

Complex assessment the efficiency of adaptation of agricultural ecosystems to climate change in the European part of Russia based on integration with European crop models

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Two crop models - *CropSyst* and *RoIMPEL* were evaluated to assess the feasibility of simulating the growth and development of the main crops: winter and spring cereals, perennial grass and potatoes using long-term datasets from Russia.

For the crop-specific simulation under former Soviet Union's climate, soil and management conditions four sites were used - Belogorka (Russia, St'Petersburg Region), Timiryazevsky (Russia, Chelyabinsk Region), Yachenka (Belarus, Minsk Region), Grakovo (Ukraine, Kharkiv Region). The first experiment was founded in 1957. Simulations with the domestic *Climate-Soil –Yield* crop growth model for this region show increase of productivity under 4 SRES emission scenarios before 2030 with slight decrease in 2030-2050. The next experiment is situated in Chelyabinsk Region (founded in 1971) and the territory represents an example of the continental climate area which significantly responds to climate change by decreasing crop productivity. Two more experiments have been chosen for comparative study more wide geographic window of the former Soviet Union. Grakov long-term experiment was established in 1967 to study fertilizers efficiency and agrochemical parameters. Yachenka long-term experiment was established in 1986 to study dynamics of basic agrochemical parameters and fertility of podsoluvisols under limited application of mineral and organic fertilizers.

All experiments include control plots and treatments with different rates of mineral N application. All the databases had been initially formatted according to input standards for local-scale *CropSyst* testing, with addition necessary experimental data about soil moisture and mineral N dynamics, crop phenology and soil physics data. To achieve compatibility of texture data the particle-size distributions according to Russian classification were transformed to a logarithmic scale, and a log-linear interpolation of the cumulative particle-size distribution was applied. All the necessary soil physics data were obtained from locally measured data or estimated with *SoilPar* model or using a set of empirical equations.

Daily meteorological information on air temperature, precipitation and solar radiation for the periods of simulation was available from the nearby meteorological stations. If solar radiation data were not available for the whole period of simulation, it was constructed with a *RadEst* – radiation estimation program on the base of daily data on maximum and minimum air temperature and precipitation. Several years with measured radiation data were used to parameterise the *RadEst* program and to estimate radiation for all the rest years.

According to *Climate-Soil-Yield* crop model (one of the commonly used domestic software) rainfed cereals yield changed compared to present in the above mentioned regions in the range -4 to -53% in 2050 without adaptation and -28 to 91% with implementation adaptation strategies. The same figures for grass yields are in the range +10 to -33% and 0 to 147% without and with adaptation. Scenarios of climate were derived from the HadCM3 model.

CropSyst was used only in short-term simulations, as it was not possible to apply the model for usual crop rotation. The main obstacle was the absence of local crop model parameters for calibration (necessity to estimate growth of spring cereal with perennial

grass (first year) as a subordinate crop) as well as absence of default set for some common crops, as winter rye.

CropSyst was able to simulate the growth stages, above-ground biomass and yield measurements of spring barley, basically with the default crop growth values. Soil water content simulations were satisfactory as well. The simulations of mineral N were not completely satisfactory. While the model roughly describes the main trends, the simulations did not reflect N fluctuations over time. Simulation of crop growth in response to nitrogen has revealed more important role of climate stress in comparison with nutrient stress, which was not supported by the long-term yield fluctuations in treatments comparing different N rates with or without sufficient PK application, especially in optimal climate years. It is also possible that factors other than soil nitrogen availability may play a significant role in defining the N uptake by the crop, for example, P deficit not simulated by the model. Another type of influence may be carry-over effects from one year to the next that may alter the starting conditions of the following crop. Issues of this type can be examined only by running long-term simulations of cropping systems and not the short-term ones. Here we can not also consider actual data of soil C dynamics which is an important indicator of long-term sustainability of the applied management system.

CropSyst gave reasonable estimates of crop growth and yields of winter wheat, oats and potatoes only after the calibration of the crop parameters. They have to be considered as an initial adaptation of the model to the local environment and may be improved with future data. The model again was quite sensitive to weather trends, while the simulation response to changes in fertilisation as an important factor of management activity was poorer than that observed in situ.

As a result comparative estimates of adaptation, climate and soil impact can be considered as preliminary ones.

Comparison of climate, soil and management effects was revealed that potential yield of spring barley in future climate conditions can be higher in the region of podzoluvisols in comparison with chernozems. Effects of climate on potential productivity were higher in all cases than soil effects. St'Petersburg region has the highest interannual changes in potential and water-limited productivity: 75% for wheat and 55% for potatoes. Potential productivity of St'Petersburg Region will increase in future climate, while those for Kharkiv and Chelyabinsk Regions has a tendency to decrease, most pronounced under A1FI emission scenario and manifested mainly after 2030. For spring cereals the effect of soil properties on water-limited productivity is more pronounced in comparison with winter wheat. The effect of climate was the main one followed by soil properties - the latter factor can cause up to 40-45% variation of cereals yield in the separate years. Among adaptation measures, change of sowing day in a future climate can lead to 6-15% increase of crop yield. In that simulation optimal sowing dates were calculated by the *Climate-Soil-Yield* model and then were used as input parameters for changes in management file. Water-limited productivity variation in time was less both for business-as-usual scenario as well as for adaptation strategies in comparison with the above mentioned outputs of *Climate-Soil-Yield*, but it is necessary to stress that we made comparison in absence of N stress for all runs. In fact, more detailed estimates are necessary for non-automatic N fertilisation as predicted by different adaptation scenarios and assessment of the model sensitivity to changes in crop parameters (as a result of cultivars change). Here we assumed reaching nutrient supply optimization as a result of adaptation strategies and possibility to change sowing on earlier date as a measure for more efficient use of soil moisture resources.

During working visit to ICPA (June 2006) necessary steps in *RoIMPEL* change for running with *Soil GIS Database of the European Russia* have been discussed, as well as common approaches in construction *Soil Geographical Data Base of Europe at the scale 1:1,000,000* based on Soil Typological Units and *Soil Database of the European Russia at the scale 1:2,500,000* with predominant and accompanying soils within one mapping unit. Information about max and min percent of granulometric fractions, bulk density and solid bulk density for the main diagnostic horizons of soils within mapping units was added to the *Soil GIS Database of the European Russia* to estimate uncertainty in water budget elements calculation with the Thornthwaite-Mather's approach. Special Excel-sheet based software was constructed by Catalin Simota to optimize output W-pF parameters for *RoIMPEL*.

The new version of *RoIMPEL* model appropriate to make calculations with the *Soil GIS Database of the European Russia* must include several changes, namely

1. Nitrogen input fixed days application module. The modern version supposes nitrogen from mineral fertilizer is applied automatically following optimization criteria.
2. Soil freezing submodel to divide rainfall penetrating into the soil and snow accumulated on the freeze surface.

3. Structure of climate data file to copy Russian climate database. The available data for Russia are based on a 0.5' grid with monthly time steps using observations for 1901-2000 and GCM HadCM3 for 2000-2060 considering the four SRES 'marker' scenarios – A1FI, A2, B1, B2. Initial database contains mean air temperature, mean precipitation, mean atmospheric humidity, mean cloudness, and mean range of daily variations of temperature. The potential evapotranspiration and amount of solar radiation were calculated. The approach is quite close to those used for *RoIMPEL* simulation over the whole of Europe but climate data files have different format. The modern version of *RoIMPEL* allows only to choose necessary data from the climate file but not to update it.

Alas, these changes were not finished by ICPA developers in 2006 and this prevented from running the model with local as well as GIS regional data.

The minimum weather data requirements for *RoIMPEL* are only monthly averages of air temperature and monthly precipitation, which makes the latter more preferable in regional modeling based on the data availability about current and future climate. Besides, sensitivity of the model to rather small rates of fertilization, which was demonstrated for the Romanian territory, makes this model a very promising tool for application in the European part of Russia.

The weather generator *ClimGen* was used to generate local weather data from the 0.5' regular grid of monthly data for St'Petersburg and Chelyabinsk Regions using observations for 1961-2000. This simulated daily weather data is then incorporated in runs of the *CropSyst*. The new simulated crop growth of wheat and barley generally matched the results received with the real daily local weather data. Thus, use of GIS databases that contain more extensive information on current climate widening the number of sites that can be practically assessed with crop growth models, for example those, where only averaged climate data are available. However, caution must be taken to ensure that aggregation of soil and management data in GIS do not cause substantial discrepancies. So these exercises could be extended by varying soil and management parameters based on available GIS data for the selected regions in a sensitive analysis of the model.

CropSyst simulations allow proposing a set of management options to alleviate reduction of crop productivity: changing sowing time, optimization of N fertilization and management of crop residues can be considered as a sound measures. Nevertheless, as

the model does not consider the effect of diseases and weeds on crop productivity, we can not make decision in favor of set-aside or more intensive agriculture based only on a restricted set of modeling options. A special interest is an introduction of a new crop in rotation – for example, multi-year alfalfa in the absence of actual local crop data. In that case uncertainty is higher in comparison with choosing from the known set of the locally tested crops.

CropSyst used in combination with the local and regional weather data is found to be a useful tool in determination the critical role of the climate factor in agriculture production of the European Russia in comparison with soil and nutrient factors. After crop-specific local calibration the model can be used for increasing relevance of long-term experimental information in forecasting purposes and also planned and not forced changes in the experiments. The main drawback is that the role of nutrient stress was not supported by the long-term yield fluctuations in treatment with different NPK availability, which can be improved by the long-term simulations of the cropping systems.

Current problems with essential changes for running *RoIMPEL* makes it necessary to find another appropriate crop model to make comparison a set of output parameters for the same local experimental data. Several models will be tested, including DSSAT 4, which was purchased especially for solution of that problem. Proposals for changes in economic scenarios construction based on adaptation to climate change can be formulated after finishing this comparison.

This work was included as a separate task in the project of agricultural monitoring based on electronic GIS databases of the Ministry of Agriculture of Russian Federation – the existing crop models adaptation as forecasting tools at regional scale (2007) and, after finalization, can be a used in economical forecasts of the federal program “Social rural development”. The results will be also applied locally for the Geographical Network of Field Experiments in development the main principles of long-term field experiments modifications after successful crop model validation with multi-crop-forecasting approaches.