Journal of Universal Computer Science, vol. 12, no. 9 (2006), 1196-1207
submitted: 31/12/05, accepted: 12/5/06, appeared: 28/9/06 © J.UCS

4M – Software for Modelling and Analysing Cropping Systems

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Abstract: Models have played an important role in scientific research for a long time. The crop models try to simulate the functioning of the atmosphere-soil-plant system with the help of computers. These models can be effective tools in research, education and solving agricultural and environmental protection related problems. The 4M package includes a crop model and several accessories that help to operate the model. The 4M crop model is a daily-step, deterministic model that simulates the water and nutrient balance of the soil, the soil-plant interactions and the plant development and growth. To mention some examples: (1) The package can be used in education to carry out 'zero-cost' virtual agricultural experiments and to challenge and enhance the system oriented thinking of the students. (2) In research it can be used for designing experiments and estimating the present and future characteristics of the investigated system. (3) In practical applications the package can be used to prepare agro-technological advise (fertilization, irrigation, etc.) for farmers, and to carry out economical analyses on farm level.

Keywords: crop model, estimation method, education
Categories: H.5.2, J.2, J.3

1 Introduction

For a long time models have played a very important role in scientific research. The primary purpose of crop models is to describe the processes of the very complex atmosphere–soil–plant system using mathematical tools (functions, differential equations, etc.) and to simulate them with the help of computers. The ultimate aim of using crop models however is to answer such questions that otherwise could only be answered by carrying out expensive and time-consuming experiments. In the 1970's developments in information technology enabled scientists to create the first crop model software using the accumulated scientific knowledge. Since then crop models have been used in numerous educational and scientific projects.

Even though, many well-developed, user friendly crop model softwares are already available such us WOFOST [Boogaard (98)], STICS [Brisson 98], DSSAT [Jones 03], CropSyst [Stöckle 03]; their source code is usually not open, therefore they can not be modified or improved by the users. Furthermore, certain required input data might only be characteristic of the area where the model was developed making it difficult or impossible to provide this data at different places. Despite the fact that there is a great emphasis on creating a single common software toolkit to facilitate the comparison and integration of the many different models in existence today [Rizzoli 04], the majority of the model enhancements are still made by small, local teams.

The purpose of the 4M software package is to be an effective tool in scientific research, education, practical problem exploration and problem solution. Its ultimate purpose is to be a tool for agrarians that integrates the processes of the crop production, its ecological and technological system of conditions into a functioning simulation model using the achieved scientific results, and to support decision making on every possible level.

2 Software Description

The source code of the CERES model [Jones (86)] was used as a starting point for developing 4M. Several studies have proved CERES to be an effective crop model [Kovács 95] [Jamieson 98]. The creator of CERES sheared its Fortran code with us enabling our team to rewrite it in Delphi. A user-friendly interface was also developed for the model to ease handling input and output data. 4M inherited all the capabilities of CERES but was developed with several new subroutines and modules in the past three years.

2.1 The outlined functioning of the 4M model

4M is a daily-step, deterministic (not stochastic) model whose functioning (computation) is determined by the numerical characteristics of the atmosphere–soil–plants system [Tab. 1].

	Characteristic/Variable
Atmosphere	daily solar radiation, temperature, precipitation, …
Soil	bulk density, organic matter content, saturated water content, hydraulic conductivity, …
Plant	phyllocron interval, base temperature, potential kernel growth rate, …

Table 1: Some of the input data required by 4M model

Besides the data that describe the physical, chemical and biological profile of the system, its is also necessary to set its initial condition in the input file of the model. The outlined functioning of the model is demonstrated on [Fig. 1].

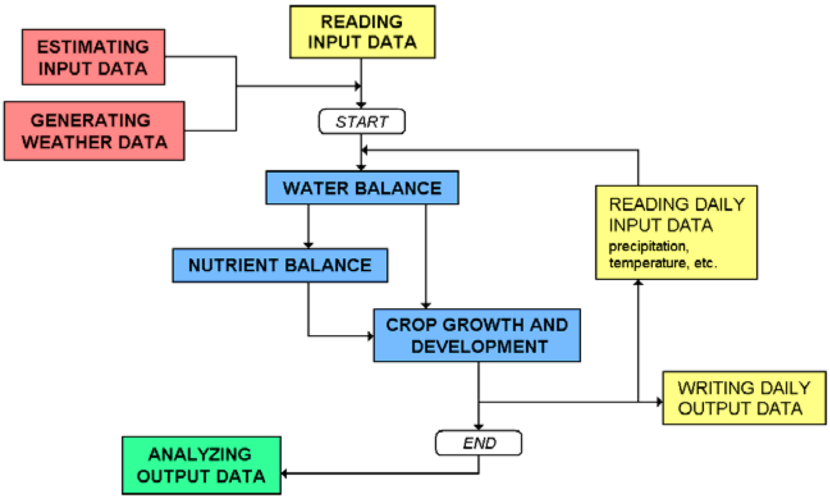

Figure 1: Simplified flowchart of the 4M model

In each calculation module (blue rectangles on [Fig. 1]) the following main processes are simulated by the model [Tab. 2].

Water balance	**Nutrient balance**	**Crop growth and development**
Soil evaporation	Nutrient (NPK) movement in the soil	Phenology
Plant transpiration	NPK mineralization	Assimilation
Surface runoff	NPK immobilization	Distribution of assimilates
Infiltration and redistribution of water in the soil	Nitrification	Leaf area growth
	Denitrification	
	NPK uptake by plant	

Table 2: Simulated processes in 4M model

The accuracy of a crop model is determined on one hand by the authenticity of the algorithms describing the processes of the real world, while, on the other hand by the quality of its input data. Even the ‘perfect’ model would not be able to simulate the real processes precisely if inaccurate input data were provided for it. One of the limitations of using crop models is the (partial) shortage of input data. To surmount this difficulty two stand-alone input data estimating modules were developed for supporting the 4M crop model.

2.2 Input data estimating modules in 4M

The differential equation for describing water flow in porous media (soil) was set up in 1931 [Richards 31]. The two highly non-linear functions included in the equation describe the hydrological characteristics of the soil. In the ideal case the parameters of the functions are determined experimentally. Since this experiment is time and money consuming many methods were developed for estimating the parameters in question from easily measurable soil properties [Gupta 79] [Tietje 93] [Rajkai 96]. Ten of these estimation methods were included in the SOiLVE 1.0 software [Fodor 05] which is a part of the 4M package. SOiLVE also includes a detailed soil map of Hungary [Fig. 2] from which hydrological data required by the crop model can be easily retrieved for every part of the country [Várallyay 94].

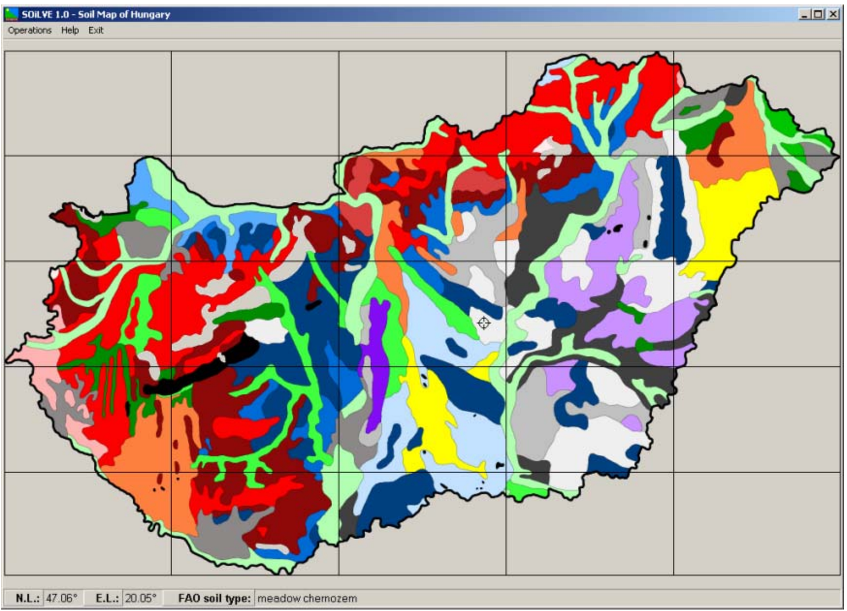

Figure 2: Clickable soil map of Hungary in SOiLVE 1.0

The minimum dataset for many crop models and likewise for 4M, includes daily solar radiation, minimum and maximum temperature and precipitation data. Unlike temperature and precipitation, solar radiation is recorded only at few weather stations [Ball 04]. Therefore using crop models radiation often needs to be estimated from readily available, commonly measured meteorological data. A powerful radiation estimation procedure was developed for Hungary based on the Hargreaves-Samani method [Hargreaves 82] and was incorporated into WeatherCenter 1.0, an other important module of the 4M package [Fig. 3]. This module also includes a simple weather generator.

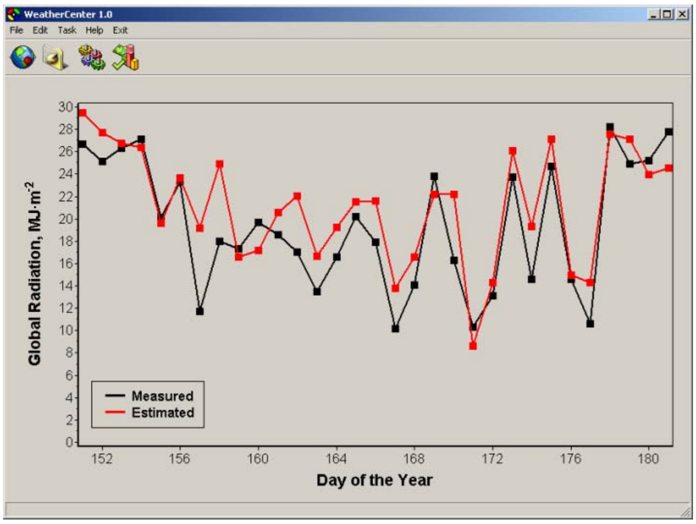

Figure 3: WeatherCenter 1.0: Measured and Estimated Radiation for Hungary, May, 1968

3 Using 4M in Education

The 4M package has a graphical tool for presenting the model results on graphs. This kind of visualization helps the students to learn basic principles of the investigated system and to enhance their system oriented thinking. By applying different treatments (irrigation, fertilization, etc.) on their virtual plants students can carry out virtual experiments in an easy, quick and cheap way and are able to establish ‘cause and effect‘ relationships.

The 4M package contains several sample exercises to present the capabilities and functioning of the software that also challenge the students to try to come up with explanation for the model results on the graphs. One particular example is a virtual irrigation experiment with corn, in a very dry year on meadow chernozem soil. The effect of having 0 mm, 50 mm, 75 mm, 100 mm and 2×50 mm (at different dates) irrigation can be seen on [Fig. 4].

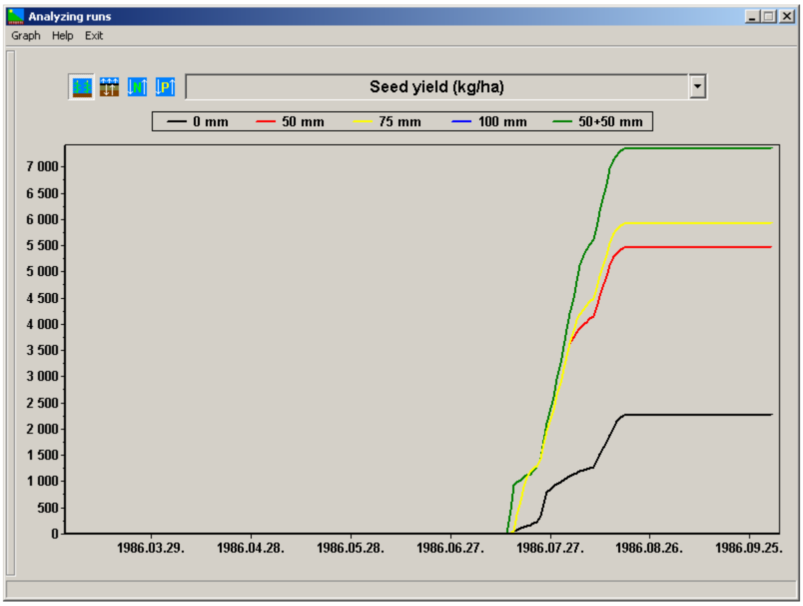

Figure 4: Graphical tool of 4M presenting the results of a virtual irrigation experiment

Students have to answer two questions: (1) Why can't we see the curve of the '100 mm' treatment (blue line)? (2) What can cause the difference between giving 100 mm irrigation water in one application and in two?

4 Using 4M in Research

The 4M crop model can be used on different areas of crop and soil sciences: estimating specific genetic coefficients of plants; estimating hydrological parameters of the soil; investigating special soil physical phenomenon such as bypass flow, bimodality and hysteresis; designing experiments, creating 0-hypothesis, and forecasting future characteristics of the investigated system by applying long-term climate change scenarios.

In a recent study the 4M crop model was used in a project involving environmental protection issues. Unnecessarily high nitrogen fertilizer doses (like in the 1970's and 1980's in Hungary) can cause serious environmental problems. The nitrate that was not taken up by the plants slowly flows down in the soil with the infiltrating water endangering the drinking water reservoirs. Based on our simulation results a high 'wave' of leached nitrate is reaching the water table at some point these years in the middle part of Hungary [Fig. 5] as a consequence of the extremely high doses of applied nitrogen fertilizers used 20-30 years ago.

In this very same study denitrification was also investigated. In certain soil types overfertilization can cause loss of NO_x gases from the soil into the air where they contribute to the increase of the greenhouse effect. The simulation results revealed which are the endangered parts of Hungary with respect to denitrification [Fig. 6].

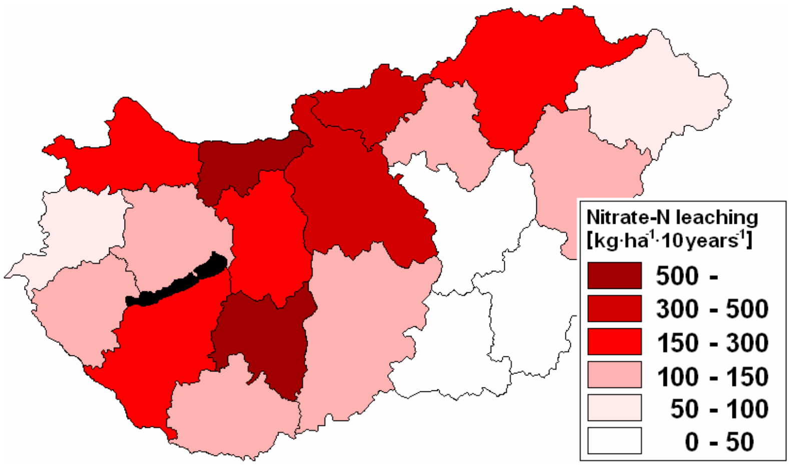

Figure 5: Nitrate-N leaching in the counties of Hungary, 1971-1996 (simulation result)

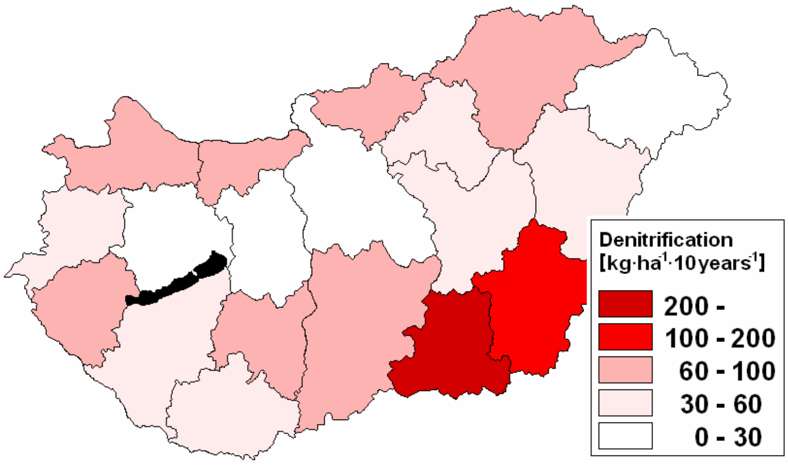

Figure 6: NO_x loss from soil to air in the counties of Hungary, 1971-1996 (simulation result)

Using the climate change scenario of the Meteorological Institute in Hamburg the 4M model was able to predict the change in nitrate leaching and denitrification patterns in Hungary. Knowing the characteristics of the climate change scenario the weather (daily values of the solar radiation, precipitation, maximum and minimum temperature) for the next century was generated with the help of WeatherCenter 1.0.

The agrotechnology (crop rotation, fertilization level, etc.) was supposed to be the same as today. The changes in nitrate leaching and denitrification values compared to our present values are presented on [Fig. 7] and [Fig. 8].

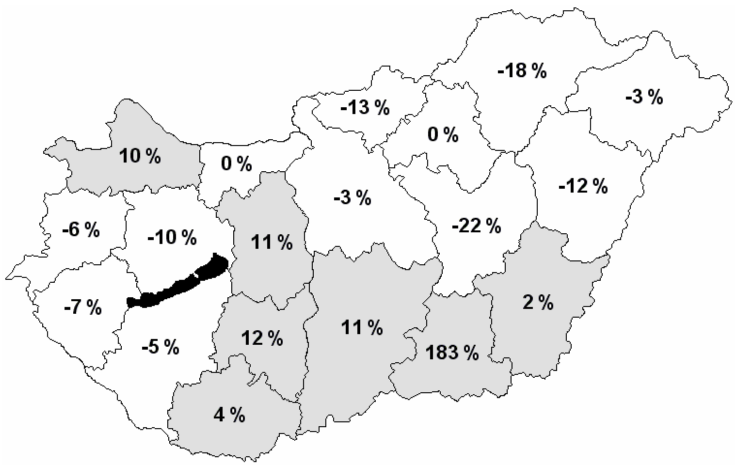

Figure 7: Predicted changes in nitrate-N leaching in the counties of Hungary for the 2031-2056 period. Numbers show the rate of change compared to the present values (simulation result)

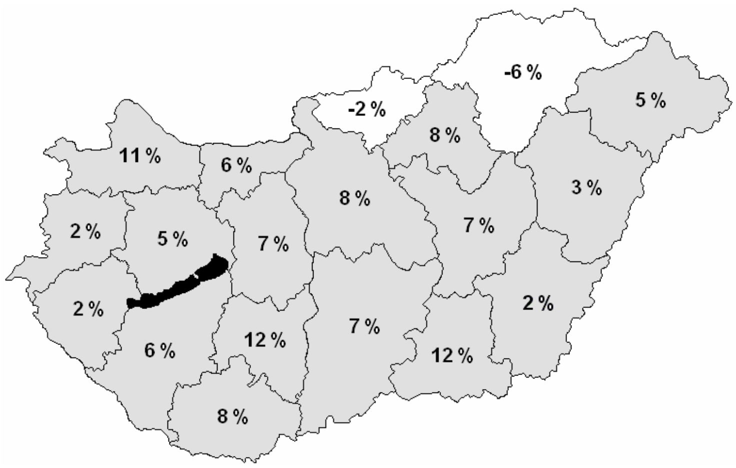

Figure 8: Predicted changes in denitrification in the counties of Hungary for the 2031-2056 period. Numbers show the rate of change compared to the present values (simulation result)

5 Using 4M in Practical Applications

The 4M crop model is suitable for making yield predictions, supporting environmental case-studies and precision agriculture. It can also be used for irrigation control. The most powerful and sophisticated module of the software package is 4M-ECO [Sulyok 03]. With the help of this module the profitable level of fertilization can be easily determined [Fig. 9] and the production of farms can be optimized. 4M-ECO helps medium-size and larger agricultural enterprises to prepare their annual plans, and their individual sectors' plans. It helps to establish the concrete situation report (condition survey), to work out future directives (conception plans) and to prepare the complex evaluation of the enterprise at the end of the year [Fig. 10.]. 4M-ECO can support planning the leasehold on country-wide, regional and local levels.

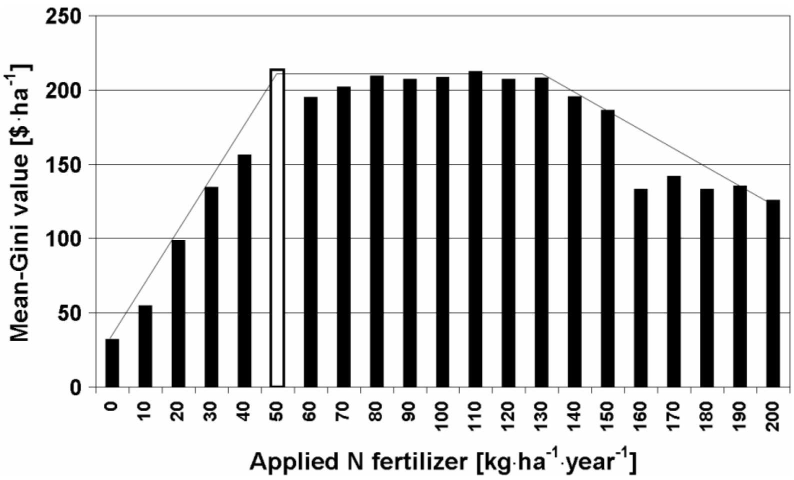

Figure 9: Profitable level of N fertilization on an average Hungarian farm calculated with 4M-ECO. The optimum level was selected by maximizing the 'Mean-Gini value' index

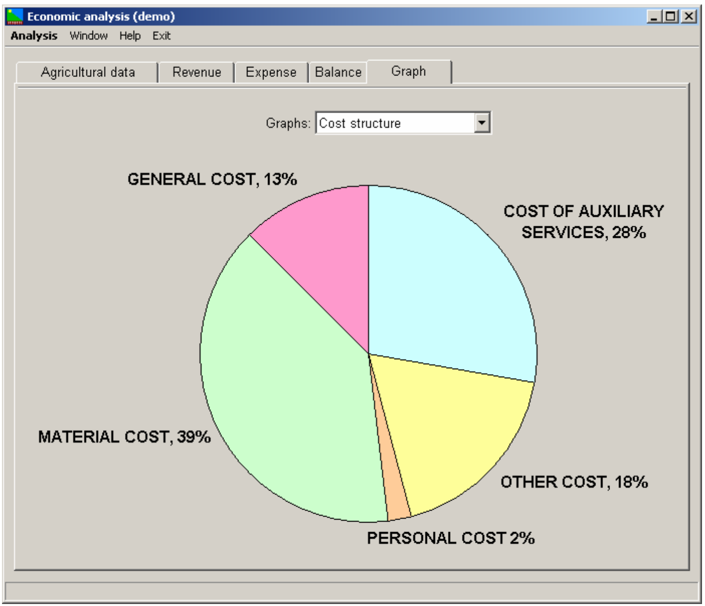

Figure 10: Cost structure of the Ánt-Ker Ltd., Hungary for the year 2003 calculated with 4M-ECO

6 Conclusions and Plans

Several recent projects have proved the 4M package to be a useful and user-friendly software tool in the areas of agriculture and environment protection related education, research and practical applications. The soil, weather, plant and agro- technological databases included in the package make the use of its modules easier by reducing the amount of information the user needs to know to operate the model and its accessories.

The main target area of using 4M is the agricultural higher education. The students are more and more equipped in information technology that is essential for using and even more for developing crop simulation models. We believe that if students learn to use the model at the university they will more likely use it as they finish school and start working on a farm or in an agricultural enterprise. This target group serves as a kind of test team. Their feedback about the errors, limitations, strengths of the model determine the directions of development.

We are continuously incorporating new crop modules into the model in order to make it usable in wider circles in agriculture. The mass balance module of the package also needs to be enhanced so that not only nutrient movement but pollutant movement in the soil can also be simulated. Our ultimate goal is to develop 4M to become an ‘all-farm’ model that can simulate every important process on a farm so that its functioning can be analyzed from ecological as well as from economical point of view.

Acknowledgements

This paper was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and the grant of OTKA F046465.

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