Scientific Papers, USAMV Bucharest, Series A, Vol. LII, 2009, ISSN 1222-5339

DEVELOPING AN INTEGRATED CROP-METEOROLOGICAL MODEL FOR HILLY TERRAINS USING DIGITAL TERRAIN MODELS

SORINA DUMITRU*, V. CHENDES, G. COJOCARU*, C. SIMOTA***

*National Research and Development Institute for Soil Science, Agrochemistry and Environmental Protection of Bucharest

**National Institute of Hydrology and Water Management of Bucharest

Keywords: *Agro-Meteorological Models, Digital Terrain Models, hilly terrains*

Abstract

Modelling the induced effect of configuration and land characteristics on crop physical environment represents a way to quantify crop variabilities, especially in hilly regions, where agricultural terrains are characterised by relatively high slopes. Therefore, there is a need to develop an integrated model of crop growth and energy and water balance on hilly terrains and it has been developed, having as outputs a series of Agro-Environmental Indicators. The model have been tested in a "virtual" example, in order to support the farmers to comply with environmental issues included in "good agricultural and environmental condition (GAEC)"

INTRODUCTION

The agriculture is one of the most important landuse in Europe, in spatial terms. The management of agricultural areas has a great impact on environment quality through nutrients dynamic, used water resources and biodiversity. On the other hand, the yields are function of soil properties, including texture and drainage characteristics controlling available soil water [3].

In Romania, there is an important part of arable land located in hilly regions, characterised by topographic complexity inducing some particularities for water, temperature and radiation regimes from soil-plant-hydrosphere system. Their conditions have direct effects on used agricultural systems and techniques, on agri-environmental potential and on vulnerability of these regions.

Large areas from the hilly regions are sub-optimal for annual agricultural crops. Therefore, for crop management optimization and for agri-environmental potential evolution prognosis from these areas, the complex approach of cropping systems by using modelling procedures and methods of the soil-atmosphere-plant-hydrosphere system from the hilly regions is necessary.

It seems that about 80% of yield variability is explained by a combination between soil and terrain properties [2]. Therefore, the enhancement of bio-physic processes modelling for hilly regions could reflect the variability induced by topography on climatic conditions and plant growth.

Generally, simulation models for the processes from the soil-plant-atmosphere system have been developed for flat lands (CERES, EPIC – SUA; SWAT, STICS – Europe; SIBIL, ROIMPEL – Romania) [1, 6]. Main specific aspects induced by the complex topography of hilly regions taking into account in simulation models are:

- Spatial distribution as function of slope and aspect of meteorological variables involved in water redistribution and crop growing processes;
- The complex hydrology of the areas (especially, water redistribution at soil surface by lateral fluxes) with direct effects on water deficit/excess.

As a consequence, the objective of this paper is to discuss the development of an integrated simulation model for the specific bio-physical processes from the hilly regions, having as outputs a series of Agro-Environmental Indicators. The model will contribute to the detection of environmental problems in the hilly regions.

MATERIAL AND METHODS

Current crop and land use models assume a flat surface for radiation regimes and for scalar (temperature and humidity) fields and energy fluxes (sensible and latent heat). This is not in accord with the physical principles, because topography, in general, and slope, in particular, greatly influence the physical environment of a catchment. Therefore, an integrated model of crop growth and energy and water balance on hilly terrains has been developed – the IAGINT model, having a series of Agri-Environmental Indicators as outputs. The model has been developed using Visual Basic language, and the link to DTM and GIS has been done using ESRI MapObject. For this purpose, several steps have been achieved as following:

Developing an integrated modelling approach

Crop and soil hydrology models are based on spatially distributed soil parameters. Their "spatialisation" is related to qualitative information and aided by using probability distributions and fuzzy relations for hydrologic properties. Spatial extrapolation of the field scale models into sub-optimal sites being an important problem, new modules describing the peculiarities of mass and energy transport processes on sloped soils have been developed to enhance the existent models.

Developing simulation modules of meteorological and hydrological variables on sloped soils

Several relationships for the assessment of net and latent heat flux variations induced by topography have been derived from measurable agrometeorological parameters (wind speed and direction, surface and air temperature, air humidity), topography (slope, slope length) and crop characteristics (canopy resistance, height, roughness). Others modules have been integrated with used DTM and evaluation platform to account for landscape effects on (a) crop water use, (b) evapotranspiration and sensible heat, and (c) soil water redistribution.

Developing some modules for describing the crop-soil interaction

Modelling crop growth have been enhanced by including some algorithms for the assessment of intercepted radiation and the soil temperature dynamics. Limits due to soil temperature and soil moisture in early growth, as well as the effects of extreme temperatures, have been explicitly accounted for yields assessment.

Integrating and aggregating modules using DTM parameters

Most regional studies are characterised by an up-scaled (black box) approach originating from hydrology. While this technique has been maintained for climate change scenarios, all surface processes have been spatially solved and finally aggregated at catchment level. Crop growth processes are observed and modelled at the field scale, resulting in the need for aggregating the result.

The flow chart (figure 1) shows the procedure used to develop the IAGINT model [4].

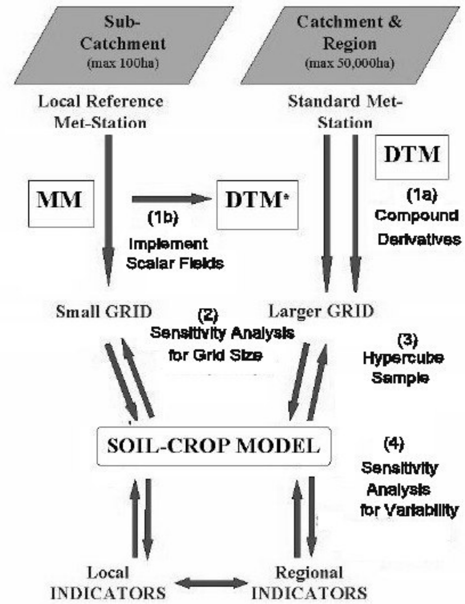

Fig. 1. Schematic flow diagram for scaling model-based AEI

The diagram outlines three main routes and the steps involved.

A. Standard meteorological data are modified using DTM compound derivatives (1a).
B. This implies a procedure of scaling (1b) – an extrapolation of the relationships between the scalar fields of the MM (micrometeorological module) and primary DTM derivatives (slope, aspect, etc.).
C. The meteorological inputs are modified via the model-hybrid DTM and fed into the SCM (Soil Crop Module), which involves the first sensitivity

analysis (2), scaling up from local to standard meteorological data, moving from one grid size to another.

A integrated soil-plant-atmosphere model, the IAGINT model, has been developed (figure 2).

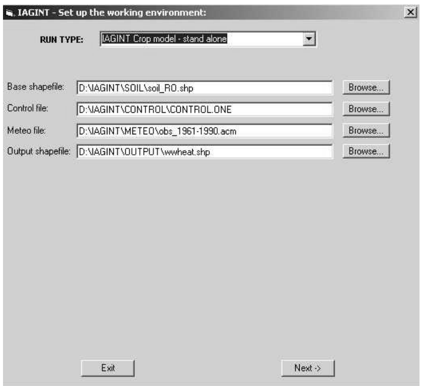

Fig. 2. The main window of IAGINT model

RESULTS AND DISCUSSION

An “virtual” example of adapting IAGINT-type output to a decission support system SSD for helping the farmers to comply with environmental issues included in “good agricultural and environmental condition (GAEC)” considering the climate changes, has been performed.

Three of the four GAEC issues are directly linked with IAGINT outputs: 1) Soil erosion with the following standards: minimum soil cover and minimum land management reflecting site-specific conditions; 2) Soil organic matter with the following standard: standards for crop rotation, national conditions, minimum 3 crops or 2 crops from 2 different crop groups, and no cropping in monoculture on the same parcel more than 3 years organic C-consumers; 3) Soil structure with the following standard: appropriate machinery use, workability assessment.

For including two crops in rotation and evaluating the effect of climate changes an alternative software with daily weather data calculated with spline functions from monthly data has been used. The software handle with various maize and winter wheet varieties (development stages are predicted using CERES type methodology, dynamics of biomass is based on radiation use efficiency and water and temperature stress factors) calculates the dynamics of soil water (predicted using Thornthwaite-Mathers-Benfratello approach) and has an economic block evaluating gross margins. All the physical and biological processes are much better simulated in IAGINT.

A simple “virtual” landscape was selected having equal areas on North and South oriented slopes and in the top-flat surface. This landscape is specific to the hilly region of South Romania. A soil profile from the region (Profile 6618, site: Valea Calugareasca, Longitude: 26.150, Latitude: 44.973) was selected for deriving the soil parameters needed for simulation (figure 3).

The crops selected were winter wheat (Ww), and maize (Mz) with early (e) and late (l) cultivars, in 5 different crop rotations CR1-CR5.

The used climate scenarios have been as follows: 1961-1990 – baseline; 2011-2020 – HADCM3 SRES A2 scenario; 2011-2020 – HADCM3 SRES B1 scenario; and 2011-2020 – PCM – SRES A2 scenario.

The resulting indicators from IAGINT model, used in SSD, are the following: Crop yield average, Crop yield standard deviation; Gross margin average; Gross margin standard deviation; Percentage of years with crop yields less than threshold (3 tha^{-1} for Ww, and 3.5 tha^{-1} for Mz for dry farming; respectively 6 tha^{-1} for Ww, and 9.5 tha^{-1} for Mz in irrigated conditions).

Crop rotation	North	Top	South
CR 1	ww / mz(e)	ww / mz(e)	ww / mz(e)
CR 2	ww / mz(e)	ww / mz(e)	ww / mz(l)
CR 3	ww / mz(e)	ww / mz(l)	ww / mz(l)
CR 4	ww	mz(l)	ww
CR 5	ww	ww / mz(e)	ww

Fig. 3. The position of the three selected points and crop rotations

The SSD outputs represents an indicator ranged from 0 – the smaller acceptable yield, to 1 – the maximum average yield, calculated using Simple Additive Weighting (Saty’s method, [5]) for each scenarios and options considered, with/without GAEC constraints (figure 4).

4. CONCLUSIONS

The value in the graph is complementary to risk associated to each crop rotation (CR 1-CR 5) corresponding to the two ways of considering weighting (no GAEC / GAEC) for the baseline (1961-1990) and some future climate change scenarios. The main conclusions coming up from this analysis are:

1. Crop rotation CR 5 is the best crop rotation in almost all scenarios (no for HADCM-A2).
2. There is a net advantage for CR 4 and CR 5 in GAEC weighting scenario.

3. 2011-2020 climate change scenario will change significantly the risk coefficients.
4. The difference between GCMs (HADCM3 vs. PCM) is higher than the differences between SRES scenarios for the same GCM (A2, B1)

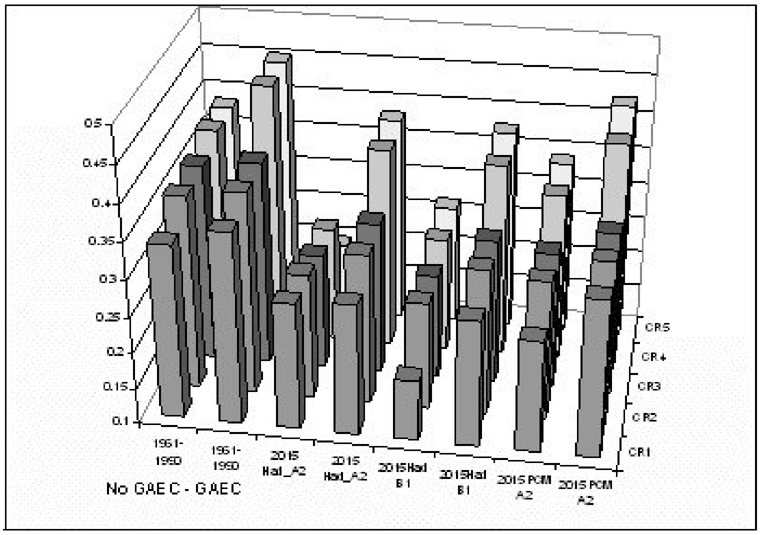

Fig. 4. Comparing the outputs for selected scenarios

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