind of weather realizations is so called “weather generator”. The examples are: SCLISS soil weather generator [5] for forest models or daily meteorological data imitator WGEN for crop models. This approach permits to get the synthetic data with desired level of temporal resolution (weekly, daily etc.) by means of statistical modeling of the weather as multi-dimensional discrete random process. All quantitative process parameters (trends of means and variations, auto- and cross-correlation characteristics etc.) are initially identified from several real weather observations. Certainly, they must be specially modified before using in Monte-Carlo procedure in order to become appropriate not for recent but for future climate conditions.

One of the key features of the computer aided agriculture methodology is a management of spatial heterogeneity of agricultural fields. Crop model, being an intellectual core of computer-based decision support system in precision and sustainable agriculture, cannot longer consider the simulated field as uniform area. Instead, it must take into account the variety of soil properties, landscape peculiarities etc. Then, the main varying factor of corresponding computer experiment is the set of management units and, again, the necessity of crop model polyvariant analysis is obtained.

It is obvious that multi-variant use or polyvariant analysis is the common challenge for crop model application. Moreover, the principles of management of multivariate computer experiment and/or model running in batch mode seems to be quite universal and do not depend on particularly selected model. The latter is a serious argument that modern crop modeling systems need special advanced infrastructure to perform multi-factor analysis. Such an idea is already embodied in some well-known and widely distributed products – DSSAT [6], GUICS [7].

APEX (Automation of Polivariant EXperiments) is a software system elaborated in Laboratory of Agroecosystem Simulation (Agrophysical Research Institute, Saint-Petersburg). It is developed for design and performing of multi-factor computer experiments with arbitrary dynamic crop models [8]. As a simplified framework of crop model multivariate use APEX encapsulates two basic functionalities. Firstly, it can be considered as versatile repository of external crop model descriptors. Specific interface permits user to register its own crop model or model version. Secondly, APEX provides generic environment for model polyvariant analysis. It means designing and preparation of multivariate computer case study, performing the model runs in batch mode and applying advanced procedures of statistical treatments for results obtained.

Almost every dynamic crop model can be registered in APEX in easy way. There are a few simple requirements allowing such registration. It is important that these requirements don’t affect inner model structure and content or format of input as well as output datasets. Let us discus the requirements for models. At first model must provide a principal ability to run in the batch mode. So, it should not be interactive. Model itself must request nothing from the user: all input data for a single run must allow the automatic preparation of the outside and all results must allow reading from the outside too. Second, since APEX is strongly oriented to the interaction with crop models the list of basic factors or informational domains for model input datasets is predefined and cannot be changed. These factors are: ”culture”, ”weather”, ”soil”, ”agrotechnology”, ”location” and ”initial conditions”. Each domain can have an arbitrary internal structure, but any input data must be assigned to one of these predefined factors. Later, computation algorithm must have strictly indicated termini for start and finish (for example, planting and harvesting). Since APEX is strongly oriented to the interaction with dynamic models the set of output data must be a vector of model state variables for each time step of model computation. Lastly, model as a software must be either dynamic library or executable file compatible with Windows platform. Thus, the process of model registration in APEX consists of assigning general characteristics, specifying the structure and formats for input and output datasets, and creating and serialization the specific adapter to support an interaction between APEX and model executable during runtime.

Model polyvariant analysis or computer experiment procedure in APEX is based on three principal concepts. They are “Factor level”, “Scenario” and “Project”. “Factor level” is a dataset (one or many tables of data) realizing one of predefined factors. “Scenario” is the tuple of the links to the levels of all factors required for a single model run. Finally, the “Project” is the common description of the single experiment to perform i.e. list of composing scenarios.

There are several ways to receive the data composing the “Factor level” in order to store it in the system database: manual input, import from different external sources, application of stochastic generators (weather generator, for instance), propagation of existing level by means of varying one or several characteristics on a grid of values.

Being once created the project can be calculated or recalculated at any time. It means the serial model runs with input data sets defined in current scenario and saving the obtained results to APEX database. After the project has been calculated its results can be analyzed by means of many special tools of statistical treatment built in the system. It should be noted, that strict specification of possible factors entails a clear understanding of the nature of compared scenarios, that, in turn, provides a big opportunities for “Semantically reach” project analysis. This allows using the current version of

APEX coupled with the "native" crop model AGROTOOL in real practice for decision support and solving of typical problems of agroecological management.

For the moment the next version of APEX is under development. The main challenge here is to use it as a core of intellectual computer systems in computer aided agriculture. The purpose is considered to be achieved by some extensions of its basic functionality. For example, advanced mechanism of integration between APEX and GIS systems [9] (cartographic interface of polyvariant model analysis and spatial interpretation of "Soil" factor levels) is under development.

Potentially, parallel run of several instances of the standard one-dimensional dynamic crop model in synchronized regime with temporal interactions as well as enhanced GIS interface can be considered as an emulation of the processes taking place in spatially heterogeneous ecosystems.

Summary

Nowadays, crop models are increasingly being used in ever expanding range of applications covering crop management, decision support, analysis and prediction of climate change impact, training of specialists, etc. New demands require more intensive use of software engineering techniques to satisfy the needs of numerous stakeholders and to ensure such vital properties of the crop modeling software as customization ability, adaptability and scalability. The authors argued that modern crop modeling systems need more advanced infrastructure to perform multi-factor computer experiments. Both in model development phase and in a broadening range of applications a multiple model calculation and analysis of polyvariant scenarios are now required. The paper emphasizes a crucial role of architectural design of modern crop modeling systems and provides particular solutions that have been recently elaborated in authors institutions.

References

[1] R.A. Poluektov, S.M. Fintushal, I.V. Oparina, D.V. Shatskikh, V.V. Terleev, E.T. Zakharova, AGROTOOL - a system for crop simulation, Archiv fuer Acker- und Pflanzenbau und Bodenkunde. 48 (2002) 609-635.

[2] R.A. Poluektov, I.V. Oparina, V.V. Terleev, Three methods for calculating soil water dynamics, Russian Meteorology and Hydrology. 11 (2003) 61-67.

[3] R.A. Poluektov, V.V. Terleev, Modeling the moisture retention capacity of soil with agricultural and hydrological characteristics, Russian Meteorology and Hydrology. 12 (2005) 73-77.

[4] V.V. Terleev, W. Mirschel, U. Schindler, K.-O. Wenkel, Estimation of soil water retention curve using some agrophysical characteristics and Voronin's empirical dependence, International Agrophysics. 24 (2010) 381-387.

[5] S.S. Bykhovets, A.S. Komarov, A simple statistical simulator of soil climate, Eurasian Soil Sci. 35 (2002) 443-452.

[6] J. Jones, G. Hoogenboom, C. Porter, K. Boote, W. Batchelor, L. Hunt, J. Ritchie, The DSSAT cropping system model, European Journal of Agronomy. 18 (2003) 235-265.

[7] B. Acock, Y.A. Pachepsky, E.V. Mironenko, F.D. Whisler, V.R. Reddy, GUICS: A Generic User Interface for On-Farm Crop Simulations, Agronomy Journal. 91 (1999) 657-665.

[8] S. Medvedev, A. Topaj, Crop simulation model registrator and polyvariant analysis, IFIP Advances in Information and Communication Technology. 359 (2011) 295-301.

[9] D. Kurtener, V. Badenko, GIS fuzzy algorithm for estimating the quality of soil parameter evaluation of attribute data quality, Geomatics Info Magazine. 15 (2001) 76-79.

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DOI References

[6] J. Jones, G. Hoogenboom, C. Porter, K. Boote, W. Batchelor, L. Hunt, J. Ritchie, The DSSAT cropping system model, European Journal of Agronomy. 18 (2003) 235-265.
http://dx.doi.org/10.1016/S1161-0301(02)00107-7
[8] S. Medvedev, A. Topaj, Crop simulation model registrator and polyvariant analysis, IFIP Advances in Information and Communication Technology. 359 (2011) 295-301.
http://dx.doi.org/10.1007/978-3-642-22285-6_32