WARM: A SCIENTIFIC GROUP ON RICE MODELLING

WARM: UN GRUPPO DI STUDIO SULLA MODELLISTICA DEL RISO

Roberto Confalonieri[1]*, Marco Acutis[2], Marcello Donatelli[3], Gianni Bellocchi[3], Luigi Mariani[2], Mirco Boschetti[4], Daniela Stroppiana[4], Stefano Bocchi[2], Francesco Vidotto[5], Dario Sacco[5], Carlo Grignani[5], Aldo Ferrero[5], Giampiero Genovese[1]

[1]*: Institute for the Protection and Security of the Citizen, Joint Research Centre of the European Commission, AGRIFISH Unit, MARS-STAT Sector, TP 268 – 21020 Ispra (VA), Italy.*
[2]: *Dipartimento di Produzione Vegetale, Sezione di Agronomia, Università degli Studi di Milano, Via Celoria 2, 20133 Milano, Italy.*
[3]*: Consiglio per la Ricerca e la Sperimentazione in Agricoltura - Istituto Sperimentale per le Colture Industriali, Via di Corticella 133, 40128 Bologna, Italy.*
[4]: *IREA CNR, Institute for Electromagnetic Sensing of the Environment, Via Bassini 15, 20133 Milano, Italy*.
[5]: *Dipartimento di Agronomia, Selvicoltura e Gestione del territorio, Università di Torino, Via L. da Vinci 44, 10095 Grugliasco (TO), Italy.*
**: Corresponding author*, *Tel. +39-0332-789872, E-mail: roberto.confalonieri@jrc.it, Fax: +39-0332-789029*

Abstract
This paper is an open letter aiming at inviting all researchers and technicians working on rice and/or on modelling aspects that can be related to rice to participate to a scientific exchange group.
The WARM (Water Accounting Rice Model) model is currently the result of an unofficial cooperation among researchers working at the Joint Research Centre of the European Commission (IPSC, Agrifish Unit – MARS STAT Section), at the Department of Crop Science of the University of Milan, at the Istituto Sperimentale per le Colture Industriali (Consiglio per la Ricerca e la Sperimentazione in Agricoltura; CRA – ISCI) and at the Institute for Electromagnetic Sensing of the Environment (IREA-CNR) of Milan. The aim of this scientific exchange is the development of a simulation model for flooded rice able to manage all the main aspects influencing crop production (e.g. crop behaviour, pests, weeds). WARM is an original model with several innovative features aiming at reproducing the peculiar conditions of mid latitudes paddy fields (e.g. floodwater effect on vertical thermal profile). The WARM software has some interesting technical features which can support the user or the developer in the calibration and testing activities. The most important ones are the tools for the automatic calibration (based on the simplex method) and for the statistical evaluation of model performances.
The results obtained from this collaboration encouraged us to enlarge the group through this invitation to all those people who are interested in testing the model, further improving existing modules and developing new ones, and/or sharing data. We believe that sharing knowledge coming from people working on different aspects of rice research is the only way to develop a complete and powerful rice model.

Keywords: Oryza sativa L., crop model, simulation, simplex, modularity

Riassunto
Questa nota dovrebbe essere letta come una open letter con lo scopo di invitare tutti i ricercatori e i tecnici che si occupano di riso e/o di aspetti di modellistica applicabili al riso a partecipare ad una nuova iniziativa di interscambio scientifico.
Il modello WARM (Water Accounting Rice Model) è il risultato di una collaborazione non ufficiale tra ricercatori del Centro Comune di Ricerca della Commissione Europea (IPSC, Agrifish Unit – MARS STAT Section), del Dipartimento di Produzione Vegetale dell'Università degli Studi di Milano, dell'Istituto Sperimentale per le Colture Industriali (Consiglio per la Ricerca e la Sperimentazione in Agricoltura; CRA – ISCI), del IREA-CNR di Milano. Lo scopo del gruppo è lo sviluppo di un modello di simulazione per il riso in sommersione che consideri potenzialmente tutti gli aspetti con influenze significative sulle produzioni (e.g. crescita della coltura, parassiti, malerbe). WARM è un modello originale con diverse caratteristiche innovative per la simulazione delle particolari condizioni che caratterizzano le risaie sommerse alle medie latitudini (e.g. effetto dell'acqua di sommersione sul profilo termico verticale). Il software WARM ha alcune caratteristiche interessanti per supportare l'utente o lo sviluppatore nelle attività di calibrazione e test. Le più importanti sono le procedure per la calibrazione automatica (basata sul metodo del simplesso) e per la valutazione statistica delle performance del modello.
I risultati ottenuti da questa collaborazione ci hanno incoraggiato ad allargare il gruppo invitando tutte le persone interessate allo sviluppo di moduli, alle attività di test e/o a mettere a disposizione banche dati. Riteniamo che l'unione delle conoscenze di persone che lavorano su aspetti diversi della ricerca sul riso sia l'unica via per sviluppare un modello di riso realmente utile e completo.

Parole chiave: *Oryza sativa L., modello colturale, simulazione, simplesso, modularità*

Introduction

This paper is, in the Authors intention, an open letter addressed to the European community of agronomists, physiologists, soil physicians, pathologists, weed experts, chemistries, agrometeorologists, modelers and technicians providing support to farmers and politicians interested in rice crop.
Although it may appear as a paper mainly oriented to modelling we want to underline that we do not consider modelling a stand – alone discipline. In fact, we feel surprised by the suspect models are often looked at whereas they are simply the result of the inductive process, which is the basis of the scientific method. Indeed the activity of collecting data aims exactly at the definition of general laws, that are models (Confalonieri, 2003).
We gratefully acknowledge the Editor of this Journal for giving us the opportunity of using this channel to reach all the above mentioned people.

The quest for balance in crop modelling

Crop models users are often unsatisfied by the models currently available. Monteith (1996), in a precious and illuminated paper entitled The quest for balance in crop modelling, indirectly advised the modelers community about the risk involved in crop modelling. By considering simply the different approaches used for the simulation of biomass accumulation, it is possible to notice that some models are very detailed in the description of the processes related to photosynthesis. The Wageningen models (van Ittersum *et al*., 2003) are clear examples of this approach. In fact they are particularly suitable to focus the attention on the gaps in the comprehension of the plant physiology, in providing help in interpreting data collected in field experiments (Monteith, 1996), in studying processes at the level of plant components (Confalonieri and Bechini, 2004) and test hypotheses. However, their complexity increases the complexity of the calibration process (Stöckle, 1992). Hence, the need of an excessive number of crop parameters to be measured to define the crop behavior often determines either an excessively empiric calibration process or the abandonment of the idea of using them.
Analogue considerations are provided by Mahmood (1998) in relation to the CERES-family models (Uehara and Tsuji, 1993). The situation gets rapidly worse for large scale simulations (Confalonieri and Bocchi, 2005).
On the other hand, other widely used models (e.g. CropSyst; Stöckle *et al*., 2003) are increasingly considered too empiric for an effective reproduction of crop behavior and they tend to give excessive importance to the calibration process because of the use of many empiric (and therefore unmeasurable) parameters.
Moreover, the theoretical support to simulation models has not been further developed in the last 20 years. Modelers reached interesting results in crop growth and development simulation and they did not invest enough on the simulation of what is strictly related to crops: weeds, pests, interactions with uncommon environmental factors, etc. The result is that most of the models are unbalanced: they can not simulate the different aspects of the system and users that need to provide information about crops status, yield forecasts or to provide early warning for some injuries can not be satisfied by them.
For these reasons, we are pushing scientific exchange to try to provide solutions either to the still open issues in rice modelling or to those issue maybe already solved but not enough diffused within the scientific community (e.g. influence of floodwater on temperatures, blast). The basic idea is that experts from all the rice – related disciplines (crop physiology, pathology, weeds management, pests, soil physics, environmental impact of agricultural practices, etc.) should develop and make available routines for the simulation of what they are expert in. We think that this is the only way to develop a really balanced model able to cover all the aspects related to rice science.
The group is open also to researchers working in fields that are not apparently directly related to rice crop science but who can contribute to those aspects which are linkable to a crop simulator. For example, three research groups are currently contributing respectively to the statistical aspects related to model evaluation, to forcing/steering the model using remotely sensed data and to develop the automatic calibration. This is very important in order to develop a powerful environment for testing hypotheses and theories specifically related to rice.
Last but not least, the developed simulation model would be not only a software for carrying out simulations but also a concrete, continuously updated and available-for-everybody state of the art in rice research (especially in Italy), giving hospitality to the different fields of rice crop science.
Therefore, the aim of this “open letter” is to show the philosophy, the general framework and the main features of the model WARM (Water Accounting Rice Model; figure 1) and to invite all the interested people to participate to this project and to share their precious knowledge. Remember that we all belong (although with different roles) to a scientific community.

The developing group

The scientific groups currently involved in the development of WARM are:

- the MARS – STAT Research Action of the Institute for the Protection and Security of the Citizen of the Joint Research Centre (JRC) of the European Commission;
- the Department of Crop Science (Di.Pro.Ve.; Section of Agronomy) of the University of Milan;
- the Agricultural Research Council Research Institute for Industrial Crops (CRA-ISCI);
- the Institute for Electromagnetic Sensing of the Environment (IREA) of the Italian Council of Research (CNR);
- the Department of Agronomy, Selviculture and Terrain Management of the University of Turin.

This initiative is supported by the Associazione Italiana di Agrometeorologia (Italian Society of Agrometeorology).
The scientific group is open to everybody who is working on any aspect of rice research or on modelling aspects useful for the improvement of WARM.

Simulation model

Algorithms and developing sub-teams

Framework and general aspects

The coordination of the group is currently managed by MARS STAT Research Action of the JRC.

The model is developed in Visual Basic. The modular structure and the object – oriented programming allows the development of class modules for each studied aspect and its test in an easy Microsoft Excel pre – defined environment. The classes are successively imported in a Visual Basic Project that is compiled as freely – deliverable executable. With respect to other more rigid although more powerful frameworks, this choice offers the advantage of making the development process easier and more flexible and allows the participation of researchers with a medium level of programming experience, without the need of professional programmers. Moreover, those researchers without programming skills can provide the documentation of new algorithms to the coordinator who will produce the related Visual Basic codes. This is feasible because of the relative simplicity of the application field (one crop, one simulation year, no interactions among different farming components are considered).

Some modelling choices (e.g. monolayer canopy, net photosynthesis) are due to the quest for a high level of robustness and an easiness of calibration.

Crop growth and development

Crop growth and development procedures are developed by the JRC.

Crop development is based on the thermal time accumulated between a base temperature and a cutoff temperature; optionally the obtained value can be corrected with a factor accounting for photoperiod.

For the simulation of the processes related to AGB accumulation, partitioning and LAI estimation, the GAIA model (Confalonieri, 2005) has been used. The net photosynthesis is simulated using a simple radiation use efficiency (RUE) approach, with the RUE ($g_{above\ ground\ dry\ matter}$ $(MJ_{photosynthetically\ active\ radiation})^{-1}$) varying according to development, drought and cold injuries. A beta – distribution function is used to account for temperature limitations to photosynthesis (Yan and Hunt, 1999). Presently, no water limitations to growth are considered: as it is the model is suitable for the Italian widespread rice growing conditions. Yet, a module for water – limited production is under development.

Aboveground biomass (AGB) accumulated each day is partitioned to leaves, stems and kernels according to the following rules.

Leaves. AGB is partitioned from emergence to flowering using a parabolic function assuming the maximum value at emergence (input parameter) and zero at flowering. The use of a function drawn by a single input parameter (easily measurable, relatively specific and constant for varieties belonging to the same group) instead of a series of partitioning coefficients function of different developing stages (this approach is used in the Wageningen models derived by SUCROS (van Keulen *et al*., 1982)) enhances the robustness of the partitioning process by limiting the degrees of freedom in the calibration. This is important because errors in AGB partitioning to leaves today cause errors in Leaf Area Index (LAI) estimation and therefore in AGB accumulation tomorrow. We consider this a satisfactory compromise between the Wageningen approach and others, excessively empiric and insufficiently linked to reality (e.g. the CropSyst approach, based on an empiric relation among a constant Specific Leaf Area (SLA), AGB and an empiric coefficient).

Kernels. AGB partitioning to kernels start at the beginning of heading and it is assumed as maximum (all the daily accumulated AGB is partitioned to kernels) at the beginning of the ripening phase. Three different shapes of the function between heading and ripening represent the difference among high –, medium – and low – yielding varieties.

Fig. 1 – WARM: the splash form
Fig. 1 *– WARM: schermata di presentazione.*

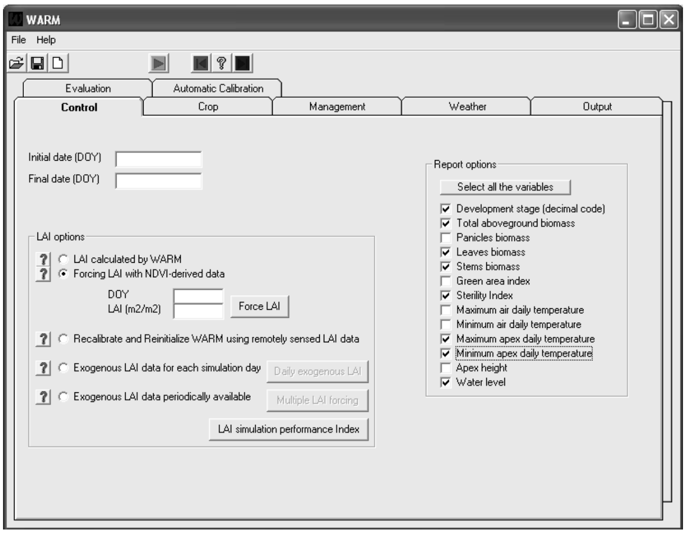

Fig. 2 – WARM: simulation options
Fig. 2 *– WARM: opzioni di simulazione*

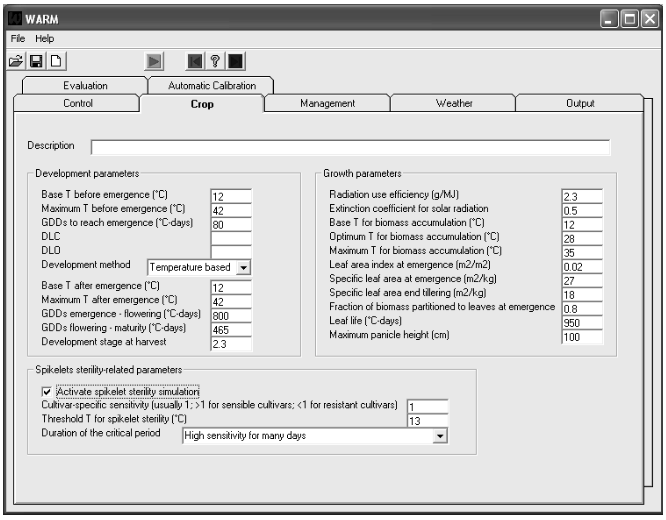

Fig. 3 – WARM: crop parameters
***Fig. 3** – WARM: parametri colturali*

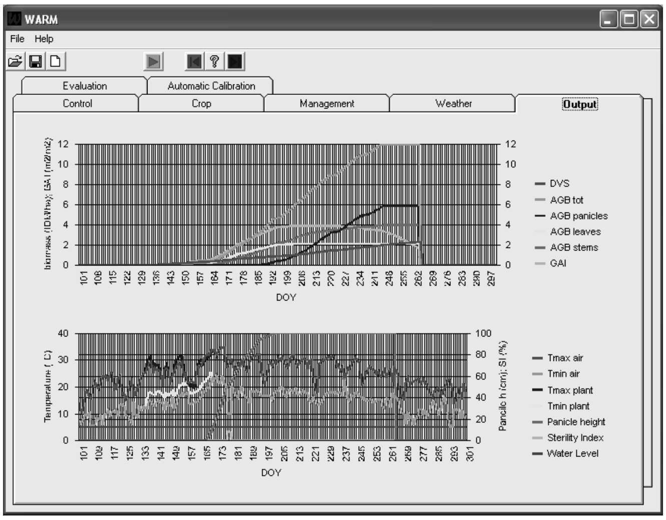

Fig. 4 – WARM: output visualization
***Fig. 4** – WARM: visualizzazione degli output*

Stems. Stems biomass is simply derived by subtracting kernels and leaves biomasses to AGB.
Leaf area index is computed multiplying the leaves biomass for a specific leaf area (SLA) variable according to the development stage and to water availability.
The height of the meristhematic apex is simulated to relate the part of the plants sensible to temperature to the real conditions along the vertical thermal profile.

Spikelet sterility induced by cold shocks and related aspects
These routines are developed at the JRC and at the Di.Pro.Ve.
WARM includes routines for the simulation of the spikelet sterility induced by cold shocks during the panicle initiation – heading period (Williams and Angus, 1994; Confalonieri *et al*., 2004). The calculated sterility index until heading is used to decrease the quantity of biomass partitioned to kernels and to reduce the assimilation efficiency through a reduction of the RUE.
Micrometeorology
This aspect, fundamental in temperate paddy fields, is developed by the Di.Pro.Ve. and by the JRC.
The modules developed by Confalonieri *et al*. (2005) for the simulation of the effect of flooding water on the vertical thermal profile are currently included in the model. An evolution of the mechanistic module is under development with the objective of relating the heat storage capability of water to different floodwater heights.

Water balance
The water balance module is developed at the Di.Pro.Ve. with the aim of simulating water infiltration and water level under flooded conditions. This module is based on the assumption of a Darcian-type gravity flow in unsaturated soil, for water content exceeding field capacity (as in many other models; e.g. ANSWERS2000; Bouraoui *et al*., 1997). Consequently, it is based on the followings: (i) the water flux in soil is only in the downward direction; (ii) the flux is 0 when the soil water content is equal or below the field capacity; (iii) the water travel time is proportional to the saturated hydraulic conductivity and the water content is in the range between saturation and field capacity; (iv) saturated conductivity is a limiting factor for infiltration. This standard approach is integrated with the computation of the floodwater level, derived from the input and output water flows, provided by the user, and the infiltration rates. The time step for hydrological processes is 1 minute.

Blast disease
A simple blast module, developed at the JRC, is currently under test. It computes a vulnerability index according to the meteorological conditions (temperature, humidity and dew) and the different varieties susceptibility.

Automatic calibration
This section, developed at the Di.Pro.Ve., implements an easy and automated process to improve the fitting of the measured data through the calibration of few (maximum 4 contemporaneously) parameters. For each parameter, a domain must be specified by the user. The simplex algorithm (Nelder and Mead, 1965) is adopted for the optimization. The objective function may be chosen among the indices proposed in IRENE DLL (Fila *et al*., 2003), including also fuzzy aggregation of more simple indicators(Bellocchi *et al*., 2002). Although this algorithm does not offer a theoretical background about its capacity of minimization, it is one of the best algorithms for obtaining a rapid reduction of the objective function without requiring the computation of derivatives (that is very difficult with models like WARM).

Forcing WARM with remote – sensed data
This section is developed by the JRC and by the IREA-CNR.
A critical topic in crop modelling is the frequent inconsistency between the availability of detailed input data and the required accuracy of models results. Often the re-

quired input information on crop management, weather data, soil properties etc. cannot be provided with adequate detail especially when passing from plot/field scale to farm/regional scale.
Moreover, models have been constrained by the lack of an efficient means of incorporating spatially distributed input variables. Remote sensing can be a source of detailed and spatially distributed data to be used as inputs for physiological models thus overcoming some of these limitations.
WARM currently includes three options for the use of remotely-sensed LAI data:

- up-dating of the state variable;
- direct use of a driving variable;
- re-initialization of the model.

The first is particularly useful for real –time simulations such as yield forecast. The simulation is carried on with meteorological data available every n days. When the remotely sensed LAI value is available, it is substituted to the simulated one. According to the current value of SLA and to the value of the partitioning functions, it is used to derive first the leaves biomass and then the other above-ground biomass components. LAI and AGB values derived from remote sensing are plotted on the chart showing the trend of the state variables with the correspondent AGB. If they are considered reliable by the user, the model is reset using the "observed" data.
The second option automatically substitutes daily or periodic remotely sensed data to the LAI value simulated by the model.
The third option, under development, aims at exploiting remotely sensed data to recalibrate and reinitialize the model.

Statistical evaluation of model performances
CRA-ISCI and Di.Pro.Ve. are developing the routines involved with the statistical evaluation of model performances. IRENE DLL (Fila *et al*., 2003) is currently implemented but a more powerful fuzzy procedure for the aggregation of the fitting indices is under development.

The executable
The executable presents a very user-friendly interface, it gives the possibility to import excel file, it is provided with a simple but quite efficacy guide and it offers routines for:

- the automatic computation of the most important indices of agreement;
- the production of a calibration history (allowing the user to recover the combination of parameters corresponding to the combination with particular values of the indices);
- visualizing on diagrams the correspondence of measured and simulated data (a chart with time on the X-axis and a chart with measured versus simulated data);
- the automatic calibration (simplex method).

The user's interface is actually organized in 7 sections. The first one (Control section – Figure 2) allows the user to define starting and ending dates for the simulation, to choose among four options for LAI (simulated, remote sensed, etc.) and to select the output variables to be saved as a report excel file. The second section (Crop – Figure 3) includes all the information necessary to describe the crop. The section Management actually includes information only about the sowing date, the latitude and the irrigation strategy (flooded or not). The fourth section (Weather) allows the import of daily weather data. The section Output visualizes the model output (Figure 4) on two charts: one for the variables related to production and the other one for the variables related to weather and to simulated stresses. The fifth section (Evaluation – Figure 5) allows the import of measured data and the comparison with simulated ones. Three modalities for model evaluation are implemented: (i) a chart with measured and observed variables as a function of time, (ii) a chart showing measured versus simulated values with automatic computation of the regression equation and its significance and (iii) the computation of statistical indices particularly suitable for model evaluation and the values of synthetic indicators resulting from the aggregation of the indices using fuzzy rules. The last section (Automatic calibration – figure 6) allows the user to introduce those few information necessary to start the automatic calibration procedure based on the simplex method for the generation of the combination of parameters.
The executable version has been codified to be very user friendly, both when you have to carry out the simulation and when you have to evaluate simulation results. We hope that these features encourage the distribution of WARM to many users in order to have a feedback for model improvement.

The excel version
The excel version of WARM is the testing bench of the developed theories. We think that, although Excel Visual Basic for Application is not a powerful environment, it very easy to test routines and to play with numbers and class modules in the simple environment of a spreadsheet. No particular programming skills are required.

The CGMS version
The CGMS (Crop Growth Monitoring System) version of WARM is, practically, a link between WARM and the MARS (Monitoring Agriculture with Remote sensing) database.
The compatibility of the three versions of WARM is ensured by using the same input and output files (e.g. when you save a crop file in the executable user interface, an excel file identical to those used for the excel version will be produced and vice versa; this file can be opened from the interface).

Perspectives

Weeds and pests
Weeds and pests are two of the main factor influencing rice productions, especially if we speak about alternative management practices. Regardless to the increasing importance of low impact management (Bocchi *et al*., 2003), they still are not sufficiently considered by crop modellers. The introduction of reliable routines to fill this gap in rice simulation is one of the major goals of WARM.

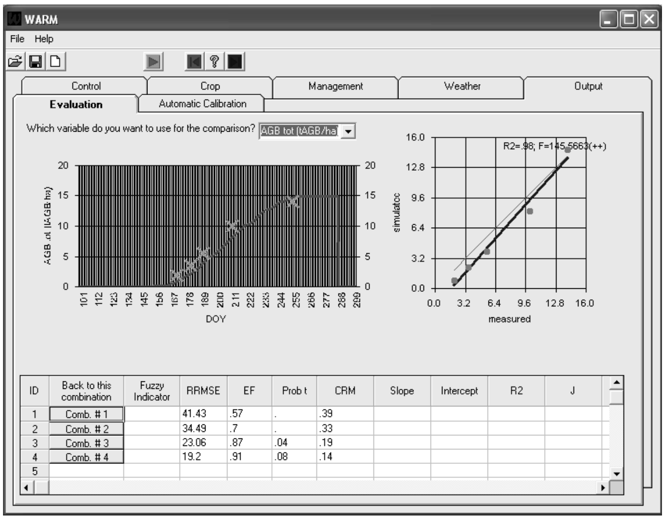

Fig. 5 – WARM: automatic evaluation of model performances (comparison with measured data)

Fig. 5 *– . WARM: valutazione automatica delle performance del modello (confronto con dati misurati)*

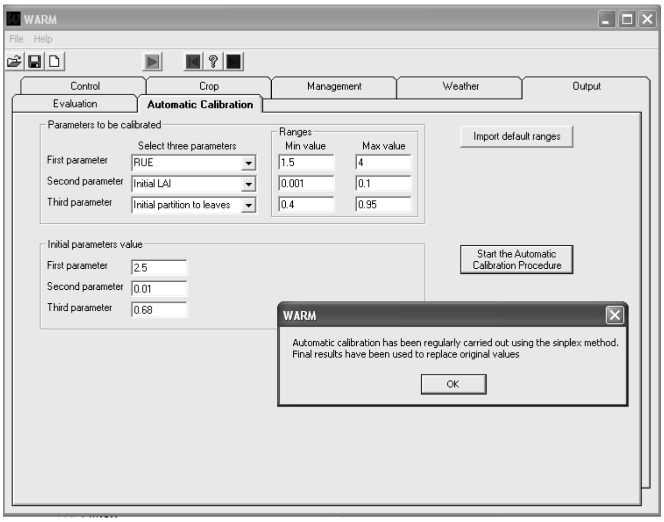

Fig. 6 – WARM: tool for the automatic calibration

Fig. 6 *– WARM: tool per la calibrazione automatica*

For example, a model of weed population dynamics has been developed in NW Italy for weedy rice, one of the most troublesome weeds infesting rice worldwide. The model uses input variables and parameters controlling weedy rice population growth that are related to traits of the weed population itself (seed bank size, seed germination and emergence, etc.), to the agronomic conditions (soil tillage, in particular), and to the practices applied pre-planting for weed control (Vidotto *et al*., 2001; Vidotto and Ferrero, 2005).

Nitrogen balance

Routines for the simulation of the effects of floodwater on oxygen availability, temperature in the first soil layers, rice peculiar parenchyma (oxygen in the rhizosphere), etc. and therefore on nitrogen balance are going to be developed. In fact, mechanistic and tested routines for accounting the peculiarities of submerged soils in this sector of rice simulation are not available in the literature.

Territorial analysis

The WARM approach is at the moment referred to micro-scale (single rice fields); a natural evolution could be represented by a specific agrometeorological and hydrological studies in order to (i) evaluate the effects of rice districts on static and dynamic features of climate (e.g. climatic effects on temperature, relative humidity, rainfall) (Ambrosetti *et al*., 2000); (ii) evaluate the influences on regional water balances also in the light of the climate inter-annual variability; (iii) evaluate the interaction of a peculiar use of soil with different weather types affecting a given territory (Goodes *et al*., 1997; Mariani *et al*., 1998).

This approach could represent a significant contribution to the quantitative evaluation of rice effects on fluxes of energy and cycles of elements at different scales and can contribute to evaluate the effects of presence of rice fields in areas with increasing human presence and activities (Mariani and Sovrano, 2001; Mariani, 2004).

Re-calibration and Re-initialization procedure using remote sensed data

Remotely sensed data will be used to improve model performance by exploiting their ability in describing spatial and temporal variability of the plant conditions. Satellite data can be used directly in vegetation monitoring and crop yield estimation (Boschetti *et al*., 2004; Gaouna *et al*., 2003) or alternatively RS data ca be exploited to derive biophysical parameter to be ingested by crop models. One of the most important parameters is the Leaf Area Index (LAI) that can be retrieved by empirical regression analysis or by using irradiative transfer models (Boschetti *et al*., 2002).

The assimilation procedure is based on the minimization of the difference between the state variable simulated by the model and the corresponding value derived by remote sensing, by the re-parameterization and/or reinitialization of the crop production model.

By assuming that the biophysical processes are well described by the model, the procedure is addressed to estimate the initial conditions, for instance by adjusting the initial LAI value (day of emergence) or using the detection of the temporal occurrence of max LAI to re-define sowing date.

A detail description of the different methods of coupling remotely sensed data and crop models is provided by Moulin *et al*. (1998).

Next steps

The intention of this "call for interest" is to network scientists in the rice – modelling field. This network could identify more appropriate tools to develop conjoint researches as Concerted Actions. This topic could be discussed in a meeting which will be possibly sponsored by the JRC in the next future.

Acknowledgment

We gratefully acknowledge the Italian Association of Agrometeorology (AIAM) for giving us the opportunity of publishing this letter and for the fundamental help in creating some of the contacts which have led to the birth of the WARM group.

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