EVALUATION OF THE SUSTAINABILITY OF THE MODERN MANAGEMENT TECHNIQUES OF AGROECOSYSTEMS

Agroecological indicators, simulation models, thematic cartography

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PhD Thesis
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– with summary in Italian

Titolo in Italiano:
'Valutazione della sostenibilità delle moderne tecniche di gestione dell'agroecosistema – indicatori agroecologici, modellistica di simulazione, cartografia tematica'
Tesi di Dottorato di Ricerca in Ecologia Agraria
XVI ciclo, Anno Accademico 2002/03
Università degli Studi di Milano

a mia moglie Barbara,
ringraziando infinitamente Dio
per ogni secondo che trascorro al suo fianco

e ad Andrea,
convinto che il cielo,
da due mesi a questa parte,
sia un posto migliore

RINGRAZIAMENTI

Desidero ringraziare i miei genitori e mia sorella per avermi supportato con entusiasmo nelle fasi più delicate di questa esperienza.

Un ringraziamento particolare al Prof. Tommaso Maggiore per avermi dato questa straordinaria opportunità. Durante questi tre anni, infatti, oltre ad aver svolto con grande libertà l'attività di ricercatore (a mio parere la più creativa e stimolante tra le attività), ho conosciuto la ragazza che è da poco diventata mia moglie.

Ringrazio di cuore il Dr. Luigi Mariani, il Prof. Stefano Bocchi, e il Dr. Luca Bechini per aver contribuito in modo decisivo alla mia formazione e ad importanti fasi del lavoro svolto in questi tre anni. A quest'ultimo sarò sempre grato per aver (vedremo con quanto successo) cercato di trasmettermi il rigore per il quale ormai è noto a livello interplanetario e per avermi insegnato a scrivere buon materiale scientifico.

Grazie al Prof. Fabrizio Adani, per avermi insegnato molto su cosa significhi fare "Ricerca", e al Prof. Marco Acutis, per avermi aperto la mente su tanti aspetti riguardanti questo lavoro.

Ovviamente ringrazio mio padre Enrico e mio zio Lorenzo per il fondamentale supporto fornito nella realizzazione dei prototipi che sono stati progettati e utilizzati con successo in queste ricerche.

Un ringraziamento speciale a mia moglie Barbara, compagna di vita e di stimolanti discussioni scientifiche, per avermi dato consigli che si sono rivelati strategici per lo svolgimento di queste ricerche. Grazie anche per avermi donato la serenità e l'entusiasmo necessari per superare momenti difficili, legati o meno al nostro lavoro.

E grazie anche al piccolo Tommaso Andrea per aver dato (nonostante manchi ancora qualche giorno alla sua nascita) una dolcissima riordinata alla mia scala di valori…

ABSTRACT

Confalonieri, R., 2003. Evaluation of the sustainability of the modern management techniques of agroecosystems. Agroecological indicators, simulation models, thematic cartography. Ph.D. Thesis, University of Milan, Italy, 240 pp, 46 figures, 30 tables, 198 references, English and Italian summaries.

In many intensified agroecosystems the efficiency of the production factors is often low, and this corresponds to a high risk of pollution. European Community policy has been training and supporting farmers with documents/laws aiming at reducing negative effects on the environment of agricultural activities and setting alternative to intensive farming system.

Because of direct measurements at field scale are too costly and time consuming, in the last years new tools have been developed for large scale evaluations of landscape management: agroecological indicators and simulation models. In this work, three indicators (yield gap, crop diversity and crop sequence) have been adapted and tested for the study area (Parco Agricolo Sud Milano). The simulation model CropSyst was set up for the simulation of alfalfa, wheat and rice growth and development (no reliable parameterizations were available) and for water and nitrogen balances. Improvements for the simulation of some processes were proposed.

New technologies were developed for micro-meteorological monitoring and for other aspects of field research.

Reference to the contents of Chapters 3, 4, 8 should be made by citing the original publications.

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GENERAL INTRODUCTION

1.1. Why monitoring the agroecosystem?

By the mid-1990s, sustainable development has become one of the most important topics in ecological discussions. The World Commission on Environment and Development defined it as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (Legg, 1999). In particular, sustainable agriculture can be defined as “an agriculture which (a) conserves the resources on which it depends; (b) restricts itself to a minimum input of production means, which do not have their origin in the same farming system; (c) control pests and diseases by internal regulation processes as far as possible; (d) provides natural resources with the ability to recover from disturbances through cultivation means and harvesting by processes of natural succession (Stinner and House, 1990; Büchs, 2003).

In modern agricultural systems, it is difficult to find echoes of the just exposed definitions. Modern agroecosystems (defined as specialized and controlled ecosystems designed for the production of agricultural products; Okey, 1996) are characterized by low efficiency, although their yields per hectare are greater than at any time in history (Okey, 1996). In fact, in the last decades, the amount of inputs required by the agroecosystem increased more than yields per hectare have done.

An example of how inefficient modern agroecosystems are is given by the extremely low nitrogen fertilizers use efficiency in irrigated rice systems (Cassman et al., 1998; Singh et al., 1999). Stutterheim et al. (1994), by examining data from 35 experiments carried out in the 1990s, calculated agronomic efficiencies ranging between 12 and 17%. Other Authors found slightly higher values and this problem is particularly evident for paddy fields than for other agroecosystems, so that this example can be considered “extreme”. However, the inefficiency in input transformation is a problem widely present in agroecosystems and this is the main cause of their high impact on the environment.

The classical points of view of agronomists and ecologists are in apparent contradiction on these themes, the firsts being mainly interested in increasing yields and the second in minimizing the impact of agrotechniques through minimizing the inputs from outside the system. I have used the adjective “apparent” because if an agroecosystem is observed with the eyes of a physician (and both agronomy and ecology are based on physical laws), it appears as an open system characterized, for definition, by high fluxes of biomass (and of energy) directed outside. On the other side, outcoming radiation can be considered the main input of natural ecosystems. This implies that the dependence from external inputs (and not only from solar radiation like natural ecosystems) is an almost unavoidable feature of agroecosystems: the high out-coming of products is a physical cause of the necessity of increasing the entering fluxes of energy (Odum, 1994; Gliessman, 1990). These considerations are simply and directly related to the first principle of thermodynamics.

Considering the problem under this third point of view, the contradiction between the objectives of agronomy and ecology disappears and the agroecosystem could become a system (i) which necessarily implies high outputs (world population is continuously increasing and cultivable surface is no more expandable) but, at the same time, (ii) is characterized by high efficiency (i.e. by lower inputs able to assure the required outputs).

Considering the agroecosystem from this point of view, the necessity of studying it becomes the necessity of evaluating its efficiency by adopting powerful tools which can allow rapid large scale evaluations. In fact, the solution of direct measurements at field scale (apparently most obvious) is possible only on an experimental farm because its extension to commercial farms for routine measurements is costly and time consuming (Sharpley et al., 1995; Bockstaller et al., 1997).

The necessity of evaluating agroecosystems efficiency is needed because the only possible base for effective political decisions is represented by science, that is by the best available scientific evidences. This is particularly true for resources management and protection of the environment (Brundtland, 1997).

This thesis is justified by a sincere trust in science and in scientific method for interpreting the system we belong to and for guiding the development of society. Lomborg, in its rigorously argued *The skeptical environmentalist* (2003), underlines that a sustainable development is really possible. Science, which is guiding the development of societies (and I think that human nature unavoidably aims at development and progress), is also the only tool able to make this development sustainable.

1.2. Simulation models and agroecological indicators

In the last years, new tools have been developed to study the agroecosystems: simulation models and agroecological indicators.

Although the first crop growth simulation models already appeared during the 1960s (we remember the pioneering work of C.T. de Wit and co-workers), people (and researchers) always look warily at models. This is strange, if we think that they are simply the result of the inductive process, which is the basis of the scientific method: the activity of collecting data aims exactly at the definition of general laws, that are models.

Although the Greeks based their knowledge on deductive method, they were already convinced that nature laws, once identified, become comprehensible. They were the first to formalize their knowledge on the idea that nature was governed by deterministic laws and it was not the result of actions of capricious gods. The confidence in understanding the reasons of what happens around us is one of the most important conquest of mankind and the optimism at the basis of this conviction has never abandoned the human species. Galileo, at the end of the XVI century, started a kind of “revolution” (completed by Newton at the end of the successive century), elevating “induction” and experimentation above “deduction”. The basis of the modern scientific method were defined and the consequences of the Galileo’s revolution are the extraordinary discoveries of the last centuries.

Isaac Asimov, in its guide to science (Asimov, 1984), defines the humans challenge to nature, aiming at finding general models able to describe reality, as constituted by the following three steps: (i) collecting observations about a particular aspect of nature; (ii) ordering these observations; (iii) finding out, from the ordered observations, a principle able to describe them. The third point implies a simplification process. The complexity of natural and anthropic systems is traduced in simplified models, giving to the word “simplification” the one by Albert Einstein: “everything should be made as simple as possible, but not simpler”. This concept is directly related to the Occam’s razor (attributed to the mediaeval philosopher William of Occam) which admonishes to not consider variables and relations which are not strictly needed to explain a phenomenon.

The scientific approach, aiming at defining laws (models), is the basis of science and research since centuries, but only in the last few decades it is supported by automatic calculations based on computer programs (van Ittersum and Donatelli, 2003). Automatic computation is needed when a system is defined by several laws and precise correlations are present between them. During the early 1960s, the arrival of mainframe computers has allowed simulation models to increase their complexity. Nowadays simulation models are constituted by hundreds of algorithms and, in many cases, this “growing” process is not without risks. Monteith (1996), in an article titled “The quest for balance in crop modeling”, gives an amusing and provocative idea of what these risks are related to.

A special issue of the European Journal of Agronomy (volume 18, issue 3-4, January, 2003) about modelling cropping systems provides complete information about the history of agroecological modelling and about the models which, nowadays, are mainly used and developed. Moreover, in this issue, different approaches to the problem are exposed and discussed, with considerations deriving from the fact that different objectives will origin different modelling approaches.

For our purposes, CropSyst (Stöckle et al., 2003) is the model which represents the best compromise between the capability of adequately describing the cropping system and the simplicity necessary to run it with a reduced number of inputs, a fundamental requirement for working at regional scale. Description of CropSyst, comparisons with other kind of models and many examples of its application are presented and discussed in chapters 4, 5 and 6.

Simulation models supply quantitative outputs starting from quantitative inputs and they need quite complex databases to run simulations. In practice, the more complex and physically based these tools are, the more inputs are required for their application. In most cases such data are not available. This is the reason why, in the last year, several agroecological indicators were developed.

An indicator is a variable which supplies information about other ones which are not easily measurable (Gras et al., 1989). An indicator does not provide quantitative information like simulation models do; for example it cannot be used to quantify variables such as outputs from the soil-crop system. At the same time, they allow the user to get objective and synthetic judgments starting from very few data. In our market-oriented agriculture, the indicators are often related to economics, however these are not sufficient for a global evaluation of agricultural management practices: indicators for the evaluation of environmental impact have to be developed and used (Bockstaller et al., 1997).

It possible to find in the literature several indicators developed for providing information about particular aspects of the agroecosystems. Bockstaller and Girardin (2000) define many agroecological indicators and provide examples of their use. Starting from the consideration that an indicator assesses the impact of a cropping practice on one or several objectives, they defined a set of indicators and connected them to the list of objectives. The indicators presented are related to the use of nitrogen, phosphorous and pesticides, irrigation, soil organic matter, energy fluxes, crop diversity, soil structure, soil cover, ecological structures, crop rotations. Bindraban et al. (2000) proposed indicators for yield gap and soil nutrients balance, involved with the agroecosystem efficiency in inputs transformation. Other important publications about agroecological indicators are the one by OECD (1999) and the two special issues of Agriculture, Ecosystems and Environment (volumes 88 and 98).

Although simulation models and agroecological indicators have been already used in many parts of the world, they have to be continuously developed in order to improve their ability in analyzing agroecosystems. Moreover, they have to be set up for the study area before being used. In fact, without an appropriate parameterization for adapting these tools to the particular situation for which they have to be used, they will probably produce outputs which have nothing to do with the reality they are trying to assess.

1.3. The study area

At the beginning of the Roman colonization, most of the areas located in the Po Valley were occupied by forests. Po affluent and risorgives were creating an environment adapted for *Quercus pedunculata* (able to resist to long flooding periods), *Quercus cerris*, *Tilia platyphyllos*, *Ulmus campestris*, *Fraxinus ornus*, *Acer campestre*, *Ostrya carpinifolia* and, near the rivers, for *Populus alba*, *Populus nigra*, *Salix alba*, *Alnus incana* and *A. glutinosa* (Giacomini and Fenaroli, 1958). In the II century b.C., Polibio described fields delimited ("*omnis possessio Silvanus colit*") by oaks ("*silvae glandarie*") which can be considered as climax vegetation. Marshes and other flooded areas were other elements which characterized the region.

Vegetables and cereals were considered very important crops for the Roman agriculture (which Varrone, in its "De re rustica", considered an excellent activity) for their importance as staple food. The most cultivated vegetables were rutabaga, chard, leek, pumpkin, onion, etc. The main cereals were wheat, spelt, barley while alfalfa, clover, bean and broad bean were the most important legumes. Hemp and flax were cultivated for webbing (Bocchi et al., 1985).

Nowadays situation is obviously very different. Many “new” crops (maize, rice, etc.) appeared along the centuries and the expansion of cultivated area implied the almost continuous reduction of forests (exceptions are represented by the period of the barbarian invasions and others during the Middle Ages).

Moreover, the increasing interactions between agriculture and chemical and mechanical industry are strongly influencing the development of agriculture in the last decades. For example, the mechanization of the last years, initially justified by the abandonment of countryside and by the consequent labor decrease, is now causing many problems both to farmers and to the environment. The present oversized mechanical power is increasing production costs and having negative effects on soil quality. Analogue considerations could be proposed for chemical products. The reason of these incoherences, which are often the results of contrasting interests between producers (chemical and mechanical industry) and users (farmers), is the lack of planning in agricultural development (Bocchi, 1985, Caporali, 2000).

Important factors which nowadays characterize the area are the wide farms size, the continuously decreasing cultivated surface and the prevalence of forage crops, finally transformed in other products by animal breeding. Maize, because of its high yields per hectare and low production costs, has become the most important forage crop, substituting irrigated meadows and meadows (both in rotations and permanent) which have been symbols of the agriculture in this region for centuries.

The development of modern irrigation techniques has reduced the necessity of canals and, in the years, this implied modifications to the cropping systems and to the landscape. The same results was reached by the necessity of eliminating obstacles for the increasingly used agricultural machines.

The agroecosystems studied in this work are the ones which characterize the region of the Po valley located in the “Sud Milano” Agricultural Park (Parco Agricolo Sud Milano; PASM). In the periphery of Milano, the increasing size of the urban areas leads to the inclusion of agricultural areas almost inside the city. The PASM was born to guide the cohabitation between agricultural and urban areas. The protection of agricultural lands aims at preserving one of the most important aspects of local culture and at valuing Milano, by defending the ultimate green areas which are resisting inside and immediately around the city.

In this context, the SITPAS (Sistema Informativo Territoriale Parco Agricolo Sud Milano) project was born at the end of the 1990s with the aim of collecting and ordering information about the different aspects of PASM and producing a dedicated geographical information system.

1.4. Objectives and organisation of the research

Simulation models and agroecological indicators are powerful tools but they have to be set up for the study area in order to correctly interpret the system analyzed.

CropSyst was already parameterized for maize simulations and, therefore, in order to adequately simulate the successions typical of the Po Valley, we have calibrated and validated the model for rice, winter wheat and alfalfa because, no reliable parameters sets were available for these crops.

Rice (*Oryza sativa* L.) is one of the most important crop for this region, both under economical and cultural (traditional) points of view. In fact, paddy fields can be considered the substitutes of the humid areas (for example marshes) which characterized Po Valley only few decades ago. The heritage of the typical, original flora/fauna equilibriums often still remains in the rice districts which are concentrated in particular regions where rice is the predominant or sole crop, giving to the landscape its mark (Confalonieri et al., 2003). This is very important considering that the more similar the agroecosystems to the natural original one are, the higher the level of sustainability (Gliessman, 2002).

A winter wheat (*Triticum aestivum* L.) parameter set was available in the literature (Giardini et al., 1998) but the calibration was carried out only on one location and two years. Moreover the used CropSyst version was an old one and some processes are now differently simulated. Because of this considerations, we have chosen to work also on this crop, which is the main winter cereal cultivated in our region.

Although alfalfa (*Medicago sativa* L.) is nowadays not widely cultivated in north Italy, the improvement of the simulation processes connected to this crop is strongly recommended (e.g. simulation of dormancy and spring restart, growth after cuts). In fact, this crop is fundamental for correctly manage crops rotations for its positive influence on soil quality. The cultivation of alfalfa with other crops (e.g. maize and wheat) in 6-year or 7-year rotations allows to reach high level of sustainability and the high quality of alfalfa forages makes this crop indispensable for farms in which crops and breeding coexist. This kind of farm is another important factor positively influencing sustainability.

Biodiversity is a necessary condition for a sustainable agriculture. Bockstaller and Girardin (2000) have proposed two indicators which can be successfully used to evaluate the biodiversity related to space and time. The crop diversity indicator was parameterized with the objective of adapting it to the small-size of north Italian fields, while the crop sequence indicator was adapted by including in its database the crops cultivated in the study region.

Moreover, the indicator yield gap (Bindraban et al., 2000) was tested for the evaluation of the difference between crop potential production and actual one. The importance of this indicator, tested in extreme conditions during this work, is connected with the possibility of evaluating the effects of sub-optimal water and nutrients availability. Another important use of this indicator is related to the evaluation of the system's inputs transformation efficiency (the actual production can be lower than the potential one also in case of higher inputs level).

Concluding, this thesis aims to discuss problems about the analysis of agricultural systems, farming systems and about resources utilization in the Po Valley through the use of simulation models and agroecological indicators. This work has also leaded to the development of new technologies for non-distructive physical monitoring of the environment in which crops grow. In particular, the objectives of this work are:

- the calibration of the model CropSyst for the simulation of growth and development of alfalfa, winter wheat and rice;
- the parameterization of CropSyst for the simulation of the processes related to water and nitrogen balances in the plant-soil system;
- the setting-up of indicators involved with crops rotation, crops spatial heterogeneity and yield gap;
- the evaluation of the technical adequacy of the calibrated tools for agricultural and environmental investigations.

1.5. Synopsis

Chapter 2 pertains to the parameterization of the crop diversity indicator and the crop sequence indicator (Bockstaller and Girardin 2000) for the specific conditions of north Italian farms. Particular attention was dedicated to the interfacing the SITPAS database and the algorithms for the computation of the indicators' value. In this way, automatic computations of the indicators can be run for all the farms of the study area. In order to adapt the crop diversity indicator (which assign higher values to farms with "smaller" fields and where more species are cultivated) to the study area, we have analyzed the dimensions of the fields, individuating (i) the dimension below which a field can be considered "small" and (ii) the one above which a field can be considered "big". The crop sequence indicator rewards the farms in which complex and orthodox crop successions are carried out. That is, successions taking into account the sustainability of the system. For this last indicator, interviews were carried out to "experts", farmers and technicians to determine (i) the coefficients representing the impact of a previous crop on the following one (including effects on soil structure, diseases, parasites, weeds and nitrogen in residues) and (ii) the recommended come-back time.

Chapter 3 is about the application of the indicator yield gap (Bindraban et al., 2000) to four farms which received insufficient amount of water for their activities during 2001 for an unexpected anomaly in water distribution system. Because the farmers mainly growth rice, this situation was judged particularly serious and the farmers asked to be helped in collecting data and information for a precise assessment of the economical damage for being refunded. In this way, the yield gap indicator was tested under extreme conditions. The declared productions were validated by running simulations with the real amount of water which was available during the different phases of crop growth. After that, the potential production was simulated with CropSyst by choosing the model option implying no water limitations for growth. Actual and potential production were compared paying attention also to the simulated transpiration and crop water stress index obtained under the limiting and not limiting water availability.

The chapters from 4 to 6 describe the calibration and validation of the morphological and physiological CropSyst parameters for, respectively, alfalfa, winter wheat and rice. For alfalfa (chapter 4), particular attention was dedicated to the calibration of the parameters involved with the processes related to dormancy and spring restart, and with the possibility of automatically schedule the cuts during the season, very important point looking at the possibility of running scenario analysis. The importance of this work is also due to the fact that this is the first example of the use of CropSyst for perennial crops simulation. Finally, an important part of the work was dedicated to the setting up of CropSyst for the simulation of soil water content.

The calibration of a CropSyst parameters’ set for wheat (chapter 5) has demonstrated the adequacy of CropSyst for aboveground biomass accumulation and nitrogen uptake simulations. The model applicability to scenario analysis was demonstrated also by verifying whether the ranking of measured data was reproduced by the model. In order to calibrate CropSyst parameters, data collected in the last years by the researchers of the Department of Crop Science of the University of Milan and data from a dedicated experiment, carried out during this thesis, were used.

The high number of cultivars registered in Italy has implied the division of these cultivars into three group: Indica type varieties; Japonica type early varieties; Japonica type medium-late varieties. The resulting three crop parameters' sets (chapter 6) can describe rice cultivation in North Italy better than a single set of parameters. The calibration was conduced on data available in our Department and on data collected in two experiments carried out during this thesis. In these last experiments data on nitrogen transformations immediately before the fertilizations and every two days after them were collected, in order to analyze the peculiar nitrogen balance characteristic of paddy fields. In fact, the reduced oxygen availability due to flooding water is the main factor implying the extremely low fertilization efficiency of paddy fields. CropSyst is a generic crop simulator and it is not explicitly developed for flooded condition simulations. The possibility of estimating the saturated hydraulic conductivity and the introduction of the measured values in the model has forced it to correctly simulate the percolation and the related rate of nitrogen leaching. A soil sampler for flooded fields was projected, built and successfully used (Appendix 2). In fact, the traditional soil samplers used for agronomic experiments cannot be used when the soil is submerged.

Flooded conditions have a strong influence on several aspects of rice cultivation and this is traduced in the necessity of adapting a generic crop simulator like CropSyst to the peculiarities which characterize a paddy field. This is why the set up activity for adapting CropSyst to flooded rice simulations has implied more work than what required for the other crops (e.g. the already mentioned reduced oxygen availability for nutrients transformations and the related difficulties in the simulation of nitrogen balance). Another important aspect related to flooding water is connected with the influence of water on the micrometeorological conditions in which rice grows. In particular, the thermal mitigation due to water is one of the factors which makes possible the cultivation of rice (a “tropical crop”) at our latitudes, which can be considered extreme for rice. In order to simulate this “mitigation effect”, two models were developed (an empiric model and a mechanistic one). Both the models (chapter 7) simulate the vertical thermal profile starting from the variables which are usually gauged by standard weather stations. The implementation of these models in the ones used for simulating rice growth and development would improve the simulation of these processes by taking into account the water mitigating effect on temperatures.

In order to collect data for developing the micro-meteorological models described in chapter 7, a floating weather station was projected and built (chapter 8). This tool has allowed us to collect micro-meteorological data at different distances from water surface (above and below the air-water interface) and by relating them to water level. The analysis of micro-meteorological data related to particular water level is fundamental because (i) water level is one of the most important factor determining the already cited “mitigation effect” and (ii) water level in a rice field is extremely variable during the crop cycle, according to crop development, weeds management, fertilizations, etc. The particular structure of the floating station allows the collection of almost undisturbed data also inside the canopy; moreover, the structure can float in very few centimeters of water. Water level was measured by using a sensor appositely developed (chapter 9), which was also used to estimate the saturated hydraulic conductivity.

In order to evaluate the collected experimental data, a software for the automatic computation of some statistical tests was developed (appendix 1). Some of the implemented test are the Shapiro-Wilk normality test, the Grubbs’ and Dixon’s tests for outliers, the Cochran test for the homogeneity of variances.

For agroecological studies, spatially distributed data are needed and, in many cases, this need is related to series of historical data. Because of this data are very often not available, a software for the spatial interpolation of meteorological data was developed, by using a simple geo-statistical approach (appendix 3). The software gives meteorological data output files in the format required by CropSyst and it's particularly useful to run large scale simulations or to replace missing data.

Note

Chapter 3 has been presented at the 3rd International Temperate Rice Conference (Uruguay, 10-13 March 2003). Chapter 4 is close to be published on the European Journal of Agronomy (in press). Chapters 5 and 6 have been submitted for publication to the European Journal of Agronomy. Chapter 7 has been submitted for publication to Ecological Modelling. Chapter 8 has been published on International Rice Research Notes. Chapter 9 has been submitted for publication to Computer and Electronics in Agriculture. The reference lists from these individual papers have been amalgamated into one list at the end of this thesis. I would like to acknowledge the editorial boards of European Journal of Agronomy and International Rice Research Notes for their permission to include the papers in this thesis.

APPLICATION OF THE INDICATORS OF CROP DIVERSITY AND CROP SEQUENCE TO TWO MUNICIPALITIES NEAR MILANO

R. Confalonieri, I. Zanichelli, L. Bechini

A synthetic version of this work has been published in the Proceedings of the 2nd International Symposium "Modelling Cropping Systems", 16-18 July, 2001, Florence, Italy

2.1. Introduction

In many intensified agroecosystems the efficiency of the production factors (i.e. water, fertilizers, pesticides) is often low, and this corresponds to a high risk of pollution. European Community policy has been training and supporting farmers with several documents/laws aiming at reducing negative effects on the environment of agricultural activities and setting alternative to intensive farming system.

Tools are needed nowadays to evaluate the achievement of objectives and/or for monitoring adequately and globally farmer activities at regional scale. Direct measurement at field scale can be too costly and time consuming. Simulation models for multi-objective evaluation are not yet available and, if so, they would be too complex and requiring too many input variables and parameters.

Bockstaller et al. (1997) proposed a set of agroecological indicators (AEIs), calculated with data available on farm and expressed on a scale between 0 and 10. These AEIs match the criteria provided by OECD (1999) for the ideal indicator (simple, representative of environmental conditions, allowing comparisons, theoretically well founded, with a threshold or reference value).

The aim of this paper is to represent the results of the application of two selected AEIs (crop diversity and crop sequence indicators) to farms belonging to the Parco Agricolo Sud Milano (PASM), in northern Italy.

2.2. Materials and methods

An extensive farm survey is ongoing in the PASM to build an integrated agricultural information system. PASM (48,000 ha wide, including about 1300 farms) surrounds the city of Milano. The survey integrates existing data related to environment and agriculture with newly collected information about agricultural practices. During the 3-year project, one interview is being made to each farmer to collect average information about crop, husbandry, equipment, buildings, irrigation, bulletins of soil analyses.

The information system includes a georeferenced farm database and many existing thematic maps.

All the data are entered in a flexible database created on purpose (Bechini and Zanichelli, 2000). The data were extracted from the database and elaborated with specific queries to match the calculation requirements for the AEIs. The analysis was carried out on a subset of the available data (50 farms belonging to the municipalities of Corbetta and Rosate, in the western and south-western area of the Park, respectively).

The crop diversity indicator (CDI) and the crop sequence indicator (CSI) (Bockstaller and Girardin, 2000) were used.

The CDI assigns higher values to farms with "smaller" plots and where more species are cultivated. The equation for the computation of CDI is:

$$CDI = k \times NC \times D \times T$$

where:

$$k = \begin{cases} 2 & NC < 4 \\ 5.0587 \times NC^{-0.6757} & NC \geq 4 \end{cases};$$

NC is the number of crops;

$$D = \frac{\sum_{i=1}^{NC} \left[p_i \times \ln(p_i) \right]}{\ln\left(\frac{1}{NC}\right)};$$

$$p_i = \frac{S_i}{S_t};$$

$$S_t = \sum_{i=1}^{NC} S_i;$$

S_i represents the surfaces occupied by the different crops;

$$T = 1 - \frac{\sum_{i=1}^{NA} (c_i \times Sa_i)}{Sa_t};$$

NA is the number of plots;

$$c_i = \begin{cases} 0 & Sa_i \le L\inf \\ \left(\frac{1}{L\sup - L\inf}\right) \times Sa_i - \left(\frac{L\inf}{L\sup - L\inf}\right) & L\inf < Sa_i \le L\sup \\ 1 & Sa_i > L\sup \end{cases};$$

Lsup is the limit over which a plot is considered “big”;
Linf is the limit below which a plot is considered “small”;

$$Sa_t = \sum_{i=1}^{NA} Sa_i;$$

Sa_i are plots surfaces.

The factor D assigns high values when many crops are present in the farm and they are equally distributed (maximum value if crops occupy the same surface).

The original limits for the fuzzy rule to describe "small" and "big" fields (5 and 15 ha) were reduced for this study (to 1.7 and 5 ha), to deal with the unvailability of true field sizes (the size of cadastral parcels is available instead).

The CSI parameterizes the effects of a crop on the following one (including effects on soil structure, diseases, parasites, weeds, nitrogen in residues) and the number of crops in rotation in the last four years.

The equation for the computation of CSI is:

$$CSI = \frac{kd \times \sum_{i=1}^{NC} (kp_i \times kr_i)}{NC}$$

where:
NC is the number of crops in rotation;

$$kd = \begin{cases} 1 & NC \le 2 \\ 0.2 \times NC + 0.6 & 2 < NC \le 4 \\ 1.4 & NC > 4 \end{cases};$$

$$kr = \begin{cases} 0.23 \times delta\_t + 0.99 & delta\_t \le 1 \\ 1.2 & > 1 \end{cases};$$

$$delta\_t = t - tr;$$

t is the come-back time for the crop in the examined rotation;

tr is the recommended come-back time for the same crop;

kp weights, for each crop, the preceding effect (1 – 6) by using the following information (table 1):

Table 1. Indicator of crop sequence. Calculation of the preceding effect

Effect on:	Score
Soil structure	from -1 to +1
Diseases	from -3 to +1
Parasites	from -2 to +1
Weeds	from -2 to +1
Nitrogen in residues	from -1 to +1

The sum of the values obtained from table 1 (S) is transformed by using the rule shown in table 2.

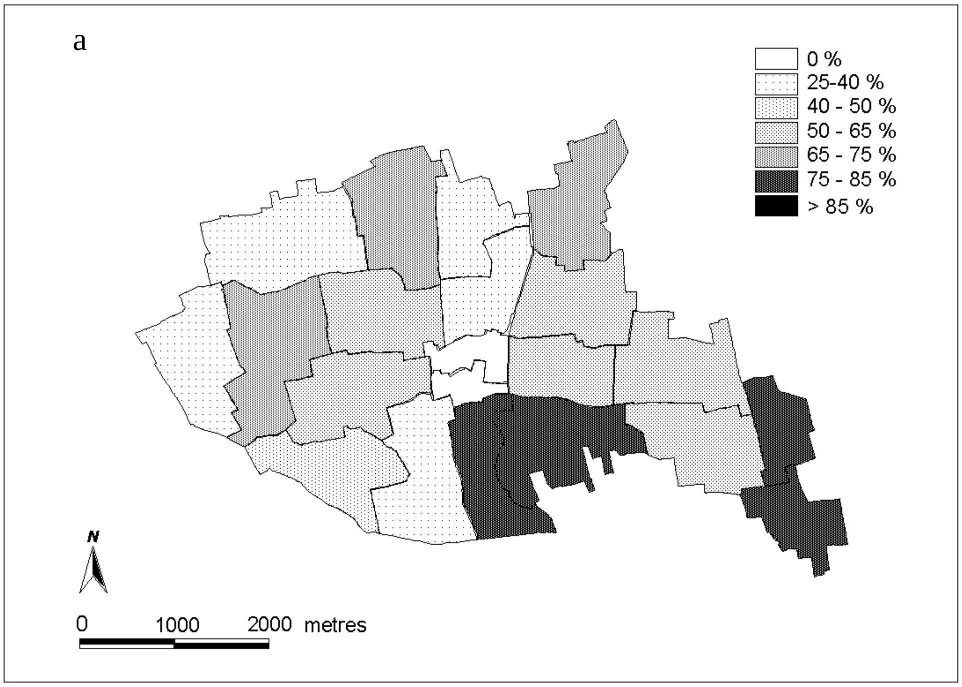
Table 2. Indicator of crop sequence. Calculation of kp

S	<= -4	-3	-2	-1	0	>= +1
kp	1	2	3	4	5	6

CSIs calculated for all rotations are averaged within each farm and calculated at farm level. The effects of previous crop on following crop were parameterized for crops not listed by Bockstaller and Girardin (2000).

2.3. Results and Discussion

Agricultural area is mainly cultivated at Rosate with rice and maize (figure 1), which together account for 87 % of the total agricultural area and with maize, winter cereals, forage crops and set-aside at Corbetta (88 %). At Rosate crop rotations are relatively simple and frequently include several years of rice followed by few years of other crops (e.g. maize).



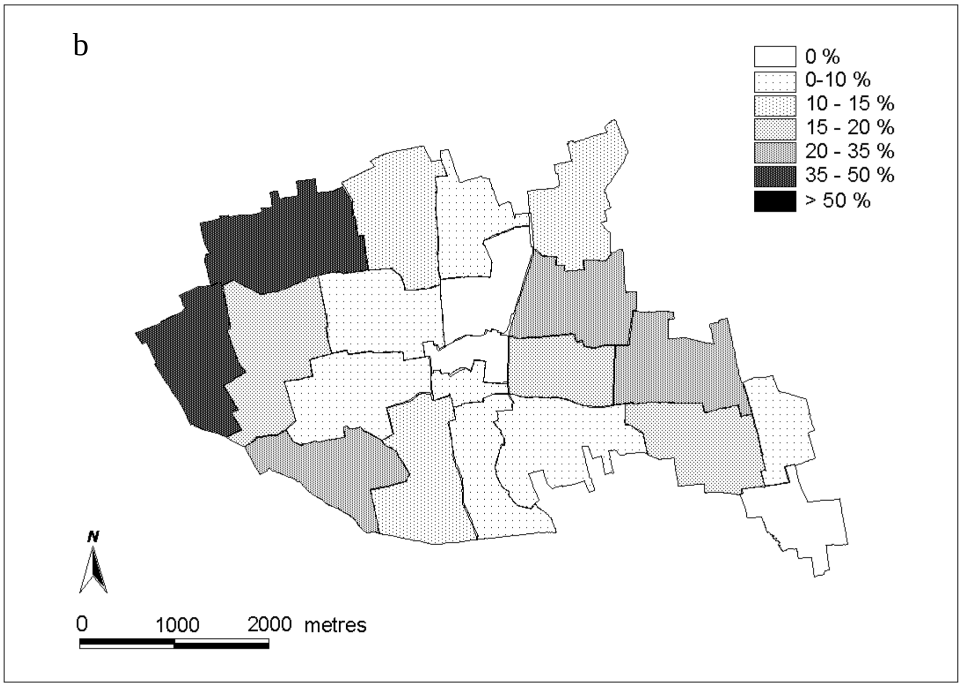
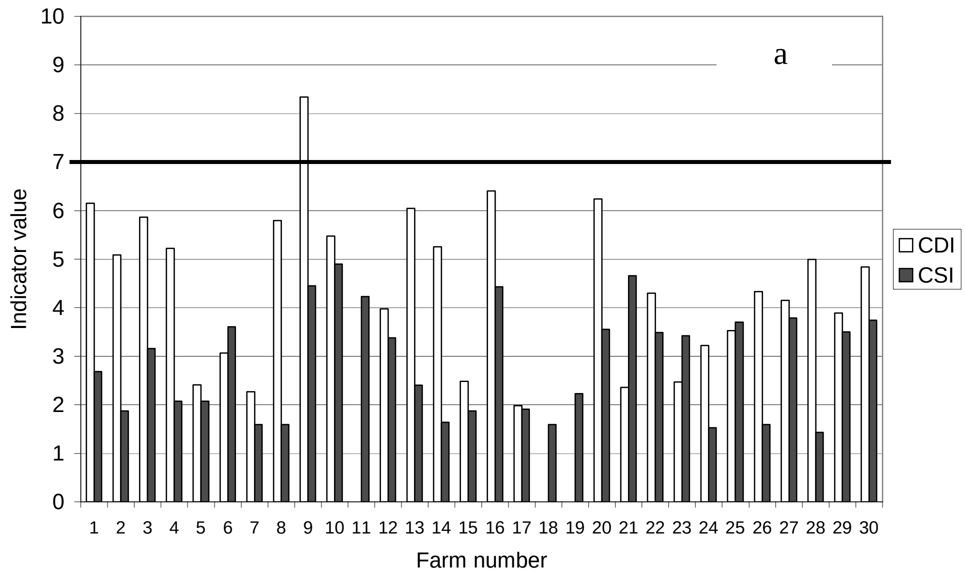


Figure 1. Percentage of polygon area cultivated with (a) rice and (b) maize at Rosate

In figure 2 the calculated indicators are shown. On average, CDI is lower at Rosate than at Corbetta, where water availability and coarse soils do not allow rice to be calculated as at Rosate. Higher scores are assigned to farms which cultivate at least 3 crops on small particles. Seven farms cultivate only one species: they got a score equal to zero (no crop diversity). The lowest scores are assigned to farms where one crop occupies most of farm area.



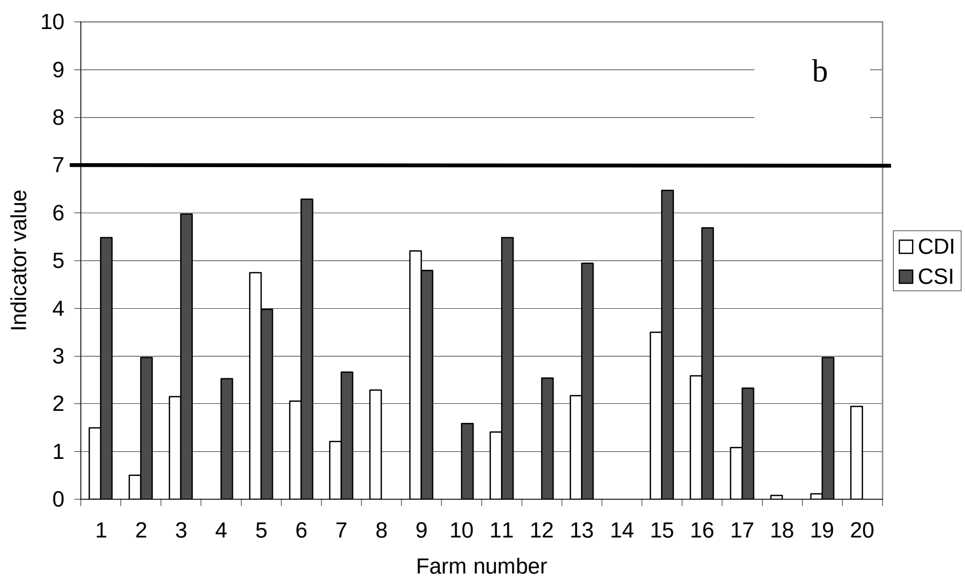
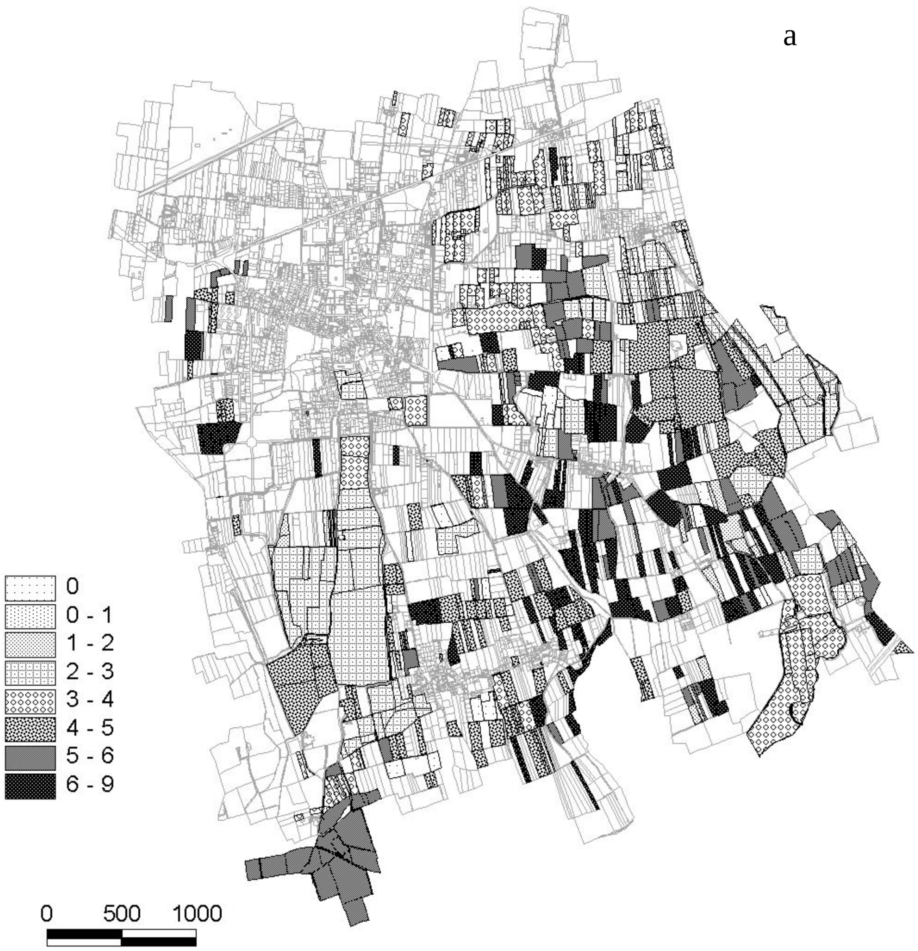


Figure 2. indicators values for the farms at Corbetta (a) and Rosate (b)

Higher values of CSI are assigned to farms with longer and more diversified rotations (e.g. maize/barley/ wheat/oat for farm number 9 and maize/rice/soybean/rape-seed/rice for farm number 16 at Corbetta; maize/maize-Italian ryegrass/barley/set-aside for farm number 6 at Rosate).

In figure 3, the maps of Corbetta and Rosate are shown, with the representation of the indicators values.




0
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
b
0 500 1000

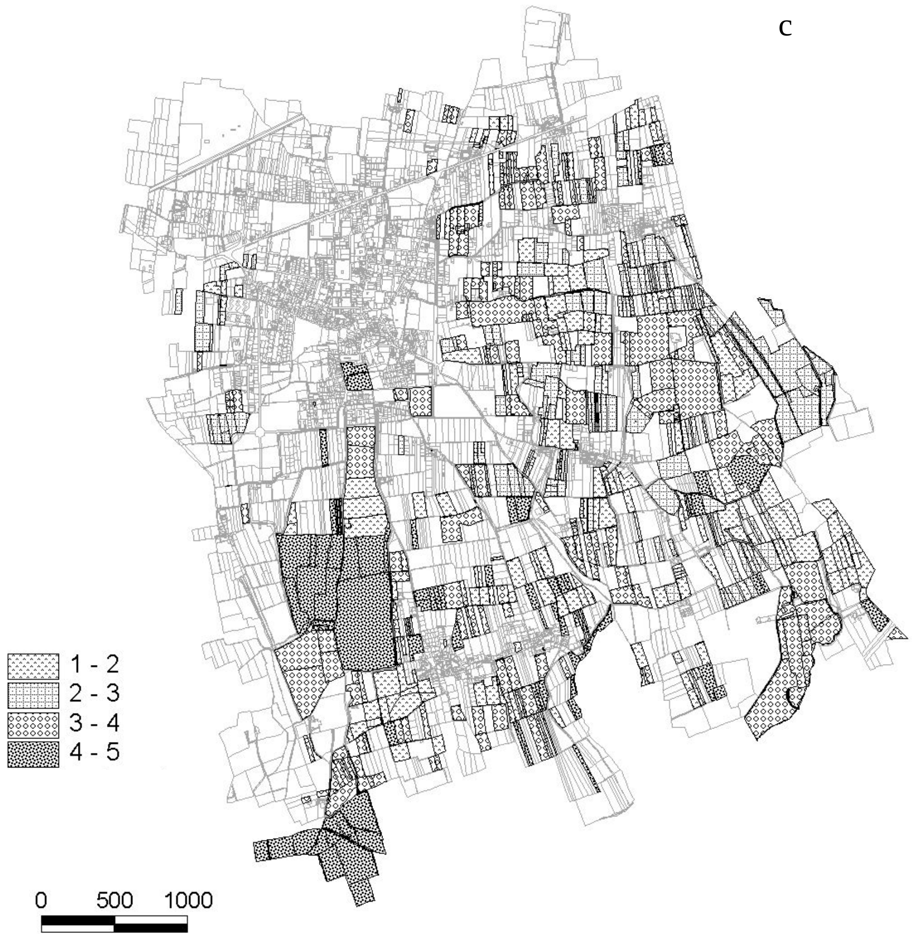

c
1 - 2
2 - 3
3 - 4
4 - 5
0
500
1000

Figure 3. Maps of Corbetta and Rosate with the representation of the indicators values. a. Corbetta – CDI; b. Rosate – CDI; c. Corbetta – CSI; d. Rosate - CSI

2.4. Conclusions

A dedicated information system was used to assess agricultural practices at regional level with detailed agronomic information. The data set and its structure were suited to calculate the indicators of crop diversity and crop sequence. The values of these indicators show the relative simplicity of farming systems belonging to the study area. These AEIs will soon be calculated for the whole Park as the database will be completed.

2.5. Acknowledgments

We would like to acknowledge D. Bergamo, U. Biino, S. Silvestri for their precious help.

The SITPAS project is coordinated by Prof. Tommaso Maggiore and Prof. Stefano Bocchi, University of Milano and is financially supported by Provincia di Milano, regione Lombardia, CCIAA Milano.

A SIMULATION MODEL AND AN AGRO-ECOLOGICAL INDICATOR TO ASSESS RICE YIELD LOSSES

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Proceedings of the 3rd International Temperate Rice Conference. 10-13 March 2003, Punta del Este – Uruguay

3.1. Abstract

In several regions of northern Italy, the increasing dimension of urban areas leads to conflicts in water use between countryside and city, particularly where rice is traditionally cultivated in flooded conditions. Sometimes, regional Irrigation Boards are not able to assure sufficient amounts of water for rice paddies determining decreases in yields. These losses have been so far estimated by agronomist and/or economist in a traditional way, basing on their own experience.

New tools, such as simulation models and agro-ecological indicators, have been developed to support this assessment. In this work, the simulation model CropSyst and the indicator Yield Gap have been used to quantify rice yield losses occurred in 2001 in some rice farms of southern Milan (Italy) due to insufficient water availability.

The Yield Gap indicator evaluates the impact of sub-optimized management or particular socio-economical conditions on yield, comparing actual and potential productions. CropSyst model has been used in order to simulate potential yields and water balances. Crop parameters have been set up by using published values calibrated and validated for similar cultivars. Simulations were based on (i) data on agrotechniques indicated by farmers, (ii) weather data collected near the farms and (iii) hydraulic soil properties obtained by regional soil maps.

The values of YG range between 22% and 43% and the average economic loss is 676.83 euro ha^{-1}. This study encourages the developement of a new integrated methodology aiming at assessing the economical damage due to insufficient water availability.

Keywords: agroecological indicator, simulation model, rice, yield losses

3.2. Introduction

Rice (*Oryza sativa* L.) crop shows its high sensitivity to sub-optimal water availability (Inthapan and Fukai, 1988; Boonjung and Fukai, 1996) by reducing significantly its yield (Boonjung and Fukai, 1996). Rice shallow root system and the consequent low ability to extract water from depth, especially for high-yielding cultivars with semi-dwarf stature and prolific tillering (Jearakongman et al., 1995), is one of the most important factors involved (Puckridge and O'Tool, 1981; Boonjung and Fukai, 1996). Under water limiting conditions rice accuses changes in leaf morphology and physiology (Cutler et al., 1980, Turner et al., 1986) which determine decreasing in interception of photosintetically active radiation and in radiation use efficiency (Inthapan and Fukai, 1988). Other important aspects connected with water availability have been documented, expecially for flooded conditions. For example, the important influence of water on vertical thermal profile at mid latitudes (Confalonieri et al., 2002), the negative correlation found between weed growth and water depth (De Datta et al., 1973) and the interaction between water and nitrogen availability (Yoshida, 1975; O'Tool and Padilla, 1984).

Food security for a very big part of the world population (Prasertsak and Fukai, 1997) is challenged by increasing food demand and threatened by declining water availability (Bouman and Tuong, 2001; Tabbal et al., 2002). In many parts of the world irrigation water accounts for a very big part (about 64% in Italy) of fresh water. Moreover, increasing urban and industrial water demand (Borrel et al., 1997) leads to conflict which are going to grow in the next years.

Also in several regions of northern Italy, increasing urban areas dimension leads to conflicts for water use between countryside and city. Sometimes, regional Irrigation Boards are not able to assure sufficient amounts of water for rice paddies determining decreases in yields. These losses have been so far estimated by agronomist and/or economist in a traditional way.

In the last years new tools have been developed to evaluate agroecosystems performance: simulation models and agroecological indicators. The first ones are very useful to simulate quantitatively variables evolution in an agricultural system at different level scales (Rabbinge, 1995). They are programs which allow us to simulate chemical, physical, biological processes and the evolution of the variables characterizing the system. Simulation models can simulate the effect of climate, soil proprieties, crop characteristics, agrotechniques on water and nutrients balances and on crop growth and development. Simulation models allow us to improve water and nutrients management and at the same time they allow us to take care of the environment (Pala et al., 1996).

In the last years, several models have been developed (Stöckle, 1996) and they have been used for simulating different crops in very different pedo – climatic conditions and, generally, they resulted effective tools for the prediction of yields and for the evaluation of water and nutrient balances.

In many cases the lack of appropriate data and the difficulty to assess parameters don't allow us to use simulation models (Pervanchon et al., 2002). This is why indicators are assuming recently such an importance role (Mitchell et al., 1995; Girardin et al., 1999). This is clear thinking about the definition of the term "indicator": an indicator is a variable which supply information about other variables difficult to measure. Indicators give a synthetic version of data and draw the system status, becoming an indispensable tools for decision makers.

In this work, the simulation model CropSyst (Stöckle and Nelson, 1999) and the indicator Yield gap (Bindraban et al., 2000) have been used to evaluate rice yield losses in four farms in the province of Milano (south of the city) in 2001. The losses were the consequence of water shortage due to an unexpected anomaly in water distribution system. Moreover, CropSyst was usefull for a validation of unofficial yield data indicated by farmers by running simulations in conditions of water shortage.

This extreme case of insufficient water availability show the usefulness of models for the evaluation of this limiting factor effects on crop yield and for the optimization of management and water use (e.g. Bergez et al., 2002).

3.3. The study case

The roggia Vettabbia is an irrigation channel that provides water for many farms sited in South Milan, where rice and maize are the main crops. During 2001 season at tillering-stem elongation phase of many rice crops of the area suffered an interruption of water delivery which caused damages to the plants and low final yields. The farmers asked to be helped in collecting data and information for a precise assessment of the economical damage for being refunded.

3.4. Materials and methods

3.4.1. Tools

The indicator Yield Gap (YG; Bindraban et al., 2000) evaluates the impact of sub-optimal management or particular socio-economic conditions on yield, comparing actual and potential productions. Comparison between potential production, which depends only from biophysical conditions (soil chemical and physical conditions, meteorological variables and physiological aspects) with the actual one (management dependent) allows us to evaluate system performances. YG takes into account 3 production levels: potential production (LP1), water-limited production (LP2) and nutrient-limited production (LP3). Real production can differ from those 3 production levels due to not-optimized management and/or socio-economic limits (Bindraban et al., 1999). The yield gap indicator is calculated as difference between the real production and the yield of one of the 3 levels you are interested in. Yields for the 3 levels are calculated using a deterministic crop growth model.

In this case YG was adopted for the quantitative evaluation of the yield decrease due to sub-optimal water management (Bindraban et al., 2000), adopting the simulation model CropSyst (Stöckle et al., 1994; Stöckle and

Nelson, 1999) for the evaluation of production level LP1. CropSyst is a deterministic, multi-year multi-crop daily time step simulation model. The model simulates crop growth and development thaking into account water and nitrogen budgets and soil erosion. The most important model inputs are: daily weather data, hydraulic characters of soil profile, dates and amounts of products applied, sowing date, crop parameters, initial conditions of soil profile (crop residues, water content, mineral nitrogen and organic matter). Main daily model outputs are above ground biomass, leaf area index, root depth, potential and actual evapotranspiration, soil water and nitrogen balance.

Crop development is simulated as a function of (i) thermal time accumulated between a base temperature (T_{base}) and a maximum temperature (T_{cutoff}), (ii) daylength and (iii) vernalization needs. Crop growth is simulated for the whole canopy as a function of intercepted radiation, water availability, air temperature and nitrogen availability. Radiation-dependent growth is calculated with a simplified mono-layer canopy sub-model as a function of intercepted photosynthetically active radiation (PAR), radiation use efficiency and a temperature limitation factor:

$$G_R = LtBC \times 0.5 \times Rad \times e^{-k \times LAI} \times T_{\lim} \qquad [1]$$

where: G_R (kg m^{-2} day^{-1}) is the daily radiation-dependent biomass production, LtBC (Light to Biomass Conversion; kg MJ^{-1}) is the net radiation use efficiency, Rad (MJ m^{-2} day^{-1}) is the daily global solar radiation (with 0.5×Rad being an estimate for PAR), $e^{-k \times LAI}$ is the fraction of PAR intercepted by the canopy, k is the radiation extinction coefficient, LAI is the Leaf Area Index, T_{lim} is a temperature-dependent limiting factor (0 if $T_a \leq T_{base}$; 1 if $T_a \geq T_{opt}$), with T_a = average air temperature and T_{opt} = optimum mean daily temperature for growth.

Water-dependent growth is calculated as:

$$G_W = Tr_{act} \times BTR / VPD \qquad [2]$$

where: G_W (kg m^{-2} day^{-1}) is the daily crop transpiration-dependent biomass production, Tr_{act} (m day^{-1}) is the actual transpiration, BTR (kg m^{-2} kPa m^{-1}) is the biomass-transpiration coefficient,VPD (kPa) is the daily mean vapor pressure deficit.

Model robustness is ensured by calculating daily leaf area development as a function of daily accumulated biomass and not the other way round. Leaf area development is calculated as:

$$GAI_{today} = \frac{LAERB_{today} \times SLA}{\left(LSP \times LAERB_{cum} + 1\right)^2} \qquad [3]$$

where: GAI_{today} (m^2 m^{-2}) is the daily green leaf area development, $LAERB_{today}$ (kg m^{-2}) is the daily leaf area expansion-related biomass, $LAERB_{cum}$ (kg m^{-2}) is the LAERB accumulated from sowing until today, SLA (m^2 kg^{-1}) is the ratio leaf area / leaf biomass (Specific Leaf Area), SLP (Stem Leaf Partition coefficient: m^2 kg^{-1}) is an empirical coefficient for partitioning accumulated biomass between "green" and "non-green" crop surfaces. As plant grows, $LAERB_{cum}$ increases and therefore GAI_{today} decreases. Therefore equation [3] simulates the effects of crop development on biomass partitioning to leaf area. Root depth is simulated as a function of leaf area development, and reaches its maximum when the plant flowers.

Soil water infiltration is simulated with a cascade approach or with the more complex finite difference solution of the Richard's equation. Potential evapotranspiration is estimated with the Penman-Monteith equation or, if air humidity and/or wind speed data are missing, with the Priestley-Taylor equation.

3.4.2. Farms

This paper shows the results obtained for 4 farms of the case study area (North Italy - plain of the Po valley - province of Milano). The rice area of the Po Valley (45° N, 10° E) presents a sub – continental climate as shown by values of Johannson continentality index (24-35). Mean yearly values are 13°C for air temperature, 650-850 mm for precipitation, 1000-1200 mm for reference crop’s evapotranspiration and 0.5-1.2 m/s for mean wind velocity.

Seasonal distribution of precipitation (table 1) shows the principal maximum in autumn and the secondary one in spring; the principal minimum is located in summer and the secondary one in winter. This summer minimum is a symptom of the influence of the Mediterranean climate and the winter one is a symptom of the closeness to the Central Europe climatic area. The coincidence in summer of precipitation minimum and evapotranspirational maximum justify the absolute need of irrigation for agricultural systems of the area.

The main determinant of the winds regime of the area are the breeze phenomena, typical of the periods of fair and sunny weather. Also important are the Alpine foehn phenomena (15-25 days / year), that produce strong and gusty winds with sky clearance, strong drop of relative humidity and sensitive increase of temperature.

Main climatic risk for rice crop is represented by low temperatures during vegetative and reproductive phases: late spring cold periods are mitigated by thermal effect of water; on the contrary, cold irruptions of artic air in summer can give problems for reproductive organs, with significant sterility effects.

Other elements of climatic risk for rice are extreme events (hail, wind gusts) associated with thunderstorms, relatively frequent in summer due to infiltration of cool Atlantic air in mid troposphere from the North of the Alps, that causes the violent lift of hot and humid air masses that stagnates in the Po basin in summer period.

Table 1 Mean climatic monthly values of some selected variables for rice crop area (Po valley – Italy)

Variable	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
max temperature (°C)	4	7	13	19	23	28	30	29	25	17	11	5	18
min temperature (°C)	-2	-1	3	7	12	15	18	17	14	9	4	0	8
mean temperature (°C)	1	3	8	13	18	22	24	23	20	13	8	3	13
rainfall (mm)	45	60	75	80	85	60	40	60	60	85	90	50	790
ET0 (mm)	7	21	57	93	125	154	172	165	140	93	54	18	1100
wind (m s^{-1})	0.7	1.1	1.1	1.4	1.4	1.1	1.1	1.1	0.7	0.7	0.8	0.7	1.0

2001 meteorological data were collected in Landriano (Pavia Province; south Milan; Longitude = 9°15'E; latitude = 32°18'N) with a agro meteorological station Lastem - Babuc. Daily collected variables were rainfall, global radiation relative humidity, temperature, and wind speed and direction.

In the four selected farms, rice crop received a sufficient amount of fertilizers: no stresses were noticed, excepted water one.

3.4.3. Model parameterization and run

Cropsyst parameters for rice crop were calibrated and tested for the selected area by Confalonieri and Bocchi (2002) while hydraulic soil properties were obtained by regional soil maps (ERSAL, 1993). The management data have been indicated by farmers.

3.5. Results and discussion

3.5.1. Validation of unofficial yield

Unofficial yield data indicated by farmers have been validated by carrying out 4 run of CropSyst using real data of water availability. The simulated above ground biomass values (LP2) are in agreement with the ones indicated by the farmers. Figure 1 shows an example of simulated values at LP1 and LP2 for the farm number 2. The whole values are reported in table 2.

Table 2 Comparison between unofficial and simulated yield data for the 4 farms

	Farm 1	Farm 2	Farm 3	Farm 4
Simulated Yield (t ha-1)	4.453	3.8455	3.4405	3.736
Unofficial Yield (t ha-1)	4.5	3.5	3.5	4

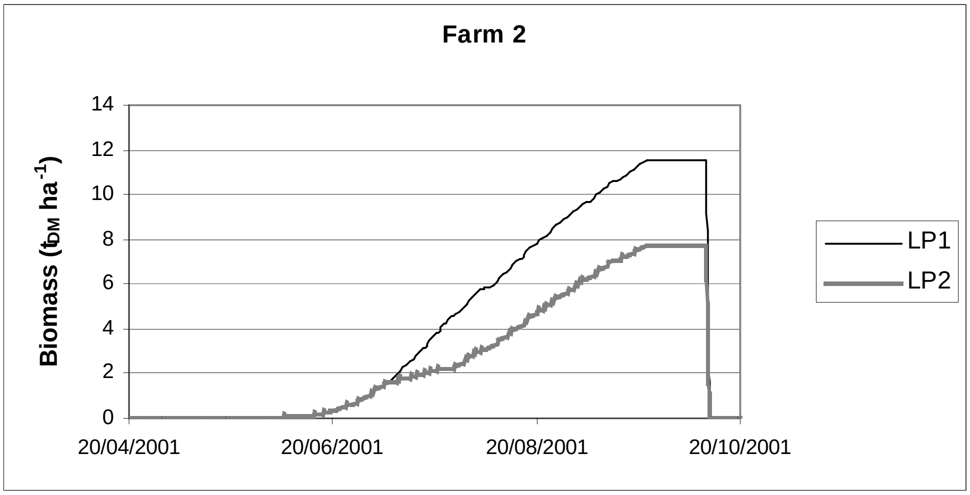


Figure 1 Farm 2. Simulated above ground biomass at LP1 and LP2

3.5.2. Calculation of Yield Gap

Table 2 shows the values of real yields compared with the one simulated at LP1 for the 4 farms. In the same table the values of YG (expressed in percentage on the potential yield and in euro ha^{-1}) are reported.

Table 2 Yield for the studied production level and yield gap

	Farm 1	Farm 2	Farm 3	Farm 4
LP1 Yield (t_{DM} ha^{-1})	5.7505	5.758	6.142	6.059
LP2 Yield (t_{DM} ha^{-1})	4.5	3.5	3.5	4
Yield Gap (%)	22	39	43	34
Yield Gap (euro ha^{-1})	360.14	808.36	945.84	592.99

It’s possible to notice that water stress strongly influenced biomass accumulation in all the studied farms. We have choosen to calculate Yield Gap as percentage on the potential yield and in euro ha^{-1} (by multiplying the yield for the prices of the cultivated varieties.

The values of YG are to be considered high, especially for farms 2, 3 and 4.

3.6. Conclusions

In this work an integrated use of a crop growth simulation model and an agro-ecological indicator has been evaluated to quantify yield losses caused by an anomalous water availability due to particular socio-economic conditions. This approach has led to get an analytical and objective assessment of the damages caused to rice fields by a water shortage. This kind of tools, properly parameterized, can be efficiently used besides classical applications for which they have been implemented and they provide solutions in legal disputes, insurance damage refunding agreements and other conflicts between resources users.

A PRELIMINARY EVALUATION OF THE SIMULATION MODEL CROPSYST FOR ALFALFA

R. Confalonieri, L. Bechini

In press: European Journal of Agronomy (2003)

4.1. Abstract

This work stems from the need to set-up appropriate simulation models for scenario analysis of intensive forage cropping systems in northern Italy, where alfalfa plays a major role. CropSyst is a deterministic, process-based, with daily time-step cropping systems simulation model. It can simulate crop growth and development, water and nitrogen balance for herbaceous annual and perennial crops. In this work, it was used to simulate aboveground biomass (AGB) accumulation and soil water content for two alfalfa meadows seeded in 1996 and 1997 in Lodi, northern Italy (45°N latitude). The crop was parameterized with data from the literature, local experience and calibration with measured data from the first two years. Data from the third year were used for validation.

The cumulative yields of the 3-year periods were 38.2 and 36.9 t AGB ha^{-1}, obtained with a total of 14 cuts. The set of crop parameters is consistent with values reported in the literature. For most of the cuts, the model simulates appropriately the growth of the crop: the relative root mean squared error (RRMSE) between observed and measured aboveground biomass ranged between 3 and 6% after calibration and between 3 and 5% after validation. RRMSE for soil water content ranged between 13 and 21% after calibration and between 10 and 20% after validation. Even if some limitations are explicitly addressed, this crop parameter set can be already used for explorative scenario simulations in the study area. This work has demonstrated the robustness of the model for perennial forage crops simulations and has suggested some improvements of the model (automatic scheduling of cuts, role of crown reserves).

Keywords: alfalfa, simulation model, forage crops, growth and development, northern Italy, soil water content

4.2. Introduction

Alfalfa (*Medicago sativa* L.) is an important crop for economic and ecological reasons: it increases soil quality by fixing nitrogen (N), improving soil structure (thanks to the deep root system) and increasing soil organic matter (the tillage is reduced compared to annual crops); moreover, among different forage species, alfalfa has high yields (Bourgeois, 1990). Due to its extraordinary adaptability, the cultivation area of alfalfa is very wide, being now extended from Scandinavia to northern Africa. In northern Italy, alfalfa plays an important role in dairy farms; in northern and central Italy, alfalfa is cultivated in about 620,000 ha (ISTAT, 2001).

Today, the complex relations between crop management, crop growth and environmental issues for intensive forage systems are to be analyzed to maximize economic return and to minimize environmental impact. In northern Italy, this is particularly true for N management in animal farms, where N losses from the system can be relevant (Ceccon et al., 1993; Giardini and Borin, 1996; Borin et al., 1997; Maggiore et al. 1998; Grignani and Zavattaro, 2000). Studies to understand N fate in cropping systems can be successfully conducted with dynamic simulation models (Morari and Giupponi, 1997; Smith et al., 1997; Acutis et al., 2000).

Up to now, several simulation models have been specifically developed for alfalfa (Holt et al., 1975; Schreiber et al., 1978; Parsch, 1982; Fick and Onstad, 1983; Savoie et al., 1985; Parsch, 1987; Denison and Loomis, 1989; Bourgeois, 1990). Some of them are very detailed in describing crops physiological and morphological aspects. For example, ALF2LP (Bourgeois et al., 1990) considers the effects of total nonstructural carbohydrates reserves for the spring restart; it also simulates daily biomass increments of different components of the plant (leaves, stems, basal buds) and considers alfalfa forage quality (crude protein, *in vitro* dry matter digestibility and crude fiber); moreover, it considers the age of the crop as a limiting factor on radiation use efficiency. The same observations also apply to ALSIM1 (Parsch, 1987) which is the previous version of ALF2LP and which was introduced into DAFOSYM (Parsch, 1982), a system simulation model for analyzing the economics of forages on dairy farms. SIMED (Holt et al., 1975; Schreiber et al., 1978) is a crop growth model which takes into account dry matter partitioning into leaves, stems and roots. Compared to these models, ALFALFA (Denison and Loomis, 1989) uses a more detailed formalization of several morphological and physiological issues (e.g. crop geometry, reserve accumulation and mobilization, root types).

This level of detail is coherent with the choice of a species-specific simulation model and with the objective to describe morphological and physiological processes at the level of plant components. However, detailed simulation models dedicated to a single species cannot simulate cropping systems; moreover, models developed for alfalfa usually do not simulate nutrient limitations on crop growth. Therefore, for management and planning purposes, a generic simulation model which includes simulation of N processes may be more useful.

Simplifications introduced in generic crop simulators for the description of some processes (e.g. monolayer canopy, absence of daily partitioning of assimilates, and of forage quality simulation) make these models able to work with a more reduced set of crop parameters and to be used at a larger scale.

CropSyst (Stöckle and Nelson, 1999; Stöckle et al., 2003) is a process-based simulation model. It is a generic crop simulator, which uses the same approach to simulate the growth and development of a wide range of herbaceous crops, including meadows. It can simulate rotations and is continuously being developed. Although it has been widely applied to cereals and other cropping systems (Stöckle et al., 1994; Pala et al., 1996; Donatelli et al., 1997; Stöckle and Debaeke, 1997; Giardini et al., 1998; Pannkuk et al., 1998), no published results exist to describe the performance of this model when used with perennial crops.

Finally, when using CropSyst for scenario analysis, automatic scheduling of management operations may be useful to run long simulations (which capture effects of weather variability) and/or to run simulations at many locations in a study area (to capture cropping systems and pedological variability). CropSyst already includes rules to set-up automatic irrigation, automatic nitrogen applications and automatic cuts of perennials.

Therefore, the objectives of this study were:

- to assess the feasibility of simulating the growth and development of perennial crops with CropSyst, in particular for processes connected with dormancy and spring restart;
- to calibrate and validate the simulation model CropSyst in simulating alfalfa growth for one site in Italy;
- to evaluate CropSyst's criterion for automatic cuts of forage crops.

4.3. Materials and methods

4.3.1. Experimental data

Experimental data were collected in Lodi at the Istituto Sperimentale per le Colture Foraggere (Experimental Institute for Forage Crops; northern Italy, latitude 45° 19' N, longitude 9° 28' E, altitude 80 m asl) between 1995 and 1999 in a medium – term experiment on forage systems. The soil is a Typic Haplustalf coarse-loamy, mixed, mesic (Soil Survey Staff, 1999) and has a medium-low organic matter content, is subacid, has sufficient available phosphorous and a low potassium content. Field capacity (FC) and wilting point (WP) were measured for each layer of a representative soil profile (Table 1). Very rare fine roots were found down to 1.9 m. Daily meteorological data (rainfall, maximum and minimum air temperatures, global solar radiation) were measured in Lodi.

Table 1 – Soil water content (SWC) at field capacity and wilting point

Layer number	Thickness (m)	SWC at field capacity (m3 m-3)	SWC at wilting point (m3 m-3)
1	0.50	0.380	0.098
2	0.50	0.330	0.072
3	0.35	0.338	0.189
4	0.30	0.214	0.040
5	0.25	0.254	0.041

The climate of the experimental area belongs to the mesoclimate of the Po valley; it is characterized by a discrete level of continentality, mitigated by the relative closeness of the Mediterranean. The mean annual temperature is about 13°C; the absolute minimum is attained between January and February and the absolute maximum between July and August. Total precipitation (about 800 mm) is relatively well distributed (about 75 rainy days per year). Precipitation regime shows two maxima (the principal in fall and the secondary in spring) and two minima (the principal in winter and the secondary in summer). Average wind speed is about 1.5 m s^{-1}.

The experiment compares two forage rotations: a 1-year rotation (Italian ryegrass, *Lolium multiflorum* Lam. - silage maize, *Zea mays* L.) and a 6-year rotation (3 years of Italian ryegrass - silage maize and 3 years of alfalfa) under 4 fertilization treatments: 2 different manures (solid and liquid, applied before ploughing) with or without topdressed ammonium nitrate (not applied to alfalfa). The experimental factors (rotation, organic fertilizer, mineral N fertilizer) are arranged in a strip-split-plot design with three replicates. The 84 elementary plots are 84 m^2 (12×7 m) wide.

Alfalfa (cv. Lodi) was sown in March (1600 seeds m^{-2}), following the harvest of maize in September. Alfalfa was cut four times in the first year of the meadow and five times in the second and third year. No evident crop stresses were noticed. The agro-techniques applied to the two alfalfa meadows are shown in Table 2a (for 1996 sowing) and 2b (for 1997 sowing).

Table 2.a – Management operations. Alfalfa meadow seeded in 1996

Date	Operation	Amount
14/03/1996	fertilization	149 kgN ha^{-1} (from manure)
		100 kgP_2O_5 ha^{-1} (from mineral fertilizer)
		250 kgK_2O ha^{-1} (from mineral fertilizer)
14/03/1996	plowing (0.3 m depth)	
14/03/1996	harrowing	
15/03/1996	sowing	
09/06/1996	1st cut	
10/07/1996	irrigation	110 mm water
17/07/1996	2nd cut	
02/08/1996	irrigation	110 mm water
23/08/1996	3rd cut	
30/09/1996	4th cut	
15/05/1997	1st cut	
20/05/1997	irrigation	100 mm water
24/06/1997	2nd cut	
17/07/1997	irrigation	110 mm water
25/07/1997	3rd cut	
23/08/1997	4th cut	
10/10/1997	5th cut	
19/05/1998	1st cut	
24/06/1998	2nd cut	
09/07/1998	irrigation	100 mm water
23/07/1998	3rd cut	
29/07/1998	irrigation	100 mm water
10/09/1998	4th cut	
20/10/1998	5th cut	

Table 2b – Management operations. Alfalfa meadow seeded in 1997

Date	Operation	Amount
11/03/1997	fertilization	122 kgN ha^{-1} (from manure)
		100 kgP_2O_5 ha^{-1} (from mineral fertilizer)
		250 kgK_2O ha^{-1} (from mineral fertilizer)
11/03/1997	plowing (0.3 m depth)	
11/03/1997	harrowing	
11/03/1997	sowing	
20/05/1997	irrigation	100 mm water
30/05/1997	1st cut	
10/07/1997	2nd cut	
17/07/1997	irrigation	110 mm water
18/08/1997	3rd cut	
10/10/1997	4th cut	
19/05/1998	1st cut	
24/06/1998	2nd cut	
09/07/1998	irrigation	100 mm water
23/07/1998	3rd cut	
29/07/1998	irrigation	100 mm water
10/09/1998	4th cut	
20/10/1998	5th cut	
12/05/1999	1st cut	
17/06/1999	2nd cut	
05/07/1999	irrigation	50 mm water
15/07/1999	3rd cut	
22/07/1999	irrigation	100 mm water
19/08/1999	4th cut	
11/10/1999	5th cut	

The measured variables were: aboveground biomass (AGB) and plant nitrogen concentration (PNC) at harvest, soil water content (SWC) every month (every 15 days in the 1995) for soil layers 0.00 - 0.30 and 0.30 - 0.60 m. AGB was determined by sampling a 18 m^2 area for each plot and by storing the samples in oven at 60 °C until constant weight, and will be always expressed as dry matter in this text. Soil was sampled by extracting one core (100 g) per plot and per soil layer at each sampling date. SWC was determined with the gravimetric method on a fraction of the soil sample, while the other fraction was kept frozen at -20 °C until soil nitrogen content was determined.

4.3.2. Simulation model

CropSyst (Stöckle et al., 1994; Stöckle and Nelson, 1999; Stöckle et al., 2003) is a deterministic, multi-year multi-crop daily time step simulation model. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and soil erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations and residue management. The most important model inputs are: daily weather data, dates and amounts of products applied for each fertilization and irrigation event, sowing date, hydraulic characteristics of the soil profile, crop parameters, initial conditions of the soil profile (crop residues, water content, mineral nitrogen and organic matter). Main daily model outputs are aboveground biomass, leaf area index, root depth, potential and actual evapotranspiration, soil water and nitrogen balance.

Crop development is simulated as a function of thermal time accumulated between a base temperature (T_{base}) and a maximum temperature (T_{cutoff}), and of daylength and vernalization requirements. Crop growth is simulated for the whole canopy as a function of intercepted radiation, water availability, air temperature and nitrogen availability. Radiation-dependent growth is calculated with a simplified mono-layer canopy sub-model as a function of intercepted photosynthetically active radiation (PAR), radiation use efficiency and a temperature limitation factor:

$$G_R = LtBC \times 0.5 \times Rad \times \left(1 - e^{-k \times LAI}\right) \times T_{\lim} \qquad [1]$$

where: G_R (kg m^{-2} day^{-1}) is the daily radiation-dependent biomass production, LtBC (Light to Biomass Conversion; kg MJ^{-1}) is the net radiation use efficiency (ratio of aboveground biomass accumulated to intercepted PAR), Rad (MJ m^{-2} day^{-1}) is the daily global solar radiation (with 0.5×Rad being an estimate for PAR), ($1-e^{-k \times LAI}$) is the fraction of PAR intercepted by the canopy, k is the radiation extinction coefficient for PAR, LAI is the Leaf Area Index, T_{lim} is a temperature-dependent limiting factor

(0 if $T_a \leq T_{base}$; 1 if $T_a \geq T_{opt}$), with T_a = average air temperature and T_{opt} = optimum mean daily temperature for growth.

Water-dependent growth is calculated as:

$$G_W = Tr_{act} \times BTR / VPD \quad [2]$$

where: G_W (kg m^{-2} day^{-1}) is the daily crop transpiration-dependent biomass production, Tr_{act} (m day^{-1}) is the actual transpiration, BTR (kg m^{-2} kPa m^{-1}) is the biomass-transpiration coefficient,VPD (kPa) is the daily mean vapor pressure deficit.

Model robustness is ensured by calculating daily leaf area growth as a function of daily accumulated biomass and not the other way round. Green LAI increase is calculated as:

$$\Delta GAI = \frac{\Delta LAERB \times SLA}{\left(SLP \times LAERB_{cum} + 1\right)^2} \quad [3]$$

where: ΔGAI (m^2 m^{-2}) is the daily growth in green leaf area index, ΔLAERB (kg m^{-2}) is the daily leaf area expansion-related biomass, $LAERB_{cum}$ (kg m^{-2}) is the LAERB accumulated from sowing until today, SLA (m^2 kg^{-1}) is the ratio leaf area / leaf biomass (Specific Leaf Area for the early growth phase), SLP (Stem Leaf Partition coefficient: m^2 kg^{-1}) is an empirical coefficient for partitioning accumulated biomass between "green" and "non-green" crop surfaces. As plant grows, $LAERB_{cum}$ increases and therefore ΔGAI decreases. Therefore equation [3] simulates the effects of crop development on biomass partitioning to leaf area. Root depth is simulated as a function of leaf area development, and reaches its maximum when the plant flowers.

Soil water infiltration is simulated with a cascade approach or with the more complex finite difference solution of the Richard's equation. Potential evapotranspiration is estimated with the Penman-Monteith equation or, if air humidity and/or wind speed data are missing, with the Priestley-Taylor equation.

4.3.3. Perennial crops

For perennial crops, CropSyst simulates the start of dormancy when, starting from a day in autumn (SD), T_a falls below a threshold ($T_{dormancy}$) for 7 consecutive days. In spring, the crop restarts when the reverse occurs ($T_a > T_{dormancy\ for\ 7\ consecutive\ days}$), starting from a date in spring (ED). The model simulates LAI and biomass after dormancy and after cuttings. LAI for the day after dormancy (LAI_i) is calculated as (Nelson, personal communication):

$$LAI_i = SLA \times AGB_i \qquad [4]$$

where AGB_i is the biomass after dormancy (0.005 kg ha^{-1}). Accumulation of carbohydrates in the crown is not simulated by CropSyst, and therefore the crown cannot affect crop growth rate after cuttings and after dormancy. We would like to underline that a calibrated perennial crop parameter set implicitly incorporates information on the crown role.

For perennials, CropSyst considers LAI = GAI. Every day a pair of values consisting of the daily increment of GAI and the corresponding increment of biomass is appended to a list which serves as a history for the crop to remember the GAI/biomass pairs for every day of its life. In the case of perennials, all these pairs are removed at the beginning of dormancy. When the meadow is cut, CropSyst determines the amount of biomass to be removed (percentage on total AGB) and removes the latest pairs of values starting from the more recent ones, until the amount of biomass to be removed is reached; in this way, it is possible to recalculate a value of LAI after the cut which is coherent with the amount of AGB after the cut.

4.3.4. Model parameterization and validation

CropSyst version 2.02.31 (September 14, 1999) was used. Potential evapotranspiration was calculated with the Priestley-Taylor equation. Soil water redistribution was simulated with the cascade method.

The starting point for the calibration of crop parameters involved in AGB accumulation was the alfalfa default parameter's set of CropSyst. Nine parameters were subjected to sensitivity analysis, which indicated SLA, SLP, BTR and T_{opt} as the parameters which cause significant variations in AGB accumulation. Three of them (SLA, SLP and T_{opt}) were calibrated as described below; BTR was set to the default value. The other five parameters were parameterized using CropSyst's default values (Table 3). The parameters Base Temperature (T_{base}) and Cutoff Temperature (T_{cutoff}) did not cause significant AGB variations in the conditions of this experiment. The parameters involved in dormancy ($T_{dormancy}$, SD, ED) were not calibrated because sensitivity analysis has shown that these parameters cannot significantly influence AGB accumulation. A possible explanation is that weather conditions between November and February don't allow significant biomass accumulation.

Table 3 – Crop model parameters for Alfalfa (cv. Lodi) and source of information (C: Calibrated parameters; D: CropSyst default values; L: local experience)

Parameter	Determination	Value	Units
Photosynthetic pathway	/	C3	/
Perennial	/	true	/
Above ground biomass-transpiration coefficient (BTR)	D	5	kPa kg m-3
Light to above ground biomass conversion (LTBC)	D	3	g MJ-1
Actual to potential transpiration ratio that limits leaf area growth	D	0.8	/
Actual to potential transpiration ratio that limits root growth	D	0.5	/
Optimum mean daily temperature for growth (Topt)	C	30	°C
Maximum water uptake	D	14	mm day-1
Leaf water potential at the onset of stomatal closure	D	1300	J kg-1
Wilting leaf water potential	D	2000	J kg-1
Maximum rooting depth	D	1.8	m
Maximum expected leaf area index (LAI)	D	5	m2 m-2
Fraction of max. LAI at physiological maturity	D	0.8	/
Specific leaf area (SLA)	C	26	m2 kg-1
Stem/Leaf partition coefficient (SLP)	C	3.5	/
Extinction coefficient for solar radiation (k)	D	0.5	/
ET crop coefficient at full canopy	D	1.2	/
Degree days Emergence	C	50	C-days
Base temperature (Tb)	L	5	°C
Cutoff temperature (Tc)	C	30	°C
Phenologic sensitivity to water stress	D	0	/
Average temperature for 7 consecutive days to induce dormancy	L	5	°C
First date to start looking for dormancy (SD)	L	15 November	/
First date to start looking for restart after dormancy (ED)	L	15 February	/
Sensitive to cold temperatures	D	disabled	/

The cascade model was preferred to the one based on the Richard's equation because using the first option the model resulted more stable, in particular with very wet or dry soil. Although FC was one of the measured hydrological properties, we have chosen to calibrate it because FC was measured on disturbed samples, whose structure was destroyed during sieving (2 mm) and, by using measured values of FC, simulated SWCs were lower than the measured ones.

For the calibration of the parameters involved with AGB accumulation, we used data from the first two years of the meadows seeded in 1996 and 1997. Data from the third year of the two meadows were used to test the calibrated parameters. For the calibration of FC, data collected between June 1995 and April 1996 for the 1-year rotation and between March 1996 and March 1997 for the 6-year rotation were used. Data collected in the period between May 1996 and March 1997 for the 1-year rotation and in the period between June 1995 and March 1996 for the 6-year rotation were used for validation.

The criterion implemented in CropSyst for automatic cuts is based on biomass: the crop is cut when the AGB reaches a user-defined threshold. In farming practices, however, forage crops are cut at a specific phenological stage to maximize forage quality (e.g. from late vegetative to early-bud for alfalfa). With the aim of understanding if such a criterion could be implemented in the simulation model, we compared biomass-based simulations with phenology-based simulations. In the first case (SimBio), the threshold was set to the average of measured yields; in the second case (SimPh), we calculated the growing degree days (GDD) required to reach either (i) the first cut from the end of dormancy or (ii) the next cut from the previous one; the average of these GDDs was used to schedule the cutting dates. For the first year, a combination of the two criteria was also tested (the first cut was based on a biomass threshold of 2.5 t AGB ha^{-1} and the others on phenology [SimBioPh], because of the lower crop growth rates of young alfalfa plants compared to well-established plants). Simulated aboveground biomass harvested at each cutting date with the three methods and measured aboveground biomass were compared.

The agreement between observed and predicted values was expressed by using the indices proposed by Loague and Green (1991): the relative root mean squared error (RRMSE, minimum and optimum=0%), the coefficient of determination (CD, minimum=0, optimum=1, indicates whether the model reproduces the trend of measured values or not), the modelling efficiency (EF, $-\infty \div +\infty$, optimum=1, if positive, indicates that the model is a better predictor than the average of measured values), the coefficient of residual mass (CRM, 0-1, optimum=0, if positive indicates model underestimation) and the parameters of the linear regression equation between observed and predicted values.

4.4. Results and discussion

4.4.1. Experimental results

Accumulated alfalfa yields for both 3-year periods are reported in Table 4. Yields of the first year are the lowest (9.60 - 11.33 t AGB ha^{-1}), due to crop establishment. Yields were highest in the second year and decrease slightly in the third one. The yields of the 3-year period measured in this experiment (38.17 - 36.87 t AGB ha^{-1}) are lower than those normally obtained for irrigated alfalfa meadows in northern Italy (yields reported in the literature range from 41.7 to 50.0 t AGB ha^{-1}: Onofrii et al., 1994 and 1997; Romani et al., 1992). This behaviour is due to the low yield obtained in this experiment in the second year (14.14 - 13.92 t AGB ha^{-1}) compared to data from the literature (16.6 - 20.4 t AGB ha^{-1}). Soil water content (Figures 3-6) showed higher temporal variation in the summer than in the winter, when it was frequently around 0.35 m^3 m^{-3} for the 0-30 cm layer and 0.30 m^3 m^{-3} for the 30-60 cm layer.

Table 4 – Yields (t AGB ha^{-1}) and standard deviations (in italic) of the three-year meadows sown in 1996 and 1997.

Sowing year	1st year		2nd year		3rd year	
1996	11.33	0.63	14.14	1.06	12.70	1.12
1997	9.60	0.56	13.92	0.77	13.35	1.62

4.4.2. Model results

Calibration

Calibrated crop model parameters are shown in Table 3. The set of temperatures reflects the origin of the cultivar used, selected in the same Institute where the experiment was carried out. Cv. Lodi can be sown in autumn or in spring (T_{base} = 5 °C, the same value used by Bourgeois et al., 1990, and by Sanderson, 1992) and has good productive performance at high temperatures (T_{opt} = T_{cutoff} = 30 °C). Many papers show lower values for alfalfa optimal temperatures: Arbi et al. (1979) obtained the highest growth rates when a combination of 21 °C during the day and 12 °C during the night was used; Fick (1984) used a functional relationship to describe the effect of temperature on physiological processes for alfalfa, with an optimum temperature below 20 °C; Bula (1972), for three alfalfa cultivars, obtained the highest biomass yields at 25 °C, but one cultivar was performing well in the range 20 °C - 30 °C; Gowgani (1977) obtained the highest daily AGB at first flowering when a 20 °C / 10 °C (day / night) regime was used. However, most of these papers deal only with few cultivars. A study carried out in growth chambers by McLaughlin and Christie (1980) analyzed the temperature effects on AGB yield for 300 alfalfa genotypes, which were separated in three groups: the first had high yields at high temperature only (30 °C / 25 °C, day / night), the second at low temperature only (20 °C / 15 °C) and the third at both temperatures. Therefore, we believe that the origin of this cultivar justifies the optimal temperature chosen as a model parameter.

On the basis of local experience, we used a value of 5 °C for $T_{dormancy}$ and the dates November 15 for SD and February 15 for ED. However, in our environment, growing conditions (temperature and radiation) do not contribute substantially to biomass accumulation between the beginning of November and the end of March; therefore, SD and ED parameters have a low impact on crop yield.

The solar radiation extinction coefficient for PAR was left to the default value of 0.5; this is consistent with the results of Sheehy and Popple (1981) who measured values between 0.42 and 0.57. The default value for radiation use efficiency (LtBC: 3 g AGB MJ^{-1} intercepted PAR) is higher than the values measured by some authors for well-watered alfalfa canopies (e.g. 1.71 g MJ^{-1} by Duru and Langlet, 1989; 1.72 g MJ^{-1} by Durand et al., 1989; 2.15 g MJ^{-1} by Whitfield et al., 1986); in fact, the parameter used by the model is defined for optimal temperature conditions, while in the field experiments the efficiency may be limited by temperature.

The calibrated value for SLA is consistent with the one (26.5 m^2 kg^{-1}) reported by Bourgeois et al. (1990) for its model, and with the one (28.2 m^2 kg^{-1}) measured by Antolin et al. (1995) for well-watered nitrogen-fixing alfalfa plants. Other measured values reported in the literature are 30.3 m^2 kg^{-1} (average of the first two sampling dates after cutting; Sheehy and Popple, 1981), and 22.7 m^2 kg^{-1} (Buntin and Pedigo, 1985, for rainfed alfalfa plants).

The default value for the ET crop coefficient at full canopy (1.2) is consistent with the value of crop coefficient suggested by FAO (Allen et al., 1998) at full cover for alfalfa.

The agreement between observed and simulated AGB values is shown in Figures 1 and 2, and in Table 5: the model is accurate in the simulation of AGB accumulation. The values of the indices shown in Table 5 confirm the goodness of model performance (low RRMSE, EF, CD and slope of the regression line close to 1, while CRM is close to zero). The agreement between measured and simulated values is very satisfactory for the first year of the meadow seeded in 1996 (Figure 1). The first cut of 1997 is correctly simulated by the model: this is important considering that it is the first cut after the end of dormancy; subsequently the model is less accurate, underestimating biomass for the third and the fourth cuts and overestimating the fifth. Cumulative biomass, however, is well simulated. The simulation results for the meadow seeded in 1997 (Figure 2) are similar to the measured values until the end of the second year, when the model does not correctly simulate the decreasing production typical of the last cut of the season.

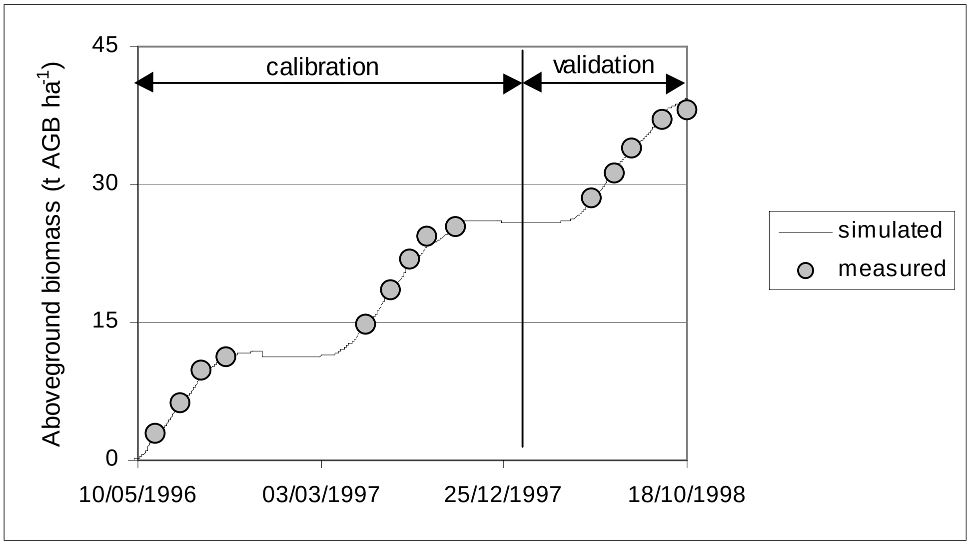


Figure 1 – Cumulated aboveground biomass of meadow seeded in 1996 after calibration (1st and 2nd year) and after validation (3rd year)

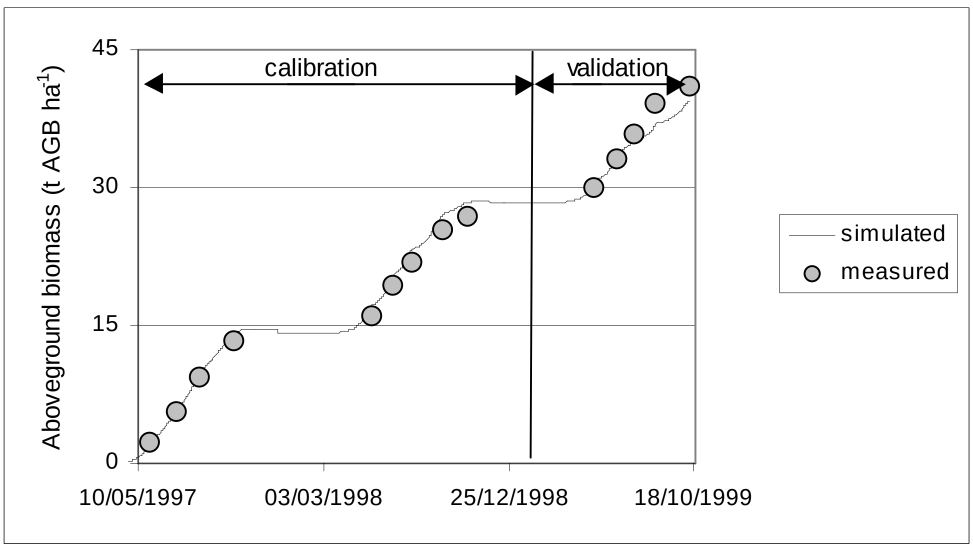
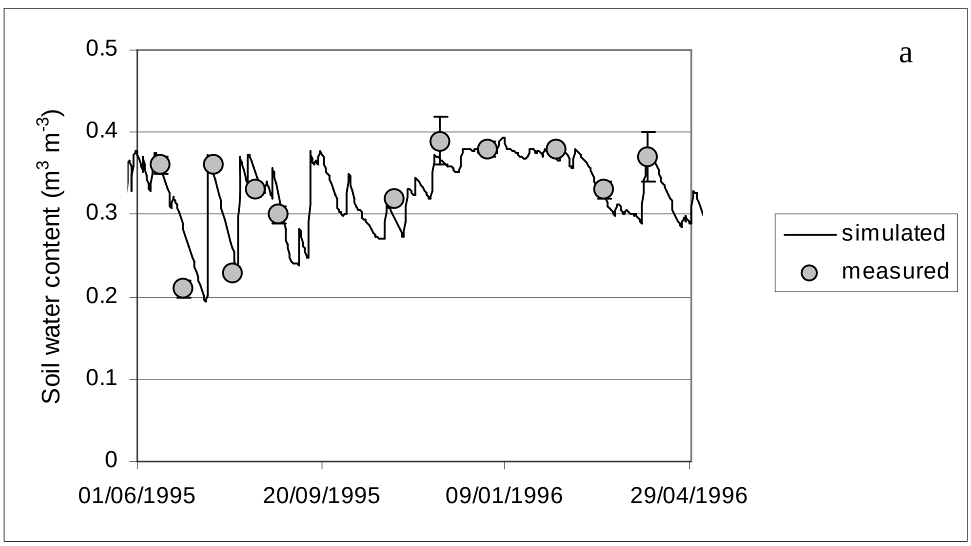


Figure 2 – Cumulated aboveground biomass of meadow seeded in 1997 after calibration (1st and 2nd year) and after validation (3rd year)

Table 5 – Indices of agreement between observed and simulated cumulated aboveground biomass

	Sowing year	RRMSE (%)	EF	CRM	CD	Slope	Intercept (t AGB ha-1)	R2
Calibration	1996	3	1.00	-0.01	1.04	0.98	0.14	1.00
	1997	6	0.99	0.05	0.91	1.06	0.01	1.00
Validation	1996	3	1.00	0.01	0.95	1.02	-0.40	1.00
	1997	5	0.99	0.01	1.09	0.95	1.37	0.99

Figures 3, 4 and Table 6 show the comparison between measured and simulated values of SWC: the model is accurate in simulating this variable, especially for the soil layer 0.00 – 0.30 m. For the soil layer 0.30 – 0.60 m, the simulated temporal variability is lower than the measured one. The values of RRMSE are low, the values of CD are very close to 1 and CRM is close to zero, except for the soil layer 0.30 – 0.60 m for the 6-year rotation. For the soil layer 0.00 – 0.30 m, the poor model performance might be due to reduced drainage (caused by intense rainfall in autumn and winter and deep soil layers with low hydraulic conductivity), which is not simulated with the cascading approach.



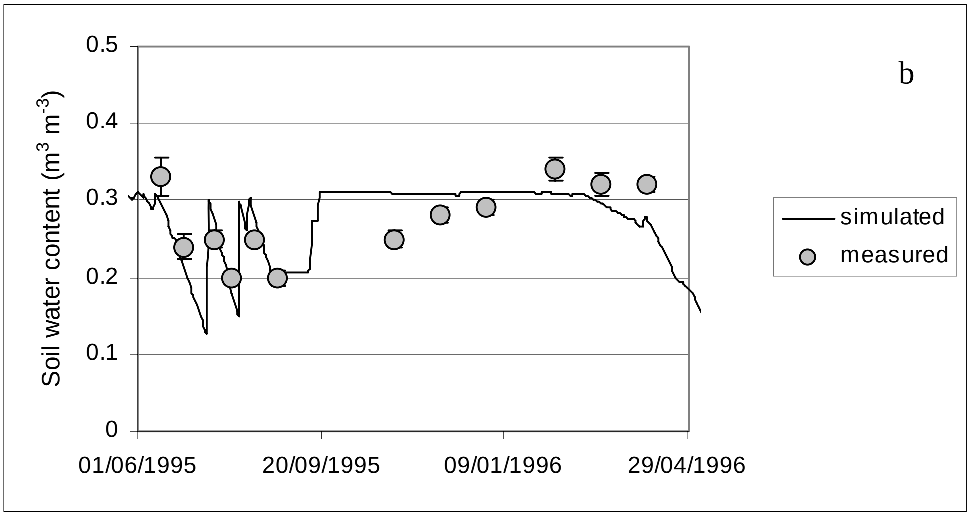
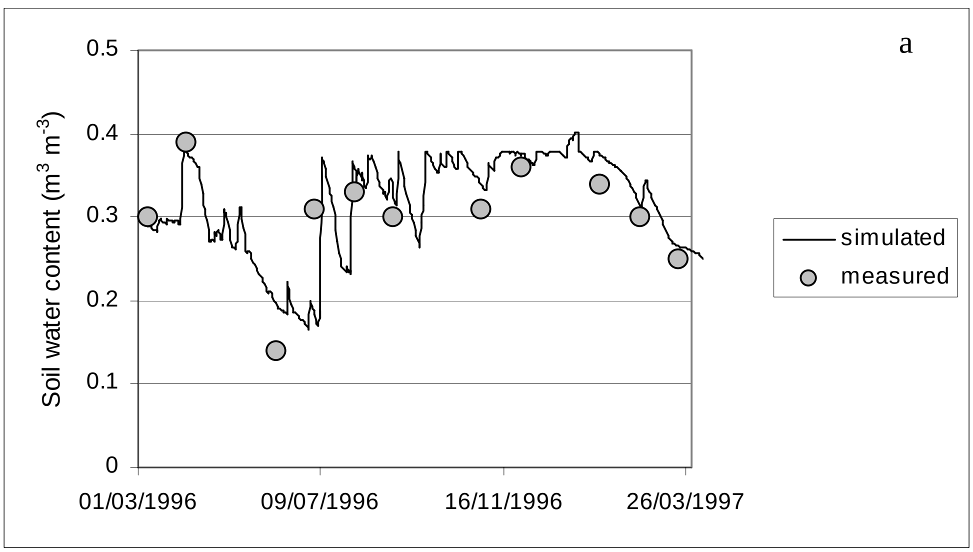


Figure 3 – Measured and simulated soil water content after calibration. 1-year rotation; June 1995 – April 1996; (a) soil layer 0.0-0.3 m; (b) soil layer 0.3-0.6 m



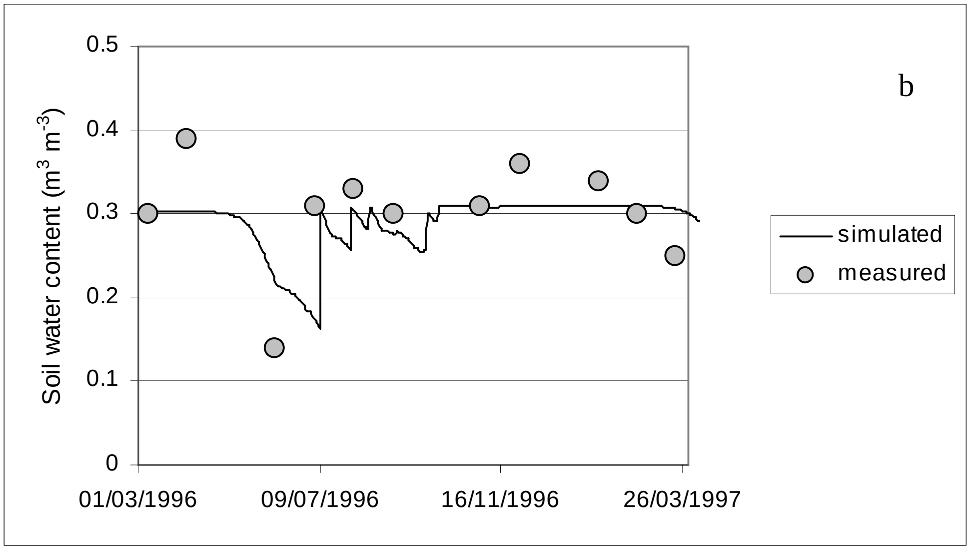


Figure 4 – Measured and simulated soil water content after calibration. 6-year rotation; March 1996 – March 1997; (a) soil layer 0.0-0.3 m; (b) soil layer 0.3-0.6 m

Table 6 – Indices of agreement between observed and simulated soil water content

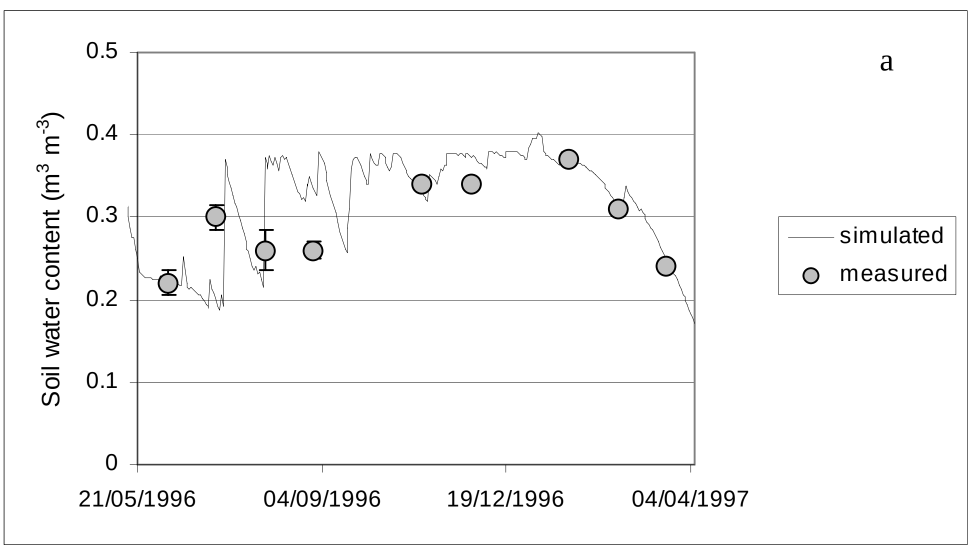
	Rotation	Soil layer (m)	RRMSE (%)	EF	CRM	CD	Slope	Intercept (t AGB ha-1)	R2
Calibration	1-year	0.0-0.3	13	0.34	0.03	1.16	0.67	0.11	0.50
	1-year	0.3-0.6	16	0.43	-0.01	1.02	0.71	0.07	0.52
	6-year	0.0-0.3	15	0.50	0.02	0.89	0.79	0.07	0.55
	6-year	0.3-0.6	21	-1.00	-0.07	2.32	0.31	0.19	0.20
Validation	1-year	0.0-0.3	19	0.20	0.05	0.62	0.72	0.10	0.29
	1-year	0.3-0.6	20	0.38	-0.03	0.99	0.70	0.07	0.48
	6-year	0.0-0.3	10	0.18	0.07	2.17	0.69	0.12	0.81
	6-year	0.3-0.6	17	0.01	0.06	1.43	0.55	0.13	0.39

Validation

Results of crop parameters test are shown in figures 1, 2 and in Table 5. In general, model performance is still satisfactory: the aboveground biomass accumulation of alfalfa is well reproduced. The simulation is more accurate for the first data set (meadow seeded in 1996; Figure 1), while for the second one (Figure 2) the biomass of the last two cuts of the third year is underestimated.

Measured and simulated values of SWC after validation are shown in Figures 5, 6 and in Table 6. As already pointed out, simulations for the upper soil layer are more in agreement with measurements than for the deepest layer. In general, however, the indices show a discrete model performance: RRMSE range from 10 to 20% and CD from 0.62 to 2.17.

We should remember that CropSyst does not explicitly simulate the role of crown and roots for regrowth after dormancy and after cuts. For this reason we believe that our crop parameter set incorporates part of this behaviour, in particular for empirical parameters such as SLP. Therefore, we think that the application of these parameters to other environments should be made with caution. Moreover, simulation of the effects of different cutting frequencies (affecting the rate of biomass accumulation and depletion from crown) would not be possible with this simulation model. To overcome this limitation, simple approaches like the one suggested by Fick (1984) could be used, where a factor for regrowth potential (representing the effect of storage and root reserves on daily crop growth rate) is calculated as a function of GDD accumulated since the last cut. This factor decreases immediately after cut, and increases again while new reserves are accumulated.



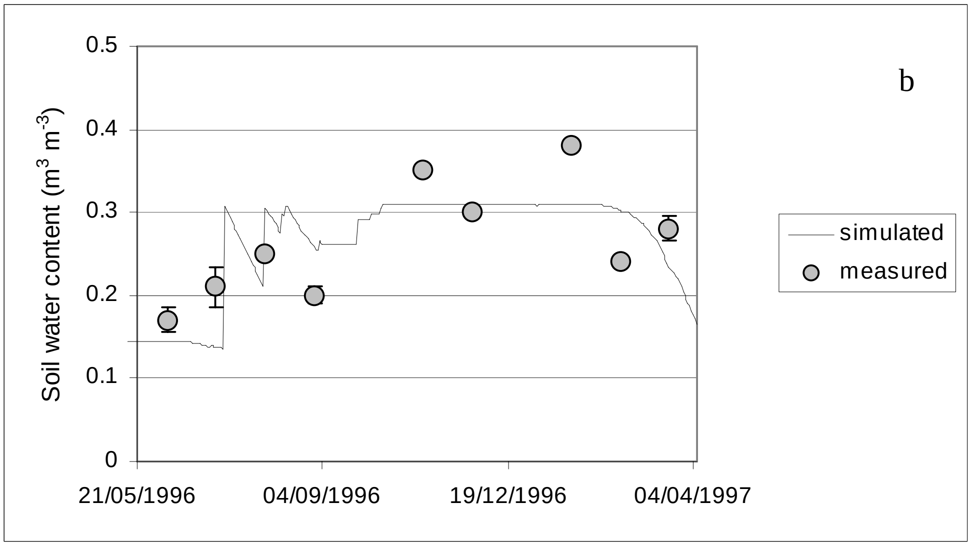
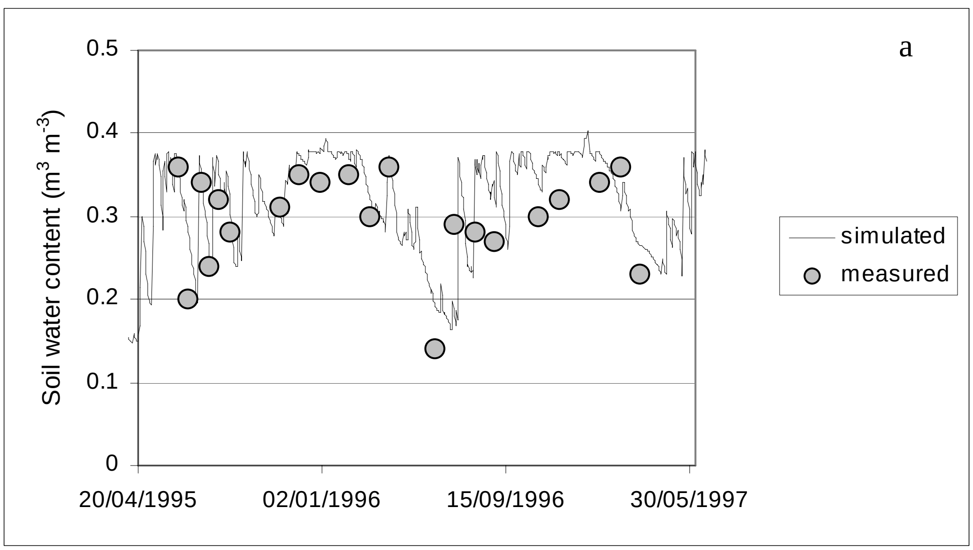


Figure 5 – Measured and simulated soil water content after validation. 1-year rotation; May 1996 – March 1997; (a) soil layer 0.0-0.3 m; (b) soil layer 0.3-0.6 m



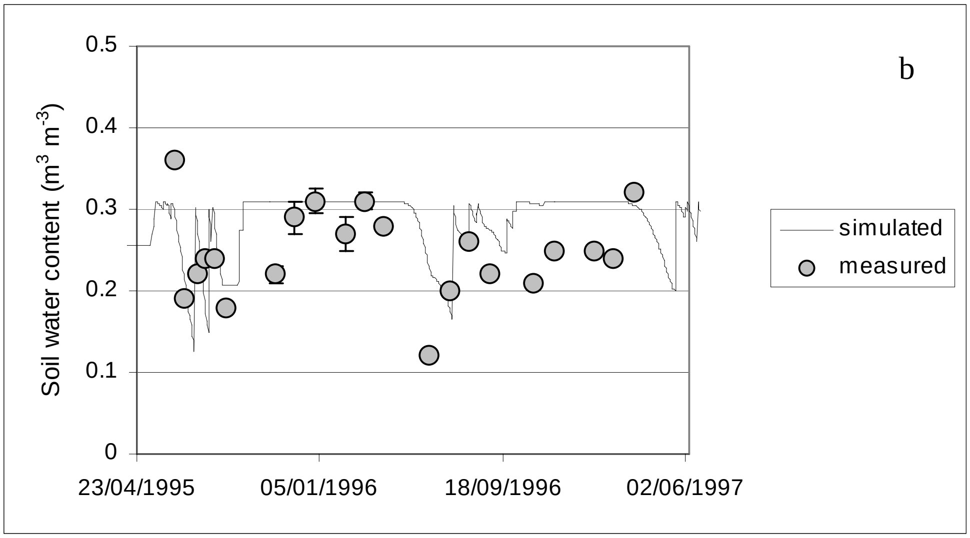


Figure 6 – Measured and simulated soil water content after validation. 6-year rotation; June 1995 – March 1996; (a) soil layer 0.0-0.3 m; (b) soil layer 0.3-0.6 m

Criteria for automatic cuts

The results of the comparison between automatic cutting methods may be summarized as follows: (i) the average value for GDD used to schedule the cutting events is 635 °C d (with T_{base} = 5 °C) and its standard deviation is 137 °C d; (ii) the method which best reproduces the harvested biomass is the SimBioPh: its RRMSE (see Table 7) is relatively low (20% in 1996 and 29% in 1997), and its CD has values very close to 1. These results might not be considered completely satisfactory. In fact, as pointed out by Sanderson et al. (1994), a general relationship between phenological stage and GDD in alfalfa for predicting morphological development may not be possible. However, when the purpose is to run scenarios comparisons, we believe that the SimBioPh method would allow to carry out better simulations than SimBio (which has comparable RRMSEs but worse CDs).

Table 7 – Automatic scheduling of cutting events: indices of agreement between observed and simulated (with the three criteria described in the text) aboveground biomass (t AGB ha^{-1})

Year	Criterion	RRMSE (%)	EF	CRM	CD	Slope	Intercept (t AGB ha^{-1})	R^2
1996	SimBio	24	-0.11	0.06	0.07	-5.01	16.85	0.10
1996	SimPh	29	-0.31	-0.01	1.15	0.37	1.79	0.16
1996	SimBioPh	20	0.16	0.04	1.26	0.58	1.32	0.41
1997	SimBio	25	-4.75	-0.01	7.69	0.19	2.17	0.26
1997	SimPh	28	0.00	0.03	1.26	0.50	1.38	0.32
1997	SimBioPh	29	-0.07	0.02	0.93	0.46	1.50	0.20

4.5. Conclusions

Even if CropSyst is a generic cropping systems simulation model, the cumulative simulated aboveground alfalfa biomass for the three-year periods is consistent with measured values, and, in general, the biomass harvested at most of the cuts is properly simulated. Soil water content simulations are satisfactory as well. Even if some limitations have been underlined, this crop parameter set may be already used for explorative scenario simulations in the study area.

Besides the parameterization of alfalfa, this work has demonstrated the robustness of the model for perennial forage crops simulation and has suggested improvements of the model (automatic scheduling of cuts, role of crown reserves). These improvements may be very important for CropSyst, which is increasingly used for management and planning purposes.

4.6. Acknowledgments

We gratefully acknowledge the contribution of Tommaso Maggiore, Stefano Bocchi, Luigi Mariani (Department of Crop Science, Section of Agronomy, University of Milano), Lamberto Borrelli and Cesare Tomasoni (Experimental Institute for Forage Crops, Lodi), Franco Previtali and Roberto Comolli (Department of Environmental Sciences, University of Milano – Bicocca) for help provided on this project. We are also deeply in debt with Claudio O. Stöckle and Roger Nelson (Washington State University, USA) for continuous support with the simulation model.

APPLICATION OF THE SIMULATION MODEL CROPSYST TO WINTER WHEAT (*Triticum aestivum* L.) IN NORTHERN ITALY

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Submitted to: European Journal of Agronomy (2003)

5.1. Abstract

Dynamic simulations models are frequently used in agriculture for assessing agronomic and environmental effects of different management practices, under different pedo-climatic conditions. Due to input variability and uncertainty and to model errors, scenario simulations are frequently run with the scope of comparison rather than estimation of absolute values of the variables studied. With the aim of extending the information available to run scenario simulations in northern Italy with the cropping systems simulation model CropSyst, we set-up crop parameters for winter wheat by deriving information from existing experimental data sets and literature.

The experiments, carried out in northern Italy between 1986 and 2001, quantified the dynamics of aboveground biomass (AGB), plant nitrogen (N) concentration (PNC) and nitrogen uptake (UPTK) by means of periodical measurements. Most of the experiments included treatments with different N fertilization levels. Crop model parameters were calibrated by using data from optimal N nutrition treatments, or derived from existing information (literature and CropSyst's default values). Part of the calibration process was carried out on modules (crop development and growth) separated from the main model. Data sets obtained under N-limiting treatments were used during validation. All the values obtained after calibration of crop parameters were in reasonable ranges. The most important are: aboveground biomass transpiration coefficient (5.8 kPa kg m^{-3}), radiation use efficiency (3.1 g MJ^{-1}), optimum mean daily temperature for growth (19 °C), specific leaf area (25 m^2 kg^{-1}), stem/leaf partition coefficient (1.5), extinction coefficient for solar radiation (0.48), base temperature (-1 °C), cutoff temperature (20 °C), photoperiodic thresholds (10 and 18 hours). The relative root mean squared error (RRMSE) obtained after calibration ranged between 9 and 30% for AGB, was 10% for PNC and ranged between 8 and 28% for UPTK. Corresponding RRMSE during validation ranged between

17 and 32% for AGB, 6 and 40% for PNC, 9 and 24% for UPTK. AGB was frequently underestimated, particularly in spring. Despite the uncomplete accuracy of model simulations, we think that our calibrated crop parameters are adequate for scenario analysis, because (i) most differences between years and fertilization levels were reproduced by the model and (ii) final aboveground biomass and cumulative N uptake were properly simulated.

Keywords: plant nitrogen concentration, nitrogen uptake, aboveground biomass

5.2. Introduction

Simulation models are nowadays widely applied in agriculture. At large scales (national or regional) they are frequently used to predict crop yields (e.g. Yun, 2003) and water requirements (Bechini et al., 2003; Sousa and Pereira, 1999), to provide quantitative basis for decision support systems and multi-criteria analysis (e.g. sustainable irrigation management analysis: Cai et al., 2003), to orient and evaluate agricultural policies (e.g. Giupponi et al., 1999; Topp and Mitchell, 2003), to support land use allocation decisions or extrapolation of a tested farming system to other areas (Hack-ten Broeke et al., 1999), and to conduct agroclimatic assessment (e.g. Badini et al., 1997). At farm and cropping system levels, models can help farm managers or farm consultants in taking strategic decisions to maximize income and/or minimize environmental impact in a given pedological, climatic and socio-economic environment (e.g. Abrecht and Robinson, 1996; Acutis et al., 2000; Berntsen et al., 2003; Donatelli et al., 2002; Hansen et al., 2000; Lewis et al., 2003; Nordblom et al., 2003; Peralta and Stöckle, 2001; Rossing et al., 1997; ten Berge et al., 2000).

For such applications, scenario simulations are used to evaluate the sensitivity of model outputs to the variability of model inputs (soils, weather data describing the climate, management options) and to provide stochastic results (e.g. Acutis et al., 2000; Badini et al., 1997; Peralta and Stöckle, 2001; Sousa and Pereira, 1999; Bechini et al., 2003); therefore they are useful to estimate the probabilities of occurrence of different events as a function of the environment in which a given crop is grown. Due to input variability, input uncertainties and model error, scenario simulations are frequently run with the scope of comparison rather than estimation of absolute values of the variables studied. Processes which may require scenario simulations in northern Italy are related to the environmental impact of rural development programmes or manure management.

A widely applied cropping system simulation model is CropSyst (Stöckle et al., 2003), a robust multi-crop simulator, which simulates rotations, has a simple user interface, an automatic management events scheduler, the possibility to run multiple simulations in connection with a GIS and is distributed free of charge. For these reasons CropSyst is increasingly used for scenario simulations (e.g. Peralta and Stockle, 2001; Bechini et al., 2003).

As for every model application, also for cropping systems models the need of realistic model parameters is strongly increasing by the users' side. Crop parameters were already published for several cultivated species in Italy (Donatelli et al., 1997; Giardini et al., 1998; Confalonieri and Bocchi, 2002; Confalonieri and Bechini, 2003; Confalonieri et al., 2003). However, the application of CropSyst to winter wheat (*Triticum aestivum* L.), the main winter cereal cultivated in northern Italy, is only addressed in one work (Giardini et al., 1998), which is related to one location with two years of data only. Moreover, the crop parameter set obtained there was calibrated on an old CropSyst version (1.09.18, 1997) where the effect of temperature on photosynthesis was implemented in a different way. Other sources of information about CropSyst's crop parameters for winter wheat were published by Stöckle et al. (1994) and Pannkuk et al. (1998), but are relative to non Italian conditions and therefore less suitable for application in northern Italy. Moreover, some do not include the complete list of parameters required to run the model (e.g. nitrogen concentrations).

In general, because resources to carry out a serious, long-term experimental work to set-up and update variety-specific sets of crop parameters are scarce, at the moment we believe that we should 1) parameterize the crops at species level, or, in the best cases, for sub-species groups (like maturity classes for maize); 2) use data collected for other purposes to derive the best amount of information for crop parameterization.

We carried out this work with the aim of extending the information available to run scenario simulations in northern Italy. The specific objectives are: (i) to set up crop parameters to be used with CropSyst for winter wheat; (ii) to show how this can be done by deriving information from relatively small existing experimental data sets and from literature.

To derive the best amount of information from existing experimental data, a work on specific sub-models (development, growth) was carried out to obtain the values of several important crop parameters (cardinal temperatures for development, photoperiodic thresholds, radiation use efficiency).

5.3. Materials and methods

5.3.1. Experimental data

Experimental data were collected in 4 experiments (table 1) carried out between 1986 and 2002 in northern Italy. The climate of this area is characterized by a discrete level of continentality, with a mean annual temperature of about 13 °C; the absolute minimum temperature occurs between January and February and the absolute maximum between July and August. Total precipitation (about 800 mm $year^{-1}$) is relatively well distributed and the average wind speed is about 1.5 m s^{-1}.

For all the experiments, the soils were sub-acid with high available phosphorous. Daily meteorological data (rainfall, maximum and minimum air temperatures, global solar radiation) were collected with automatic weather stations near the fields. Plant samples were stored in oven at 70 °C (until constant weight) to determine the dry matter weight of aboveground biomass (AGB).

The first experiment was carried out in S. Angelo Lodigiano (province of Lodi) between 1986 and 1988, with the aim of verifying the effects of nitrogen fertilization on winter wheat (cv. Gemini) growth and yield. The soil had medium organic matter and low potassium contents. No water stress was observed.

Table 1. The data sets used in this work

Experiment n.	Location	Latitude Longitude Altitude	Years	Soil texture	Treatments	Experimental design	Replications	Measured variables	N. of samples	Sample size
1	S. Angelo Lodigiano	45° 15' N 9° 22' E 73 m a.s.l.	1986-87 1987-88	sandy-loam sandy-clay	3 N levels (0, 140, 210 kg N ha^{-1})	Complete randomized block	3	AGB *** PNC ****	6	0.180 m^2 (0.18 m x 1.0 linear m)
2	S. Angelo Lodigiano	45° 15' N 9° 22' E 73 m a.s.l.	1989-90 1990-91	sandy-loam		Split-plot (plot: species; subplot: cultivars)	4	AGB *** PNC ****	15 16	0.180 m^2 (0.18 m x 1.0 linear m)
3	Lodi	45° 19' N 9° 28' E 80 m a.s.l.	1996-97	sandy-loam		Split-plot (plot: species; subplot: cultivars)	3	AGB *** PNC ****	8	0.180 m^2 (0.18 m x 1.0 linear m)
4	S. Angelo Lodigiano	45° 15' N 9° 22' E 73 m a.s.l.	2001-02	sandy-loam	9 N levels (0, 50, 100* x 0, 40, 80** kg N ha^{-1})	Split-split-plot (plot: preseeding fertilization; subplot: top-dressing fertilization; sub-subplot: cultivars)	3	AGB ***	5	0.216 m^2 (0.18 m x 1.2 linear m)

* pre-seeding fertilization
** top-dressing fertilization
*** Aboveground biomass
**** Plant nitrogen concentration

The second experiment, carried out in S. Angelo Lodigiano between 1989 and 1991, had the purpose of describing the spring dynamics of biomass accumulation and forage quality of five species (winter wheat, Italian ryegrass, barley, rye, triticale). The soil had medium organic matter and low potassium contents. Two cultivars were used for each species (Pandas and Centauro for wheat). AGB samples were collected every 10 days until head emergence (Zadoks stage 55), every 3 days between earing and late milk maturity (Zadoks stages 77) and every 10 days between late milk maturity and physiological maturity (Zadoks stage 89). The system was maintained at potential production level (Van Ittersum and Rabbinge, 1997).

The third experiment was conducted in Lodi in 1997 to study the spring dynamics of forage quality and biomass accumulation of winter wheat, barley and Italian ryegrass. The soil had low organic matter and low potassium contents. Two cultivars were grown for each species (Eridano and Soissons for wheat).

The fourth experiment was carried out in S. Angelo Lodigiano in 2002 to compare the effects of nine fertilization treatments on the yields of three wheat cultivars (Guadalupe, Enesco and Eureka). The soil had medium organic matter and potassium contents. In this experiment, plant sample size was determined by using the following method. An elementary sub-sample size (S) was chosen (0.20 linear m = 0.036 m^2). Nine dry matter samples of size $\alpha \times S$ (with α integer from 2 to 10) were weighted, recording separately the values for each elementary sub-sample. For each sample the mean weight of the α sub-samples and its standard deviation were calculated. The means and the standard deviations were plotted against α. The minimum sample size for the experiment corresponded to the value of α with stable means and reasonably low standard deviations.

The experimental data were analyzed with the software CoLiDaTa (Confalonieri and Scaglia, 2002), which automatically applies many statistical tests for the validation of analytical data. In particular, the

Grubbs's test (Grubbs, 1969; ISO 5725-2, 1994) was used to discard outliers.

5.3.2. Simulation model

CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model (Stöckle et al., 2003) developed to evaluate the effects of different pedo – climatic and management conditions on crop growth and on environmental impact.

Crop development is simulated thorough thermal time accumulation, by computing the growing degree days (GDDs), using T_b (base temperature; °C) as a lower threshold and T_{cutoff} (°C; optimum temperature for thermal time accumulation) as an upper threshold. Options for the simulation of photoperiod and vernalization are available.

The potential daily AGB production is calculated as the minimum of the values computed with equations [1] and [2] proposed, respectively, by Tanner and Sinclair (1983) and by Monteith (1977):

$$AGB_{PT} = \frac{K_{BT} \times T_P}{VPD} \qquad [1]$$

where AGB_{PT} (kg m^{-2} day^{-1}) is the crop potential transpiration-dependent biomass production, T_P (kg m^{-2} day^{-1}) is crop potential transpiration, VPD (kPa) is the daytime mean atmospheric vapor pressure deficit and K_{BT} (kPa) is a biomass-transpiration coefficient, which corresponds to the water use efficiency (WUE: aboveground biomass accumulated / water transpired) multiplied by the VPD.

$$AGB_{iPAR} = RUE \times iPAR \times T_{\mathrm{lim}} \qquad [2]$$

where AGB_{iPAR} (kg m^{-2} day^{-1}) is the intercepted PAR-dependent biomass production, RUE (kg MJ^{-1}) is the net radiation use efficiency, iPAR (MJ m^{-2} day^{-1}) is the daily amount of crop-intercepted photosynthetically active radiation and T_{lim} is a temperature limitation factor, calculated as:

$$T_{\lim} = \begin{cases} 0 & T_m < T_b \\ \dfrac{T_m - T_b}{T_{opt} - T_b} & T_b \leq T_m \leq T_{opt} \\ 1 & T_m > T_{opt} \end{cases} \qquad [3]$$

where T_m (°C) is the average air daily temperature and T_{opt} (°C) is the optimum temperature for growth.

The equation [2] is necessary because of the instability of the equation [1] at low values of VPD. Water and nitrogen limitations are then applied to AGB_P (= the minimum between AGB_{PT} and AGB_{iPAR}) to calculate actual daily AGB production. Water limited growth (AGB_T) is calculated by multiplying AGB_P for the ratio of actual to potential transpiration; subsequently actual daily AGB production is calculated by applying the concept of critical nitrogen concentration (Greenwood et al., 1990) to AGB_T.

Leaf area growth is calculated on the basis of equation [4]:

$$LAI = \frac{SLA \times AGB}{1 + p \times AGB} \qquad [4]$$

where LAI (m^2 m^{-2}) is the leaf area index, AGB is the accumulated aboveground biomass (kg m^{-2}), SLA (m^2 kg^{-1}) is the mean of specific leaf area values measured at early growth stages and p is an empirical partitioning coefficient.

CropSyst uses the following equations to identify the maximum, critical and minimum nitrogen concentrations from emergence to flowering for the aboveground partition of the plant:

$$N_{\max} = \min\left(N_{\max_e}, a_{\max} \times AGB^{-b}\right) \qquad [5]$$

$$N_{crit} = \min\left(0.8 \times N_{\max_e}, a_{crit} \times AGB^{-b}\right) \qquad [6]$$

$$N_{\min} = \min\left(0.4 \times N_{\max_e}, a_{\min} \times AGB^{-b}\right) \qquad [7]$$

where:

$$a_{\max} = \frac{N_{\max_e}}{2^{-b}} \qquad [8]$$

$$a_{crit} = \frac{0.8 \times N_{\max_e}}{1.5^{-b}} \qquad [9]$$

$$a_{\min} = \frac{0.4 \times N_{\max_e}}{0.5^{-b}} \qquad [10]$$

where N_{max}, N_{crit} and N_{min} (%) are, respectively, the maximum, critical and minimum nitrogen concentrations; N_{maxe} (%) is the maximum nitrogen concentration during early growth, AGB (kg ha^{-1}) is the aboveground plant biomass; a_{max}, a_{crit}, a_{min} represents thresholds at which nitrogen concentrations begin to decrease and b = -0.4. For the period between flowering and physiological maturity, maximum and minimum nitrogen concentrations decrease linearly to "maximum nitrogen concentration at maturity" (N_{maxm}) and "minimum nitrogen concentration at maturity" (N_{minm}) input parameters.

5.3.3. Model parameterization and validation

CropSyst version 3.02.23 (January 8, 2002) was used. Potential evapotranspiration was calculated by using the Priestley-Taylor equation. Soil water redistribution was simulated with the cascade model.

Data from the second and fourth experiments were used for the calibration of crop parameters, while data from the first and third were used for validation. The calibration was carried out on the parameters SLA, p, T_{opt}, T_b, T_{cutoff}, day length photoperiod to inhibit flowering (PI), day length photoperiod for insensitivity (PL), RUE, K_{BT}, GDDs to reach maximum LAI, GDDs to begin flowering, GDDs to begin grain filling, GDDs to reach physiological maturity; the other crop parameters were either set to the default, found in literature or measured. T_b and T_{cutoff} were calibrated using the Microsoft Excel Solver (Microsoft Corporation, 1997), with the scope to minimize the coefficient of variation among the GDDs required to reach flowering and physiological maturity as already made by Bonhomme et al. (1994); this procedure was applied to the data sets used for calibration. The same method was used to calibrate PI and PL for the period from emergence to flowering.

For the calibration of RUE the following method was used. Sub-models for the calculation of AGB_{iPAR} and AGB_{PT} were reproduced as separate modules and both were used to simulate daily AGB accumulation for the period between the closed canopy stage (full radiation interception) and flowering. In this period, AGB_{iPAR} depends only from solar radiation and temperature. Because CropSyst uses the minimum of AGB_{iPAR} and AGB_{PT} as the potential daily AGB production, the periods in which AGB_{iPAR} was lower than AGB_{PT} were selected. The Microsoft Excel Solver was then used to calibrate RUE, with the objective of minimizing the difference between measured and calculated AGB values.

The parameter N_{maxe} was parameterized according to the critical nitrogen dilution curve for winter wheat proposed by Justes et al. (1994); they propose the value of 4.4 % for the critical nitrogen concentration during early stages (until the biomass reaches a value of 1.55 t ha^{-1}).

The agreement between observed and simulated cumulated values of AGB, plant nitrogen concentration (PNC) and aboveground plant nitrogen uptake (UPTK) was expressed by using the indices proposed by Loague and Green (1991) and recently reviewed by Martorana and Bellocchi (1999): the relative root mean squared error (RRMSE, minimum and optimum=0%), the coefficient of determination (CD, minimum=0, optimum=1, indicates whether the model reproduces the trend of measured values or not), the modelling efficiency (EF, $-\infty \div +\infty$, optimum=1, if positive, indicates that the model is a better predictor than the average of measured values), the coefficient of residual mass (CRM, 0-1, optimum=0, if positive indicates model underestimation). The parameters of the linear regression equation between observed and predicted values were also calculated; because these data are not independent (Donatelli et al., 2003), no conclusions were drawn about their statistical significance.

5.4. Results and discussion

5.4.1. Calibration of crop model parameters

Calibrated crop model parameters are shown in table 2.

Table 2. Crop model parameters for winter wheat: their values and source of information (C: Calibrated parameters; D: CropSyst default values; L: derived from literature)

Parameter	Source	Value	Units
Photosynthetic pathway	/	C3	/
Above ground biomass-transpiration coefficient (K_{BT})	C	5.8	kPa kg m^{-3}
Light to above ground biomass conversion (RUE)	C	3.1	g MJ^{-1}
Actual to potential transpiration ratio that limits leaf area growth	D	0.95	/
Actual to potential transpiration ratio that limits root growth	D	0.5	/
Optimum mean daily temperature for growth (T_{opt})	C	19	°C
Maximum water uptake	D	10	mm day^{-1}
Leaf water potential at the onset of stomatal closure	D	1300	J kg^{-1}
Wilting leaf water potential	D	2000	J kg^{-1}
Maximum rooting depth	D	1.6	m
Fraction of max. LAI at physiological maturity	D	0.5	/
Specific leaf area (SLA)	C	25	m^2 kg^{-1}
Stem/Leaf partition coefficient (p)	C	1.5	/
Extinction coefficient for solar radiation (k)	D	0.48	/
ET crop coefficient at full canopy	L *	1.15 *	/
Degree days Emergence	L **	100 **	C-days
Degree days Peak LAI	C	550	C-days
Degree days Begin flowering	C	564	C-days
Degree days Begin grain filling	C	715	C-days
Degree days Begin Physiological maturity	C	1352	C-days
Leaf duration	C	1000	C-days
Base temperature (T_b)	C	-1	°C
Photoperiod simulation	/	activated	/
Cutoff temperature (T_{cutoff})	C	20	°C
Phenologic sensitivity to water stress	D	0.5	/
Day length photo period to inhibit flowering	C	18	hours
Day length photo period for insensitivity	C	10	hours
Unstressed harvest index	D	0.48	/
Nitrogen uptake adjustment	C	0.06	/
Nitrogen availability adjustment	C	0.16	/
Maximum N concentration during early growth ($N_{max}e$)	L ***	0.055 ***	kgN $kgAGB^{-1}$
Maximum N concentration at maturity	C	0.015	kgN $kgAGB^{-1}$
Minimum N concentration at maturity	C	0.007	kgN $kgAGB^{-1}$

* : Allen et al., 1998
** : Pannkuk et al., 1998
*** : Justes et al., 1994
AGB = aboveground biomass (dry matter)

With the values of -1 °C and 20 °C for T_b and T_{cutoff}, a coefficient of variation of 6% among the GDDs to reach physiological maturity was obtained for the three data sets used for calibration. The calibrated value for T_{cutoff} is coherent with what reported in the review by Porter and Gawith (1999) (optimal temperatures for development between sowing and emergence, around anthesis and during grain filling were 22.0, 21.0 and 20.7 °C respectively). In CropSyst, the minimum cardinal temperature is the same for growth and development (T_b): moreover, in CropSyst this parameter can not be stage-specific. Therefore it is not easy to compare our calibrated value with the mean values reported by Porter and Gawith (e.g. -1.9 °C for leaf growth, -1 °C for leaf initiation). Slafer and Rawson (1995) reported a value of 0 °C for T_b-development during early stages, concluding that cardinal temperatures vary between growth and development, and between varieties. In general, values of T_b reported in the literature are higher than our calibrated value and very variable for the last part of the crop cycle (Porter and Gawith, 1999). The same Authors have reported values for the optimum temperature for growth ranging from 19 to 24.3 °C, with average values for leaf initiation, shoot growth and grain filling, respectively, of 22.0, 20.3 and 20.7 °C. Our calibrated value for T_{opt} (19 °C) is in agreement with these values.

Our calibrated value for RUE (3.1 g MJ^{-1}) is in good agreement with what reported by many authors. Kiniry et al. (1989), in a review paper about RUE, report values for wheat ranging from 2.6 to 3.1 g MJ^{-1}, with an average value of 2.8 g MJ^{-1} and a standard deviation of 0.2. Yunusa et al. (1993) obtained a value of 2.93 g MJ^{-1} from continuous measurements during the vegetative growing period. This work was also indicated by Sinclair and Muchow (1999) as an accurate measurement of potential RUE, because most of the other works reviewed by them are related to spot measurements or to absorbed PAR measurements: none of them can be used with the modelling approach of CropSyst. Rodríguez et al. (2000) measured variable values of RUE at different crop growth stages. They reported values between 4.6 g MJ^{-1} for the first sampling (from 27 to 34 days after emergence (DAE)) and 1.3 g MJ^{-1} for the last sampling (from 48 to 61 DAE) in non-limiting conditions for water and nutrients. In other papers about wheat simulations with CropSyst, RUE was maintained at the default value of 3 g MJ^{-1} (Stöckle et al., 1994; Pannkuk et al., 1998) while Giardini et al. (1998) used a value of 3.5 g MJ^{-1}. The measurements of RUE normally derive from field experiments rarely carried out in non-limiting temperature conditions, while the RUE used by CropSyst is a potential RUE (temperature limitation is applied separately). For this reason, our calibrated value was considered correct, although it lies at the upper limit of the range of values discussed.

The calibrated value for K_{BT} (5.8 kPa kg m^{-3}, Table 2) is hardly comparable with values from literature, because the water use efficiency (WUE) is usually calculated by dividing yield by transpired (or evapotranspired) water; on the other side, CropSyst uses the VPD - corrected WUE (Tanner and Sinclair, 1983; Amir and Sinclair, 1991; Amir and Sinclair, 1996). Our calibrated value is the same which was calibrated by Stöckle et al. (1994) and reported by Amir and Sinclair (1991; 1996).

The default value of 0.48 for the extinction coefficient for solar radiation (k) is similar to the one proposed by Abbate et al. (1997), which calculated a value of 0.49 ± 0.018 for spring wheat by using data collected in five experiments carried out in Argentina. Calderini et al. (1997) reported lower values (between 0.37 and 0.46) by analyzing the effects of wheat breeding on biomass and its physiological determinants. Other Authors set this parameter at a value of 0.45 (Stöckle et al., 1994 for winter wheat; Donatelli et al., 1997 for durum wheat).

The calibrated value of SLA (25 m^2 kg^{-1}) is consistent with the one assumed by Sinclair and Amir (1992) for a model with a fixed value of this parameter, higher than the values by Van Delden et al. (2000) (around 20 m^2 kg^{-1} for SLA at tillering) and lower than those by Yuan et al. (1998) (42 m^2 kg^{-1} at early tillering). No measured data of LAI were available in our data sets; therefore it was not possible to carry out a proper model evaluation of leaf area simulations. Nonetheless, we checked that the simulated maximum LAI never exceeded the value of 9 m^2 m^{-2}.

Although the coefficients of the nitrogen dilution equations used by CropSyst and by Justes et al. (1994) show little differences, the resulting curves are very similar, with a small underestimation for N_{max} and N_{min} in the first part of the cycle (Figure 1). This allows to confirm the goodness of the value of N_{maxe} (5.5 %).

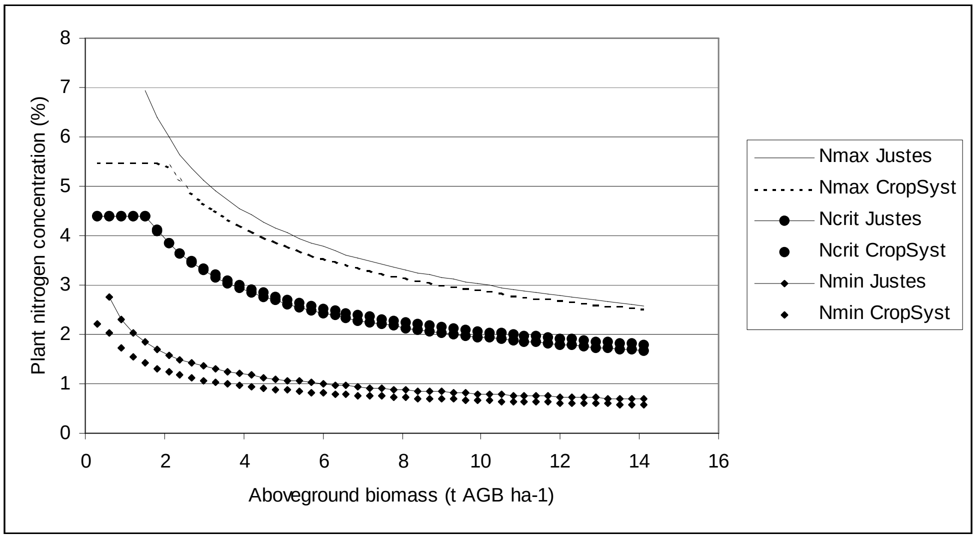


Figure 1. Comparison between the maximum, critical and minimum nitrogen curves proposed by Justes et al. (1994) and calculated by CropSyst

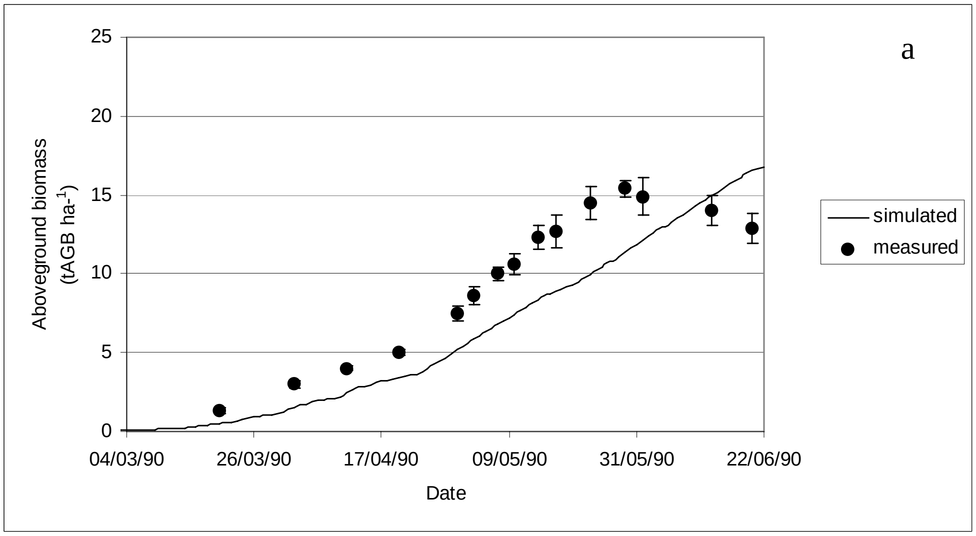
The agreement between measured and simulated AGB values after calibration is shown in figure 2 and in table 3. With the exception of S. Angelo Lodigiano – 1989 (figure 2.a) the model has demonstrated to be accurate in the simulation of AGB accumulation; this is confirmed by the indices (low RRMSE; CD and slope of the regression line very close to 1; EF always close to 1). Figure 2.b and 2.c show that the model correctly simulates early growth for 1990 and 2001 sowings, while for the wheat sown in 1989, AGB is clearly underestimated until the beginning of June, when lodging decreased the measured AGB. The underestimation in 1989-

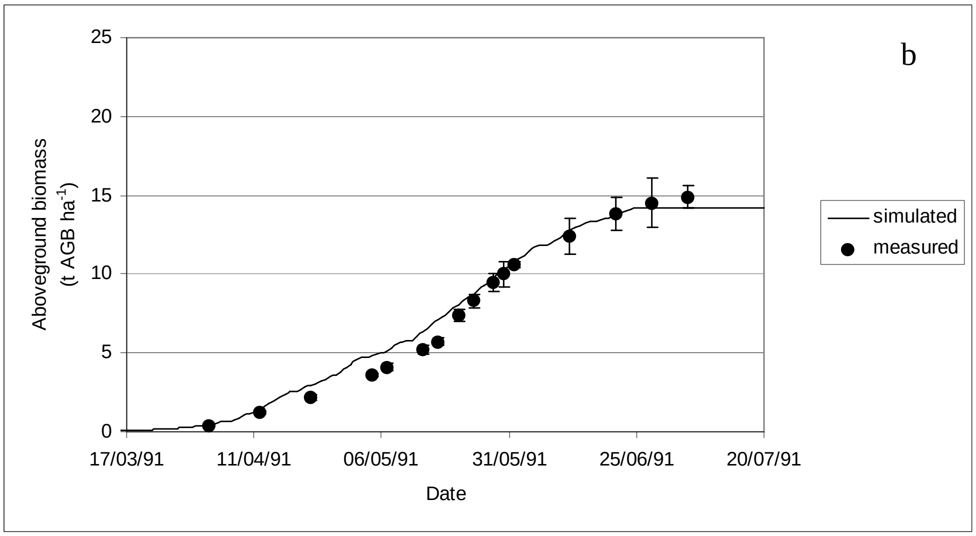
90 can not be corrected by further modifying the parameters involved with AGB accumulation (e.g. by using a lower value for T_{opt} or a higher value for RUE and/or K_{BT}) because these parameters are already set to the extreme values found in the literature. Moreover, a comparison of the results obtained (for two years) with a more extended weather data set for the same location (including relative humidity and wind speed) has shown that the use of Penman-Monteith equation to estimate the reference evapotranspiration did not improve AGB simulations. This might mean that the use of the Priestley-Taylor equation did not cause a significant underestimation of transpiration and therefore of AGB accumulation (equation [1]).

Table 3. Indices of agreement between observed and simulated values of aboveground biomass (AGB) and plant N concentration (PNC)

Variable	Process	Location	Sowing year	Treatment	RRMSE (%)	EF	CRM	CD	Slope	Intercept *	R^2
AGB	Calibration	S. Angelo	1989	optimal N	30	0.57	0.21	1.26	0.92	-1.28	0.80
			1990		9	0.98	-0.06	0.89	0.93	0.97	0.99
			2001		15	0.96	0.10	0.87	0.91	-0.15	0.98
	Validation	S. Angelo	1986	0 kg N ha^{-1}	32	0.49	0.28	0.79	0.93	-0.56	0.87
				140 kg N ha^{-1}	26	0.59	0.20	0.84	1.09	-2.68	0.85
				210 kg N ha^{-1}	24	0.62	0.22	1.00	1.09	-2.20	0.95
			1987	0 kg N ha^{-1}	26	0.69	0.23	0.91	0.61	1.76	0.96
				140 kg N ha^{-1}	22	0.75	0.22	1.21	0.76	0.84	0.98
				210 kg N ha^{-1}	19	0.83	0.17	1.31	0.81	-0.38	0.97
		Lodi	1996	optimal N	17	0.69	-0.12	0.87	0.93	-0.56	0.84
PNC	Calibration	S. Angelo	1989	optimal N	10	0.95	-0.03	0.86	0.90	0.00	0.96
			1990		10	0.95	-0.05	0.82	0.88	0.00	0.97
	Validation	S. Angelo	1986	0 kg N ha^{-1}	27	0.17	-0.21	2.11	0.58	0.85	0.66
				140 kg N ha^{-1}	8	0.86	-0.01	1.42	0.94	0.08	0.92
				210 kg N ha^{-1}	6	0.91	-0.01	0.84	0.88	0.26	0.92
			1987	0 kg N ha^{-1}	40	-7.67	-0.28	11.63	1.97	-0.92	0.54
				140 kg N ha^{-1}	26	0.32	-0.11	3.09	1.89	-1.70	0.98
				210 kg N ha^{-1}	25	0.56	-0.17	2.25	1.53	-0.75	0.96
		Lodi	1996	optimal N	16	0.70	-0.02	0.42	0.46	0.94	0.98

* : t AGB ha^{-1} for aboveground biomass; % for plant nitrogen concentration


a
25
20
15
10
5
0
Aboveground biomass
(tAGB ha-1)
04/03/90
26/03/90
17/04/90
09/05/90
31/05/90
22/06/90
Date
simulated
measured


b
25
20
15
10
5
0
Aboveground biomass
(t AGB ha-1)
17/03/91
11/04/91
06/05/91
31/05/91
25/06/91
20/07/91
Date
simulated
measured

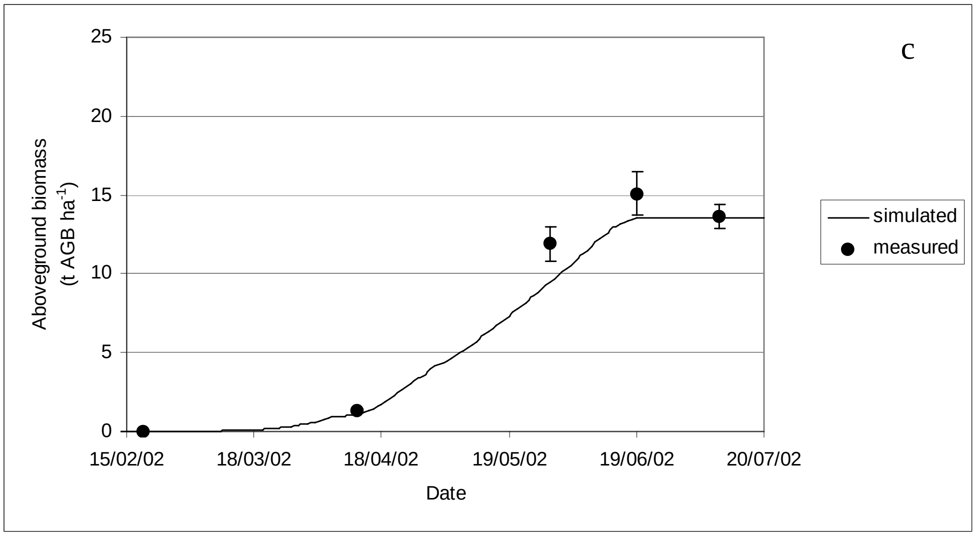
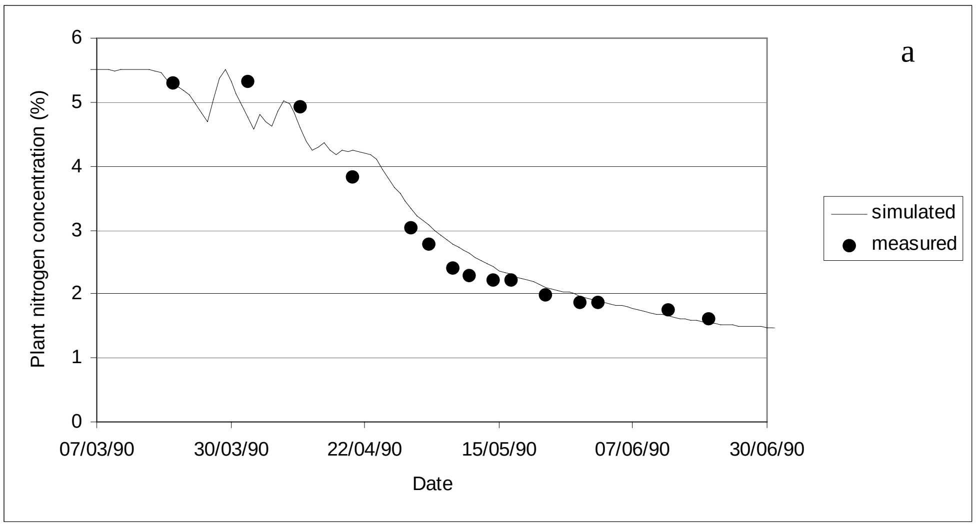


Figure 2. Measured and simulated AGB values after calibration; (a) S. Angelo Lodigiano – 1989-90; (b) S. Angelo Lodigiano – 1990-91; (c) S. Angelo Lodigiano – 2001-02. The vertical bars indicate the standard deviation of measured data

Figure 3 and table 3 show the good agreement between measured and simulated PNC values: RRMSE is low and EF, CD and the slope of the linear regression are close to one. With the purpose of evaluating the goodness of these simulations for calculating N budgets estimates, we reported in table 4 the agreement between measured and simulated values of UPTK (kg N ha^{-1}). The errors in the simulation of AGB and PNC are in general not compensating each other, yielding similar or higher errors for the simulation of UPTK. This is particularly true for the first data set (1989-90), where the underestimation of AGB is not compensated by an overestimation of PNC.

Table 4. Indices of agreement between observed and simulated values of aboveground plant nitrogen uptake

Process	Location	Sowing year	Treatment	RRMSE (%)	EF	CRM	CD	Slope	Intercept (kg N ha^{-1})	R^2
Calibration	S. Angelo	1989	optimal N	28	-0.29	0.25	2.14	0.92	-38.65	0.74
		1990		8	0.95	-0.07	1.13	1.04	4.75	0.97
Validation	S. Angelo	1986	0 kg N ha^{-1}	10	0.75	0.08	1.02	0.62	37.00	0.94
			140 kg N ha^{-1}	20	0.52	0.17	0.84	0.69	26.91	0.90
			210 kg N ha^{-1}	13	0.79	0.09	0.69	0.79	33.08	0.94
		1987	0 kg N ha^{-1}	23	0.72	0.03	0.26	0.53	52.55	0.94
			140 kg N ha^{-1}	20	0.54	0.20	1.36	0.72	4.22	0.99
			210 kg N ha^{-1}	24	0.40	0.22	1.50	0.95	-35.28	0.91
	Lodi	1996	optimal N	9	0.19	0.02	0.28	0.32	66.67	0.25



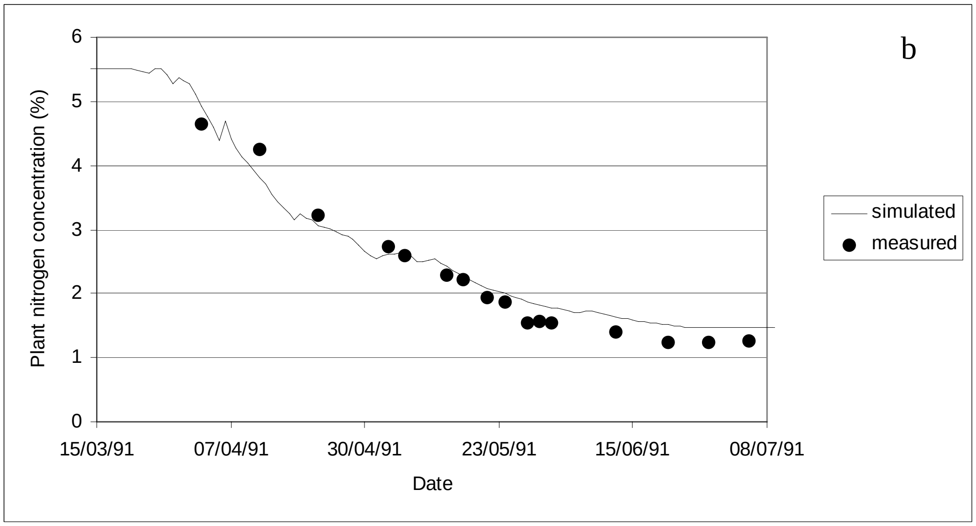


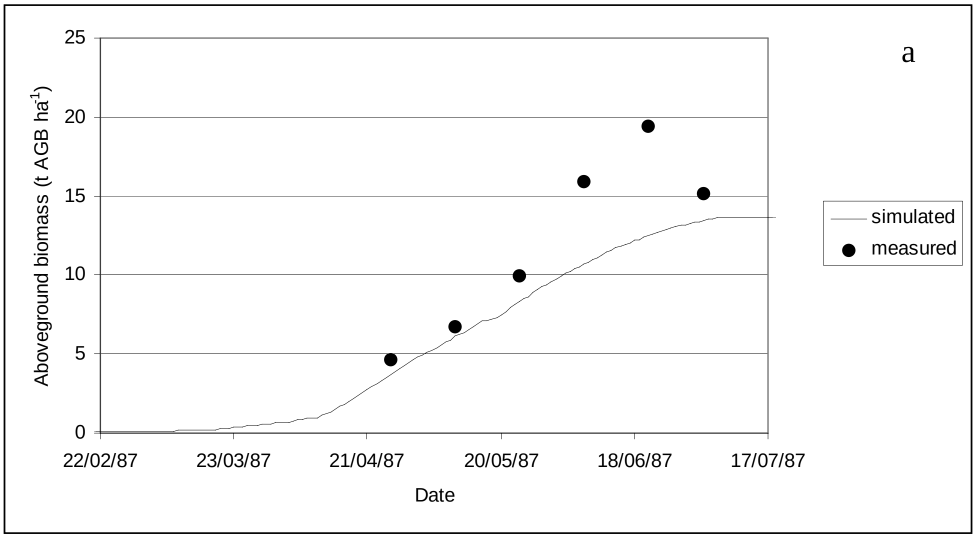
Figure 3. Measured and simulated PNC values after calibration; (a) S. Angelo Lodigiano 1989-90; (b) S. Angelo Lodigiano 1990-91

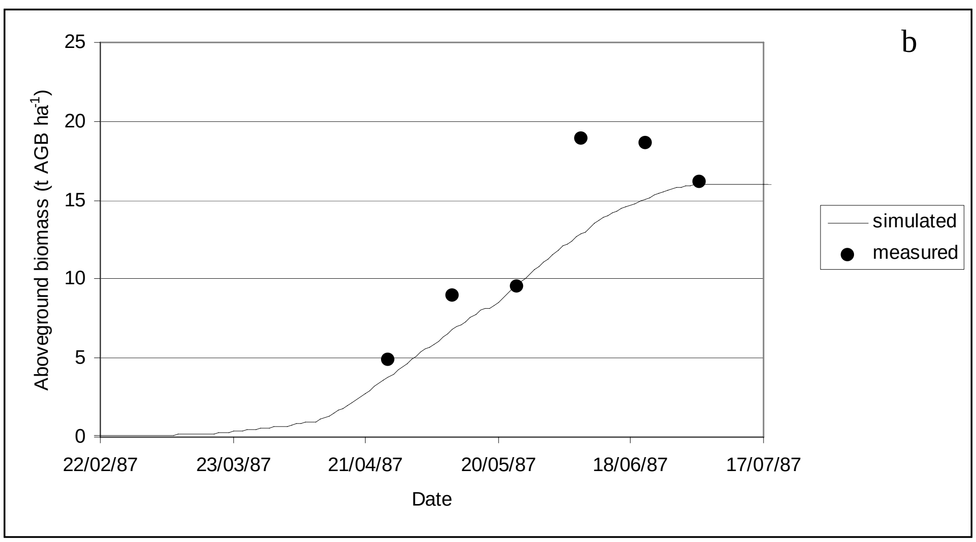
5.4.2. Validation of crop model parameters

The agreement between measured and simulated values of AGB is shown in figures from 4 to 6 and in table 3. The validation has confirmed the applicability of our parameter set. Several fitting indices are close to their optimum values (EF always abundantly positive, R^2 always close to one), even if there is a systematic underestimation, evident for the crop sown in 1986; in particular, the model is substantially underestimating crop growth rates in spring (linear phase of growth).

Figures from 7 to 9 and table 3 show the agreement between measured and simulated values of PNC. With the exception of the unfertilized treatment of S. Angelo Lodigiano – 1987-88 (RRMSE = 40 %, CD = 11.63), the model has reproduced the trend of measured data (CD ranging from 0.42 to 2.11) with a discrete approximation of the absolute values (RRMSE between 6 and 27 %). The indices of agreement between measured and simulated values of UPTK are shown in table 4: the simulations of UPTK are in most cases acceptable (RRMSE between 9 and 24 %, EF between 0.19 and 0.79, CRM always positive but never exceeding 0.22, CD between

0.28 and 1.50). A compensation effect (opposite errors in the simulation of AGB and PNC partially improve the simulations of UPTK) can be observed for S. Angelo Lodigiano 1986-87 (unfertilized treatment), S. Angelo Lodigiano 1987-88 (all treatments) and Lodi 1996-97.





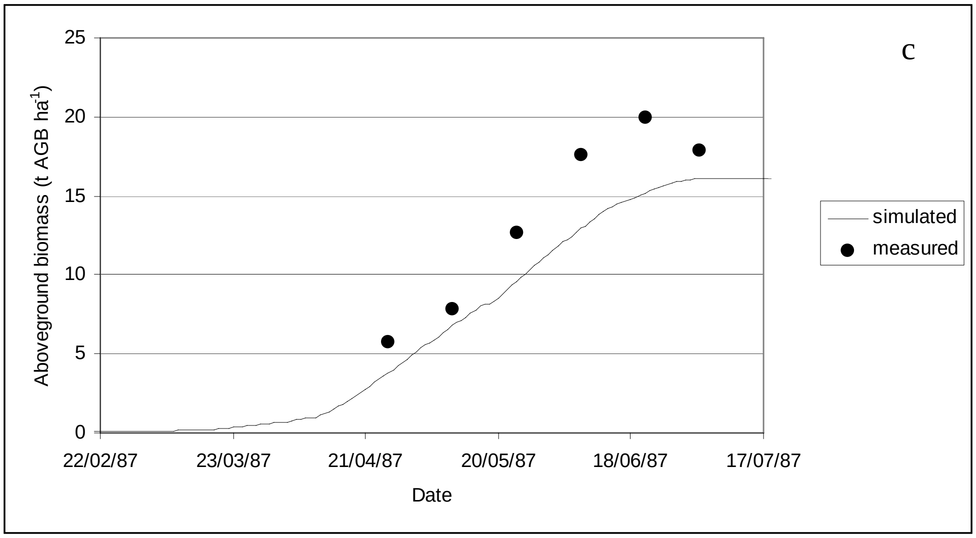
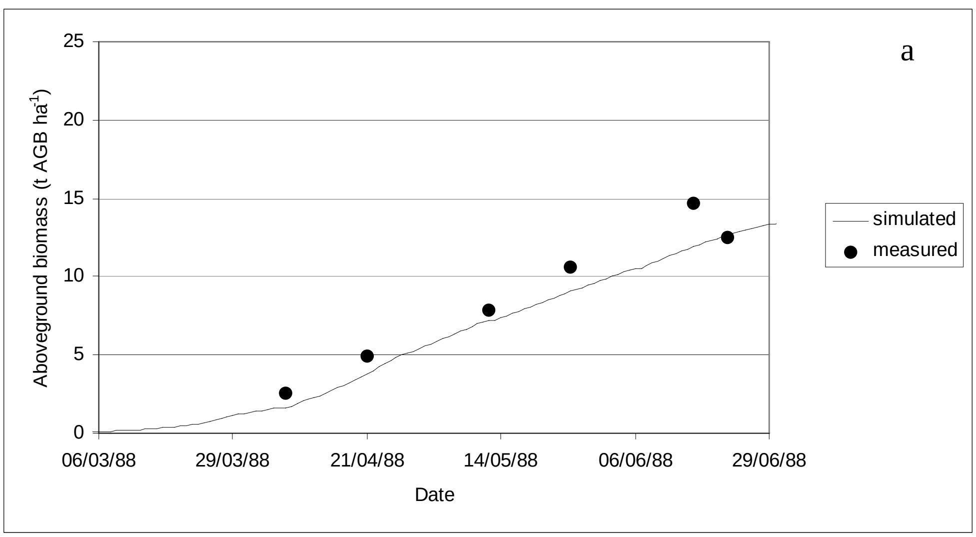
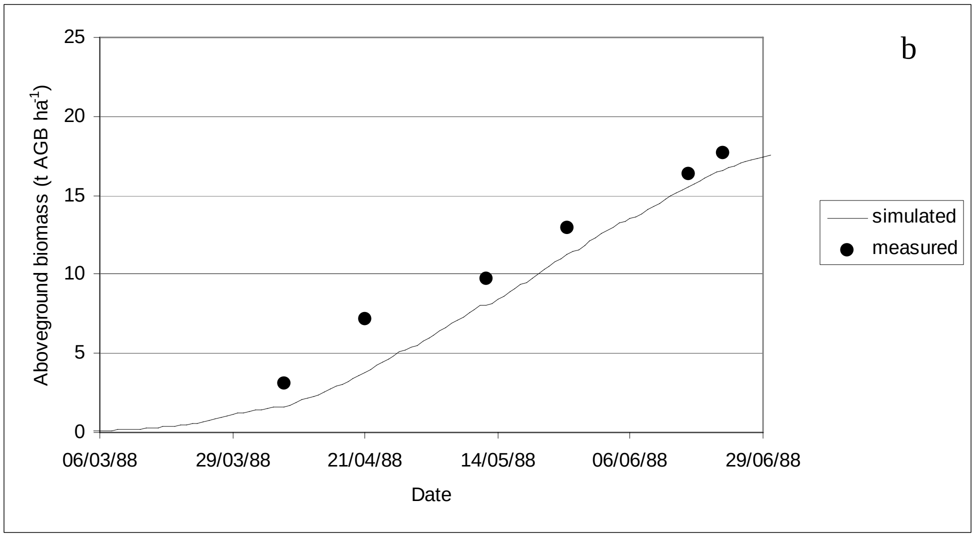


Figure 4. Measured and simulated AGB values after validation; S. Angelo Lodigiano – 1986-87; (a) nitrogen fertilization: 0 kg N ha^{-1}; (b) nitrogen fertilization: 140 kg N ha^{-1}; (c) nitrogen fertilization: 210 kg N ha^{-1}





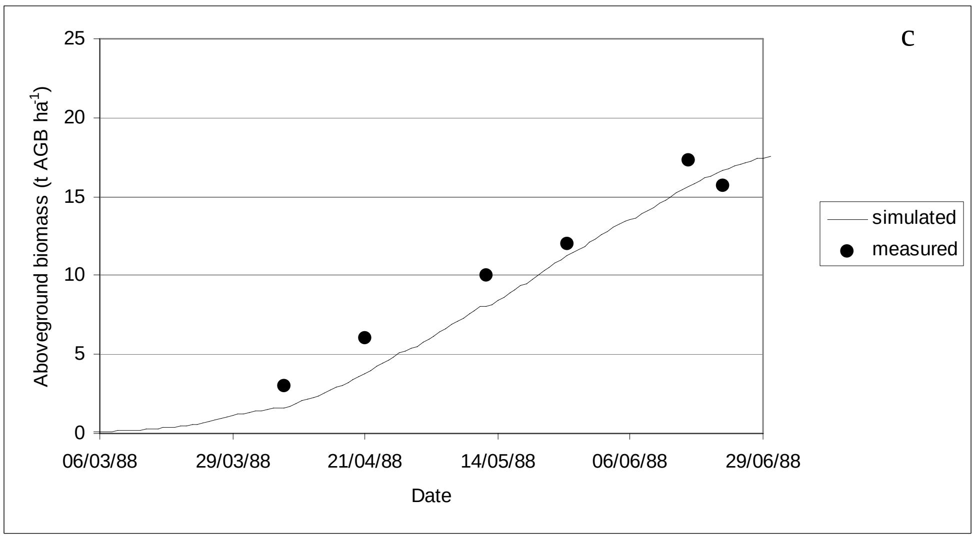


Figure 5. Measured and simulated AGB values after validation; S. Angelo Lodigiano – 1987-88; (a) nitrogen fertilization: 0 kg N ha^{-1}; (b) nitrogen fertilization: 140 kg N ha^{-1}; (c) nitrogen fertilization: 210 kg N ha^{-1}

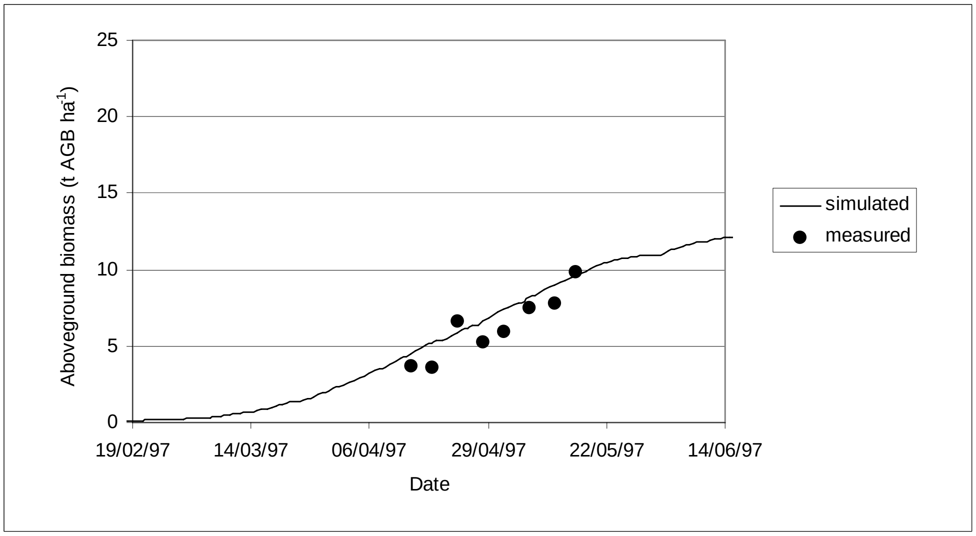
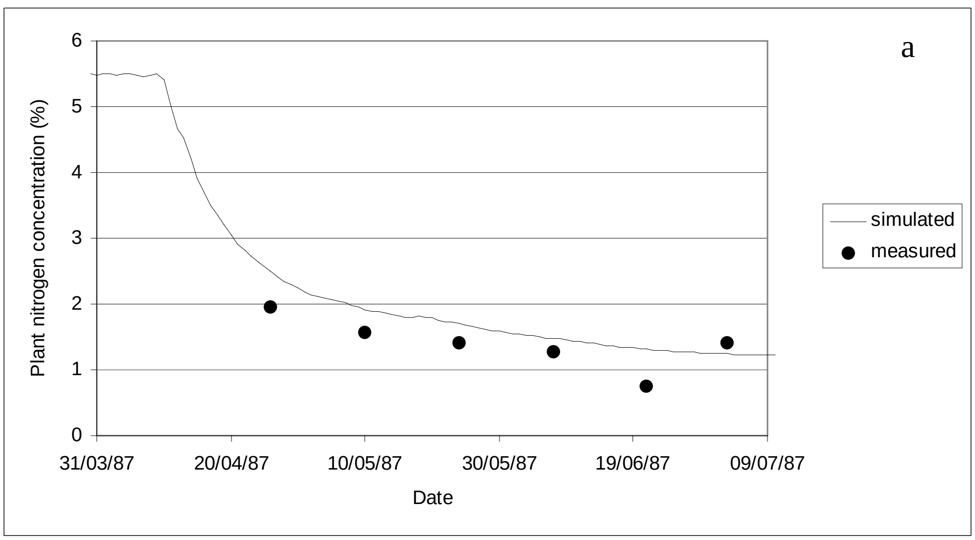
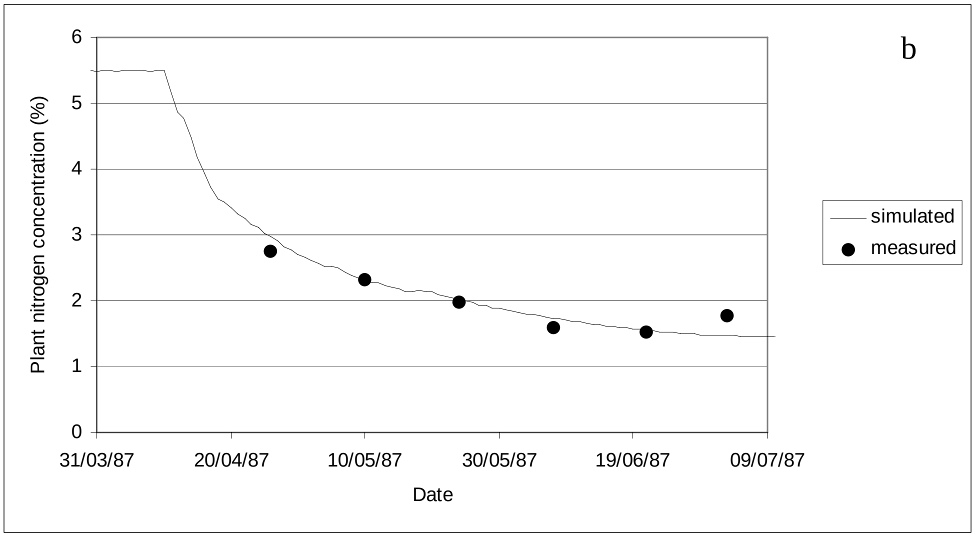


Figure 6. Measured and simulated AGB values after validation; Lodi – 1996-97





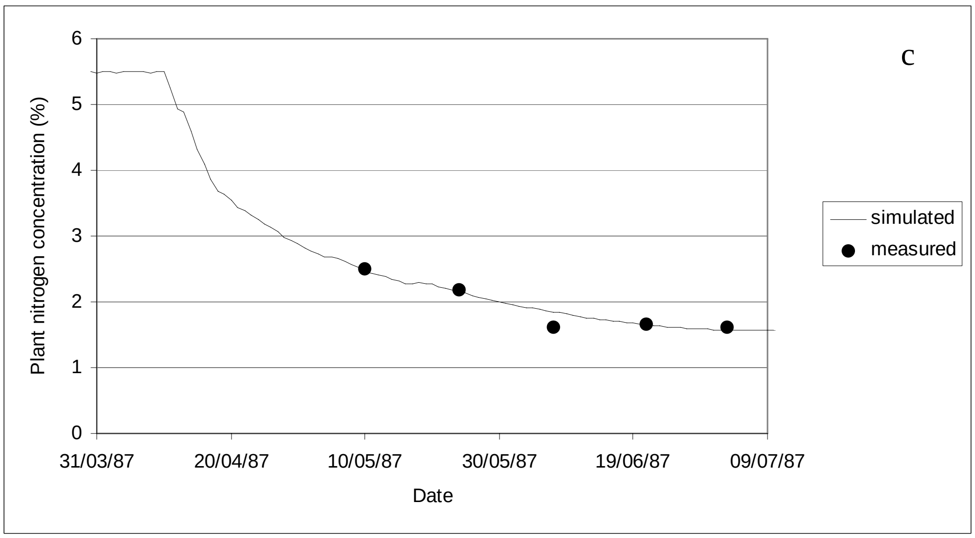
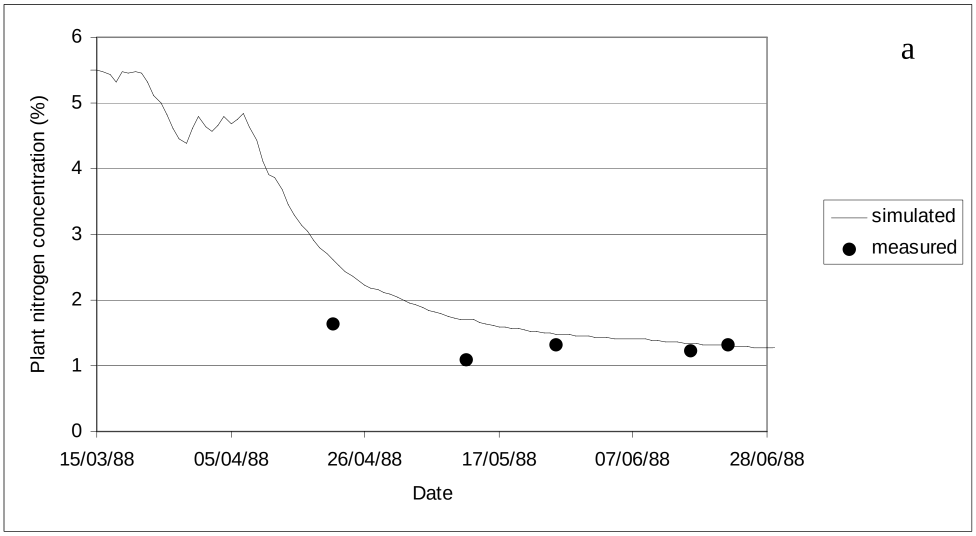
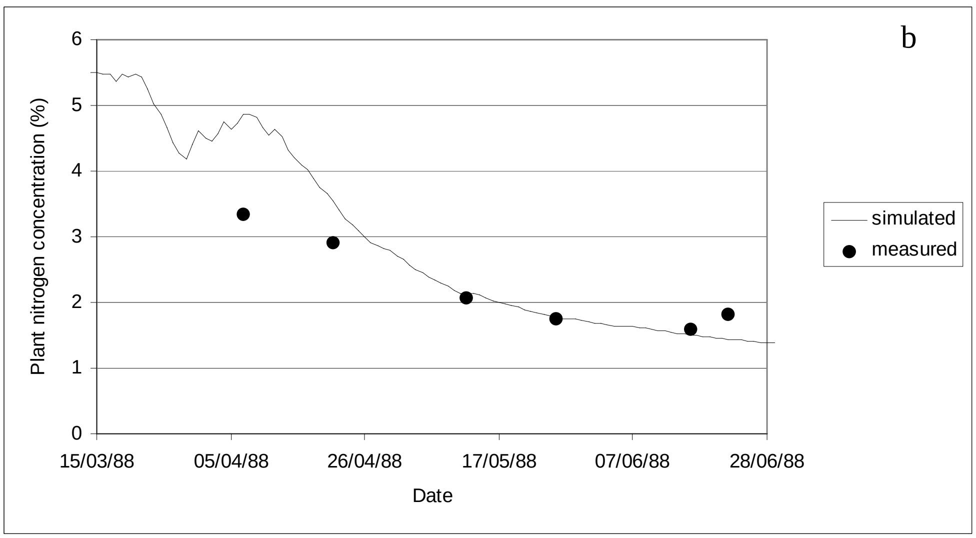


Figure 7. Measured and simulated PNC values after validation. S. Angelo Lodigiano 1986-87: (a) 0 kg N ha^{-1}; (b) 140 kg N ha^{-1}; (c) 210 kg N ha^{-1}



a
Plant nitrogen concentration (%)
6
5
4
3
2
1
0
15/03/88
05/04/88
26/04/88
17/05/88
07/06/88
28/06/88
Date
simulated
measured



b
Plant nitrogen concentration (%)
6
5
4
3
2
1
0
15/03/88
05/04/88
26/04/88
17/05/88
07/06/88
28/06/88
Date
simulated
measured

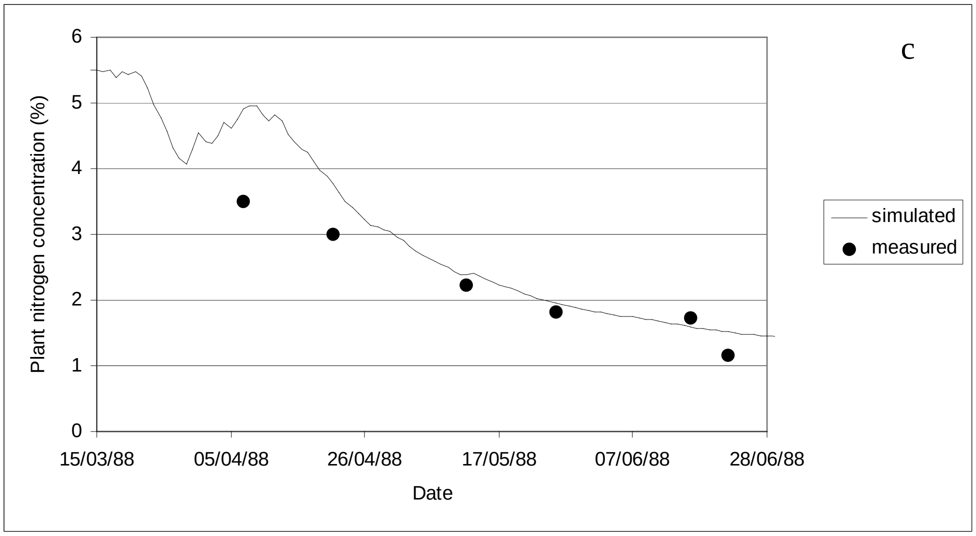


Figure 8. Measured and simulated PNC values after validation. S. Angelo Lodigiano 1987-88: (a) 0 kg N ha^{-1}; (b) 140 kg N ha^{-1}; (c) 210 kg N ha^{-1}

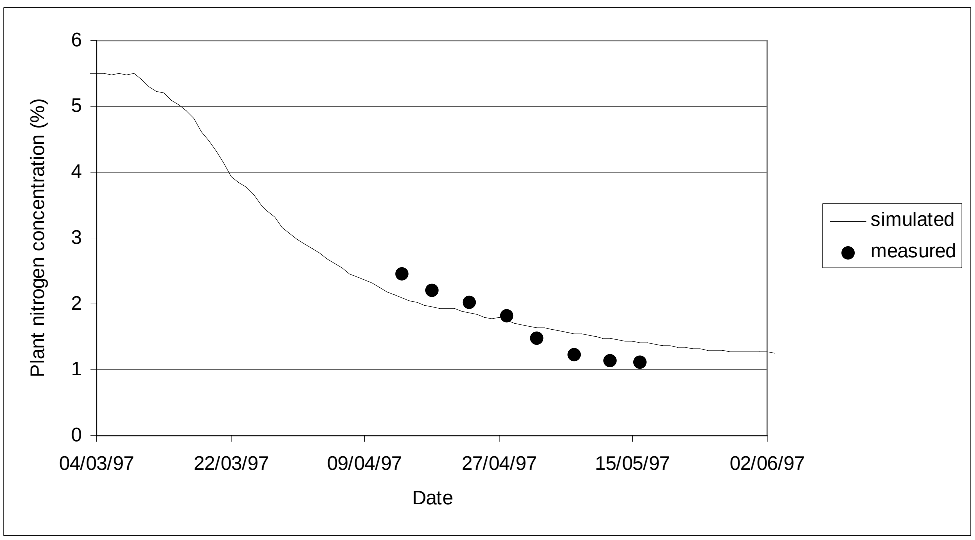


Figure 9. Measured and simulated PNC values after validation. Lodi 1996-97

Finally, although CropSyst uses a single equation of N dilution for all herbaceous crops (i.e. the b parameter of N_{max}, N_{crit} and N_{min} equations is not user – defined and is by default set to 0.4), other Authors found different values for the parameter b of the N_{crit} equation. Bechini et al. (2001) found a value of 0.76 for Italian ryegrass, while Tei et al. (2001) found for tomato a lower value (0.327). Therefore, although the value used by CropSyst is very similar to the one proposed by Justes et al. (1994) for wheat and to the values proposed by other Authors for other crops (e.g. 0.37 for maize, Plénet and Lemaire, 1999), a possible improvement of CropSyst is to give the user the possibility to change this parameter.

5.4.3. Model adequacy for scenario simulations

Model performance was not always satisfactory, and therefore this crop parameter set can not be used already for applications requiring very good simulation accuracy. However, when used for comparing scenarios, the model is required to reproduce the ranking of real values and to correctly simulate simple and synthetic variables across a range of simulations. For this purpose, we evaluated the overall model performance by calculating the indices of agreement between measured and simulated values of AGB and UPTK only for last sampling date: this information describes the goodness of the results when yearly or seasonal budgets are compiled with the model (biomass produced, cumulative N uptake). The results are shown in table 5; they can be considered satisfactory because RRMSE is lower than 20%, the efficiency is positive, the CD and slope of the regression equation close to 1, and R^2 higher than 0.71. We also calculated the Spearman correlation coefficient (data not normally distributed) between measured and simulated values on a merged set of all our data (across years, locations and treatments); this was carried out for AGB, PNC and UPTK. We obtained values of, respectively, 0.94, 0.97 and 0.89, all highly significant (n=71; $P<0.001$).

These results show that this crop parameter set can be already used for scenario simulations in the study area because seasonal outputs (total biomass produced at harvest, cumulative N uptake) are simulated with sufficient accuracy and because the ranking of measured and simulated values is approximately the same.

Table 5. Indices of agreement between observed and simulated values of aboveground biomass and aboveground plant nitrogen uptake for the last sampling date of each data set

Variable	RRMSE (%)	EF	CRM	CD	Slope	Intercept *	R^2
AGB	7	0.73	0.03	0.75	0.74	3.51	0.79
UPTK	20	0.48	0.13	1.06	0.77	22.88	0.71

* : t AGB ha^{-1} for aboveground biomass; kg AGB ha^{-1} for plant nitrogen concentration

5.5. Conclusions

The cropping systems simulation model CropSyst could be satisfactorily parameterized for winter wheat by using existing experimental data collected for purposes other than modelling and the wide range of available literature. The set of crop parameters allowed to obtain discrete estimates of aboveground biomass, plant nitrogen concentration and plant nitrogen uptake at different times during spring crop growth, for various locations/years/treatments in northern Italy. The simulated values were characterized by different estimation errors (in the range 6 - 40%). A systematic underestimation of aboveground biomass could not be corrected, otherwise unacceptable model inputs would have been obtained. Ranking of model results was similar to that of measured values; in particular, crop response to model inputs (radiation, temperature, N fertilizer application) was properly simulated.

This suggests that the proposed set of crop parameters, even if improvable, can be already used for scenario simulations in the study area (northern Italy). Also, this work shows how the increasing need of realistic model parameters can be partly satisfied by properly combining work on separate simulation modules, existing data sets collected during traditional agronomic experiments and extensive literature review.

EVALUATION OF CROPSYST FOR FLOODED RICE SIMULATION AND NITROGEN BALANCE IN NORTH ITALY

R. Confalonieri, S. Bocchi, T. Maggiore

Submitted to: European Journal of Agronomy (2003)

6.1. Abstract

Rice represents the staple food for more than half of the world's population and an increase in yield will be required in the next years, mainly through a better management of water and nitrogen. Simulation models are useful tools to study the interactions between crops, pedo-climatic conditions and agro-techniques and for this reason several simulating approaches have been developed in the last years. CropSyst model presents peculiar characteristics (e.g. reduced crop parameters set, capability of simulating potentially all the herbaceous crops with the same approach, possibility of simulating rotations) which make this model particularly useful for working at farm and regional scale for evaluating the effects of different management practices both on crop growth and on the environment. Although it has been already used for many herbaceous crops, CropSyst has not yet been parameterized for rice (*Oryza sativa* L.). In this work, CropSyst crop parameters were calibrated and validated for the simulation of the behavior of three groups of varieties (Japonica early, Japonica medium-late and Indica) by using data collected in different locations of northern Italy between 1989 and 2002. Moreover, it has been tested for the simulation of soil nitrogen concentration under flooded conditions, by using measured data of crop nitrogen uptake, water infiltration rate and soil N-NH4 and N-NO3 concentrations, gathered during 2002 growing season at two experimental sites.

The average relative root mean squared error (RRMSE) between measured and simulated values of aboveground biomass after the calibration and after validation was 20 and 22%. The model has simulated nitrification and denitrification rates similar to the ones found in literature for flooded soils and has reproduced with sufficient accuracy the soil nitrogen content during the season.

Keywords: *Oryza sativa* L., CropSyst, simulation model, flooded rice, nitrogen balance

6.2. Introduction

Rice represents the staple food for more than half of the world's population (Mae, 1997; Mahmood, 1998). In the last decade, the rate of increase in rice yields was less than the population growth rate in many developing countries (FAO, 1996). This is why, although total rice production has more than doubled since 1965, problems about food security still persist (Cassman et al., 1997). It's therefore crucial to increase rice production and this will be possible only through an increase in yield from rice-cultivated land because an expansion of irrigated area probably will not be realizable (Mae, 1997).

Although in modern agricultural systems (intensive: high yield and high impact) nitrogen is the most important element influencing potential yield (Nambiar and Ghosh, 1984; De Datta et al., 1988; Mae, 1997), irrigated rice systems are characterized by very low N fertilizer use efficiency (Cassman et al., 1998). Cassman et al. (1993) reported N fertilizer efficiencies ranging between 36 and 39% in two favorable irrigated rice domains (Philippines). Stutterheim et al. (1994) found lower values analyzing data from 35 experiments performed between 1981 and 1991 in many European countries. They calculated agronomic efficiencies ranging between 12 and 17%. Singh et al. (1999) reported values between 12 and 42% for different fertilizing levels. This is why nitrogen is most commonly the nutrient limiting rice yield throughout the rice-growing regions of the world (Reddy, 1982). The main losses which determine such low efficiency are from NH_3 volatilization and denitrification (Cassman et al., 1998) with losses ranging between 10 and 65% of the applied N (Vlek and Byrnes, 1986). Moreover, emission of greenhouse gases and groundwater contamination are direct consequences of this low efficiency.

It's necessary to analyze the agro-ecosystem in all its complexity to maximize profits and to minimize environmental impact (Confalonieri and Bechini, 2003). Dynamic simulation models are useful tools to successfully pursue this objective.

The first applications of simulation models for rice in Europe were carried out by adapting L1Q (Penning de Vries et al., 1989) to rice. This work led to RICAMO/L1Q, a simulation model of rice production (Bocchi, 1992; Bocchi et al., 1993; Bocchi et al., 1995). In the last years, several crop growth simulations models have been developed. It's possible to distinguish three major modeling groups (Bouman et al., 1996): (i) the USA one in the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project (Uehara and Tsuji, 1993) which produced the CERES-family models; (ii) the Australian group which is developing the APSIM (Agricultural Production system SIMulator) system (McCown et al., 1995); (iii) the group working in the Netherlands at Wageningen which has developed the family of model described by Van Ittersum et al. (2003).

The Wageningen models derive from the pioneering work of C.T. de Wit and co-workers in the 1960s and 1970s which led to the model BACROS (Penning de Vries and van Laar, 1982). This model has inspired several models, such as SUCROS, L1Q, WOFOST, MACROS and ORYZA. Bouman et al. (1996) and Van Ittersum et al. (2003) present a history of this family of models with brief descriptions of them. It's possible to find examples of the use of these models for rice simulation in literature (e.g. Aggarwal et al., 1997; Lansigan et al., 1997; Casanova et al., 2000; Bocchi et al., 2003). The Wageningen approach is very detailed in describing crop physiology. For example, it considers assimilates partitioning (into leaves, stems, panicles and roots), stem reserves, N concentration in different organs. Although this level of detail is useful to draw attention to gaps in understanding, to give a help in interpreting data from field experiments in different environments (Monteith, 1996) and to study processes at the level of plant components (Confalonieri e Bechini, 2003), it's known that the calibrating process became more complex as the number of parameters or, in general, the level of detail of a model increases (Stöckle, 1992; Monteith, 1996). This is particularly true when large-scale simulations are needed because of the elevated number of parameters required by the higher spatial variability. For example, the partition of assimilates influences leaves development and therefore light interception and thus intercepted light influences assimilation. A very small error in one of the rings of this chain, maybe due to a parameter not correctly calibrated, would became greater at every integration step. This is why many of these models are described in the literature but very few have been used to successfully solve management problems (Monteith, 1996).

Also the CERES-Rice model considers many processes with a similar level of detail (e.g. dry matter production and partitioning, root system dynamics, photosynthate partitioning). To estimate these detailed characteristics of growth it requires a detailed input data set and this may be an impediment for its extensive use (Mahmood, 1998). Moreover, CERES-Rice belongs to a family of model and each member of this family is able to simulate only the processes related to one crop. This may create some problems for cropping systems simulations. It’s possible to find examples of the use of CERES-Rice model in literature (e.g. Luo et al., 1997; Mahmood, 1998; Yun, 2003).

The APSIM model, a farming system simulator, is not currently able to simulate rice although it has been parameterized for different crops (Keating et al., 2003).

CropSyst (Stöckle and Nelson, 1999, Stöckle et al., 2003) is a process-based simulation model and we can consider it a management-oriented model. It uses the same approach to simulate the growth and development of potentially all herbaceous crops. To reach this aim, simplifications have been introduced to describe some process (e.g. monolayer canopy, constant specific leaf area (SLA), absence of daily assimilates partitioning). This makes CropSyst easier to be calibrated and a reduced set of crop parameters is needed. These aspects and the possibility of simulating rotations make CropSyst an useful tool for large scale simulations (Confalonieri and Bechini, 2003). Although it has already been applied to several crops and cropping systems (Stöckle et al., 1994; Pala et al., 1996; Donatelli et al., 1997; Stöckle and Debaeke, 1997; Giardini et al., 1998; Pannkuk et al., 1998; Confalonieri and Bechini, 2003), it’s not possible to find in literature a calibrated rice parameters set or information about the technical adequacy of CropSyst for rice simulations.

In Europe more than 140 rice cultivars are grown. This is due to the high pedo-climatic and cultural heterogeneity which characterizes our continent. It's possible to distinguish two main group of varieties: Japonica and Indica types. The first one refers to some old varieties, selected before the second World War and to more recent ones, selected between the 1970s and the 1990s, usually lower (semi-dwarf) and high yielding. The second group of varieties spread out in Europe mainly in the 1990s and it's characterized by slender grains required by North European market. The main part of the recent Japonica type varieties consists of medium and medium-late cultivars (the cycle is longer than 150 days), while few others are early varieties particularly useful when false sowing is needed because of red rice infestation.

Therefore, the objectives of this work were:

- to calibrate and test CropSyst for Indica type varieties, Japonica type early varieties, Japonica type medium-late varieties;
- to test CropSyst in simulating soil nitrogen balance in flooded conditions.

6.3. Materials and methods

6.3.1. Experimental data

Experimental data were collected in 5 experiments carried out between 1989 and 2002 in northern Italy. The climate of all the experimental areas belongs to the mesoclimate of the Po Valley, characterized by a discrete level of continentality, mitigated by the relative closeness of the Mediterranean. The mean annual temperature is about 13°C; the absolute minimum is attained between January and February and the absolute maximum between July and August. Total precipitation (about 800 mm year^{-1}) is relatively well distributed (about 75 rainy days per year). Average wind speed is about 1.5 m s^{-1}.

The first experiment was carried out conduced in the provinces of Milano (Gudo Visconti, latitude 45° 22’ N, longitude 9° 0’ E) and Vercelli (latitude 45° 19’ N, longitude 8° 25’ E) during 1989 and 1990. The soils are sandy loam, are subacid with a low organic matter content, high available phosphorous and low potassium content. Daily meteorological data (rainfall, maximum and minimum air temperatures, global solar radiation and albedo) were measured with automatic weather stations installed near the experimental fields. Three varieties (Japonica type) with different cycles (Loto [early], Cripto [medium-late] and Europa [late]) were grown (600 seeds m^{-2}) in a completely randomized block design with four replications. The elementary plot size was 50 m^2 and the system was maintained at Production Level 1 (PL1; de Wit and Penning de Vries, 1982). Aboveground biomass (AGB) and leaf area index (LAI, measured only at Gudo Visconti) were measured on 5 plants from each plot (Yoshida et al., 1976) every 10-15 days. The AGB was determined by storing the samples in oven at 60 °C until constant weight, and will be always expressed as dry matter in this text. Phenological phases (emergence, flowering and maturity) were determined (observed on at least 50% of the population).

The second experiment was conduced in province of Pavia (Castello d’Agogna, latitude 45° 14’ N, longitude 8° 41’ E) at the Rice Research Centre (ENR) in 1994 and 1995. The soil is silty clay, tendentially acid with sufficient organic matter, low C/N, has medium-low cation exchange capacity (CEC) and with medium nutrients availability. Daily meteorological data (rainfall, maximum and minimum air temperature and global solar radiation) were measured near the field with an automatic meteorological station. Six varieties (Thaibonnet [medium-late], Loto [early], Cripto [medium-late], Carnaroli [medium-late], Ariete [medium-late] and M203 [medium-late]; Indica type the first, Japonica the others) were grown (650 seeds m^{-2}) in a completely randomized block design with four replications. The size of the resulting 24 elementary plots was 25 m^2. Fertilizers and weed control strategies allowed to maintain the system at PL1. AGB was measured every 14 days starting from 1 month after sowing and every 7 days after flowering. The sample size was 1 linear meter and AGB was determined by storing samples in oven at 105 °C until constant weight. Emergence, flowering and maturity phenological phases were determined.

The third experiment was conduced in 1996 in two localities in province of Pavia (latitude and longitude are the same of the second experiment): at the Rice Research Centre of Castello d'Agogna (ENR) and at Mortara. The soil of the first locality is very similar to the one described for the second experiment. The soil of the second locality is sandy-loam, subacid, with sufficient organic matter content, medium-low CEC and medium nutrients availability. Daily meteorological data were measured as already described for the second experiment. Two Japonica type varieties (Loto [early] and Drago [medium-late]) were grown (530 seeds m^{-2}) under 3 levels of nitrogen (N) fertilizer (urea; 60, 120 and 180 kgN ha^{-1}), distributed in 1, 2 or 3 events. The experimental design was a split-split-plot (3 replications) with the first factor (variety) in the plot, the second one (N level) in the split-plot and the third one (fertilizing events) in the split-split-plot. The elementary plot size was 25 m^2 for the first locality and 18 m^2 for the second one. The measured variables were: AGB, plant nitrogen content (PNC), soil nitrogen content (SNC, N-NO3 and N-NH4). Six samplings were conduced during the crop cycle for each variable. AGB was determined by storing an half linear meter in oven at 70 °C until constant weight. PNC was determined with a calibrated automatic NIR analyzer while for the SNC a continuous-flow automatic analyzer was used. Emergence, flowering and maturity phase have been determined.

The fourth experiment was conduced during 1999 and 2000 in province of Pavia (Velezzo Lomellina, latitude 45° 9' N, longitude 8° 44' E). The soil is sandy loam, is acid, with a sufficient organic matter content, a low CEC, sufficient available phosphorous and potassium content. Daily meteorological data (rainfal, maximum and minimum air temperatures, global solar radiation) were measured near the field. The Indica type variety Thaibonnet was grown (850 seeds m^{-2}) to compare the effects of two different kind of N fertilizers (urea and calcium cyanamide). Four levels of each fertilizer were applied (0, 40, 80 and 120 kgN ha^{-1}), distributed in 1 or 2 times. The experimental factors (N fertilizer, fertilizing events) were arranged in a completely randomized block design with 3 replications. The size of the 60 elementary plot was 36 m^2 (4 m × 9 m). At the phenological phase of 4°-5° leaf the field was flooded. The measured variables were: AGB and PNC (6 sampling events). The AGB was measured on a 20 plants per plot sample by storing the samples in oven at 70 °C until constant weight. PNC was measured with an elementary analyzer while SNC was measured with a continuous-flow automatic analyzer.

The fifth experiment was conduced in two localities in province of Milan: Vignate (latitude 45° 29' N, longitude 9° 22' E) and Opera (latitude 45° 22' N, longitude 9° 12' E) in 2002. The soil of the first locality is silty loam and has a high potassium contents. The soil of the second locality is loam, and has a medium potassium content. Both the soils are subacid, have a medium organic matter content and have a high phosphorous content. Daily temperature data for the first locality were measured with a floating hand made weather station, able to float in very shallow water bodies with a structure studied in order to keep the canopy near the sensors undisturbed (Confalonieri et al., 2002). The floating station carries thermometers at different high from water surface, at 1 cm below it and at the soil-water interface. Relative humidity, wind speed and rainfall have been measured with a commercial weather station while solar radiation has been estimated using the algorithm proposed by Donatelli and Campbell (1998). An automatic water level recorder was used (Confalonieri, 2003). Daily meteorological data (maximum and minimum air temperature, solar radiation and albedo) for the second locality were measured with a standard meteorological station installed near the field. During this experiment, explicitly conduced to study nitrogen balance in paddy rice fields, two Indica type varieties were grown (Sillaro in the first locality, 850 seeds m^{-2}; Thaibonnet in the second one, 650 seeds m^{-2}). Three levels of N fertilizer was distributed in both the localities, using a completely randomized block design with 3 replicates. The size of the elementary plot was 42 m^2 for the first location and 30 m^2 for the second one. For the first locality the three fertilizer levels corresponded to 0, 70 and 150 kgN ha^{-1} (three fertilizing events: one pre-seeding and two topdressed) while for the second one the three levels (thesis 0, thesis 1 and thesis 2) corresponded to 0, 50 and 110 kgN ha^{-1} (two topdress fertilization events). The second field received less N because it presented a high SNC due to an organic fertilization (liquid manure) received some months before the sowing. The measured variables were: AGB, LAI, SLA, PNC and SNC (N-NO3 and N-NH4). Six samplings have been carried out for AGB and PNC, four for SLA and three for LAI. AGB was measured by storing samples in oven at 60 °C until constant weight; LAI by measuring the area of leaves and stems with a software for graphical elaborations and SLA by dividing leaves area by leaves weight. These variables were measured on a 20-plants per plot sample (two 10-plants sub-samples per plot). SNC was determined on an aggregated sample (two sub-samples per plot). SNCs were measured for the soil layer 0.00-0.10 m with a continuous-flow analyzer. Bulk density (BD), saturated hydraulic conductivity (K_{sat}) and phenological phases (emergence, flowering and maturity) were determined.

For all the experiments the harvest index (HI) was determined and the chemical and physical soil analysis at the beginning of the experiments were conduced.

6.3.2. Simulation model

CropSyst (Stöckle et al., 1994; Stöckle and Nelson, 1999; Stöckle et al., 2003) is a process-based, multi-year, multi-crop, daily time step cropping system simulation model. The model simulates the soil water budget, soil-plant nitrogen budget, crop growth and development, residue production and decomposition, and soil erosion. The main model inputs are: daily weather data, dates and amounts of products applied for each fertilization and irrigation event, sowing date, hydraulic characteristics of the soil profile, crop parameters, initial conditions of the soil profile (crop residues, water content, mineral nitrogen and organic matter). The most important model outputs are aboveground biomass, leaf area index, root depth, soil water and nitrogen balance.

Crop development is simulated as a function of (i) thermal time accumulated between a base temperature (T_{base}) and a maximum temperature (T_{cutoff}), (ii) daylength and (iii) vernalization requirements. Crop growth is simulated for the whole canopy by calculating unstressed biomass growth based on potential transpiration and on crop intercepted PAR and by correcting with water and nitrogen limitations to simulate actual daily biomass accumulation. The potential transpiration-dependent biomass accumulation is calculated by using the following equation:

$$B_{PT} = \frac{BTR \times T_{act}}{VPD} \quad [1]$$

where: B_{PT} (kg m^{-2} day^{-1}) is the daily potential transpiration-dependent biomass production, BTR (kg m^{-2} kPa m^{-1}) is the AGB-transpiration coefficient, T_{act} (m day^{-1}) is the actual transpiration, VPD (kPa) is the daily mean vapor pressure deficit. Radiation-dependent growth is calculated as:

$$B_{Rad} = LtBC \times 0.5 \times Rad \times \left(1 - e^{-k \times LAI}\right) \times T_{\lim} \quad [2]$$

where: B_{Rad} (kg m^{-2} day^{-1}) is the daily radiation-dependent biomass production, LtBC (Light to Biomass Conversion; kg MJ^{-1}) is the ratio of aboveground biomass accumulated to intercepted PAR (radiation use efficiency), Rad (MJ m^{-2} day^{-1}) is the daily global solar radiation (with 0.5×Rad being an estimate for PAR), ($1-e^{-k \times LAI}$) is the fraction of PAR intercepted by the canopy, k is the radiation extinction coefficient for PAR, LAI is the Leaf Area Index, T_{lim} is a temperature-dependent limiting factor (0 if $T_a \leq T_{base}$; 1 if $T_a \geq T_{opt}$), with T_a = average air temperature and T_{opt} = optimum mean daily temperature for growth.

Model robustness is ensured by calculating daily leaf area growth as a function of daily accumulated biomass and not the other way round. LAI increase during the vegetative period is calculated as:

$$LAI = \frac{SLA \times B}{1 + SLP \times B} \qquad [3]$$

where: LAI (m^2 m^{-2}) is the LAI increase, B (kg m^{-2}) is accumulated AGB, SLA (m^2 kg^{-1}) is the ratio leaf area to leaf biomass (Specific Leaf Area for the early growth phase), SLP (Stem Leaf Partition coefficient: m^2 kg^{-1}) is an empirical partition coefficient controlling the fraction of biomass partitioned to leaves. Root depth is simulated as a function of leaf area development, and reaches its maximum when the plant flowers. Once potential growth is calculated (lower value between AGB productions calculated with equation [1] and [2]), N and water limitation are applied.

Soil water infiltration is simulated with a cascade approach or with the more complex finite difference solution of the Richard's equation. Potential evapotranspiration is estimated with the Penman-Monteith equation or, if air humidity and/or wind speed data are missing, with the Priestley-Taylor equation.

Nitrogen transformations in the soil (ammonification of organic matter nitrogen, nitrification, denitrification) are simulated by using first order kinetics. Influence of soil temperature and oxygen availability (function of degree of saturation) for chemical transformation are considered. Mineralization, nitrification and denitrification rate adjustments (MRA, NRA and DRA) are then applied to reproduce the behavior of different soil types. N transport in through the soil profile is simulated with a simple mass-balance approach.

6.3.3. Model parameterization and validation

CropSyst version 3.02.23 (January 8, 2002) was used. Potential evapotranspiration was calculated with the Priestley-Taylor equation. Soil water redistribution was simulated with the finite difference method.

For Vignate and Opera data sets, the K_{sat} (m day^{-1}) was estimated with a water level recorder with the procedure described in Confalonieri (2003) which considers actual ET and soil water infiltration. This procedure should be considered reliable with the high infiltration rates characteristic of north-

Italian paddy fields and, generally, of delayed-flooded fields (Confalonieri, 2003).

Three crop parameter sets have been calibrated and validated. The first, called Japonica-Early (JE), is referred to the Japonica type early varieties which are represented, in the available data sets, by the variety Loto. The second one (Japonica-Medium; JM) represents the Japonica type medium-late varieties; we have grouped in this family of varieties the cultivars Cripto, Ariete and Drago. The third group, called Indica (I), refers to the Indica type varieties Thaibonnet and Sillaro.

Table 1 – Data sets used for calibration and validation of crop parameters. D: phenological stage; C: calibration; V: validation

Experiment	Locality	Year	Group of varieties	Considered variables	Activity
1	Vercelli	1989	JM	AGB, D	C
1	Gudo Visconti	1990	JE	AGB, D, LAI	C
1	Gudo Visconti	1990	JM	AGB, D	V
1	Vercelli	1990	JE	AGB, D	C
1	Vercelli	1990	JM	AGB, D	V
2	Castello d'Agogna	1994	JM	AGB, D	V
2	Castello d'Agogna	1995	JE	AGB, D	V
2	Castello d'Agogna	1995	JM	AGB, D	C
3	Castello d'Agogna	1996	JE	AGB, D	V
3	Castello d'Agogna	1996	JM	AGB, D	C
3	Mortara	1996	JM	AGB, D	V
4	Velezzo Lomellina	1999	I	AGB, D	C
5	Vignate	2002	I	AGB, D, PNC, SNC, LAI	C
5	Opera	2002	I	AGB, D, PNC, SNC, LAI	V

Data sets used for calibration and validation of crop model parameters are shown in Table 1. A sensitivity analysis allowed us to select 4 parameters for calibration (SLA, SLP, Topt, leaf duration). The other crop model parameters were set to values found in literature or derived from local experience (Table 2). For the group of variety I, measured values of SLA were available. We have initialized the correspondent CropSyst parameter (Specific Leaf Area) by using the average of the values measured during the first part of the crop cycle (Stöckle, personal communication). For the calibration of the parameters involved with AGB accumulation, only data collected in non-limiting conditions for water and N were used. We have chosen to not use data from Gudo Visconti – 1989, Vercelli – 1989 (JE), Castello d'Agogna – 1994 (JE), Mortara – 1996 (JE) and Velezzo Lomellina

– 2000 because of problems occurred during the experiments. The experimental results for these data sets will be not discussed in this text. For the initialization of the parameters involved with PNC, data collected in Vignate and Opera – 2002 were used. For this experiment (the fifth one) the values of AGB measured for the 3 levels of fertilization are very similar although the values of PNC and SNC are significantly different. For this reason, we have initialized the parameters MNEG, maxNM and minNM and we have tested the model performances in simulating PNC by using data from all the three thesis.

Table 2 – Crop model parameters for rice and source of information (C: calibrated parameters; L: literature; E: local experience)

Parameter	Determination			Value			Units
	JE	JM	I	JE	JM	I	
Photosynthetic pathway		/			C3		/
Above ground biomass-transpiration coefficient (BTR)		D			5		kPa kg m^{-3}
Light to above ground biomass conversion (LTBC)		D			3		g MJ^{-1}
Actual to potential transpiration ratio that limits leaf area growtl		D			0.95		/
Actual to potential transpiration ratio that limits root growth		D			0.5		/
Optimum mean daily temperature for growth (Topt)		C		28	28	27	°C
Maximum water uptake		D			13		mm day^{-1}
Leaf water potential at the onset of stomatal closure		D			1200		J kg^{-1}
Wilting leaf water potential		D			1800		J kg^{-1}
Maximum rooting depth		E			0.3		m
Fraction of max. LAI at physiological maturity		E			0.5		/
Specific leaf area (SLA)	C	C	M	27.0	29.5	39.0	m^2 kg^{-1}
Stem/Leaf partition coefficient (SLP)		C		4.5	3.0	1.5	/
Leaf duration		C		700	850	950	C-days
Extinction coefficient for solar radiation (k)		D			0.5		/
ET crop coefficient at full canopy		D			1.05		/
Degree days Emergence		M		82	80	80	C-days
Degree days Peak LAI		M		800	950	893	C-days
Degree days Begin flowering		M		825	975	900	C-days
Degree days Begin grain filling		M		864	1020	952	C-days
Degree days Physiological maturity		M		1087	1500	1328	C-days
Base temperature (Tb)		E		12	11	12	°C
Cutoff temperature (Tc)		L			42		°C
Unstressed harvest index		M		0.6	0.48	0.48	/
Maximum N concentration during early growth	C	C	M	0.050	0.050	0.036	kgN $kgAGB^{-1}$
Maximum N concentration at maturity	C	C	M	0.012	0.012	0.008	kgN $kgAGB^{-1}$
Minimum N concentration at maturity		C			0.007		kgN $kgAGB^{-1}$

For the calibration and the test of the parameters involved with the simulation of SNC (MRA, NRA and DRA), data collected in Vignate and Opera during 2002 were used. Also in this case, the data from the three thesis of the fifth experiment were used. Data from the thesis 0 and 2 were used to calibrate MRA, NRA and DRA for the soils of both the localities and the ones from thesis 1 to test the calibrated parameters.

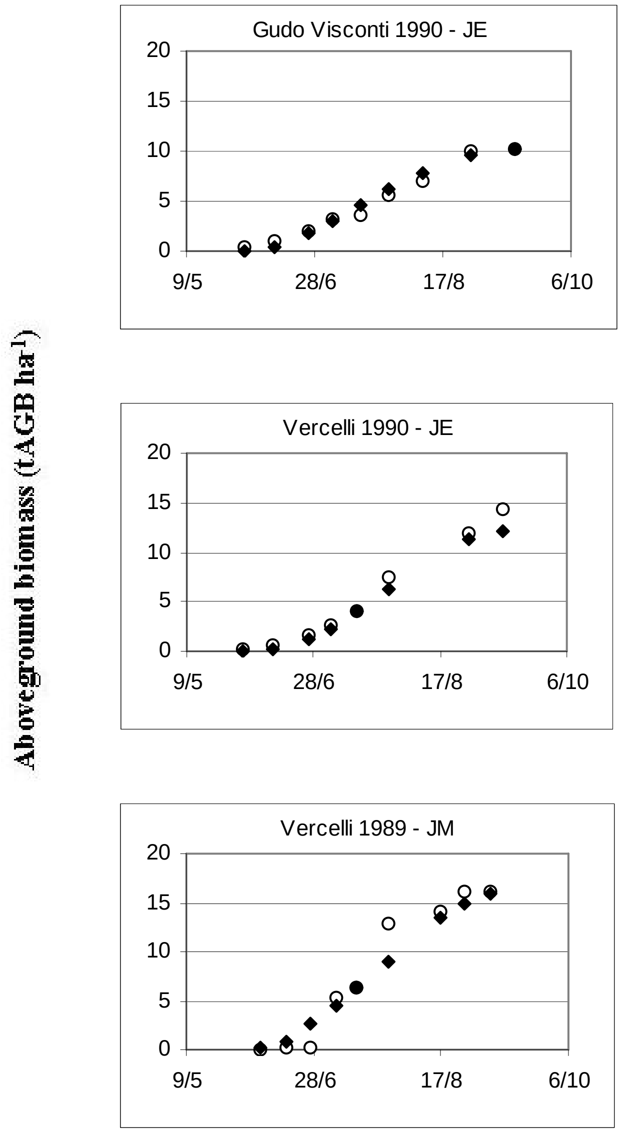
The agreement between observed and predicted values was expressed by using the indices proposed by Loague and Green (1991): the relative root mean squared error (RRMSE, minimum and optimum=0%), the coefficient of determination (CD, minimum=0, optimum=1, indicates whether the model reproduces the trend of measured values or not), the modelling efficiency (EF, $-\infty \div +\infty$, optimum=1, if positive, indicates that the model is a better predictor than the average of measured values), the coefficient of residual mass (CRM, 0-1, optimum=0, if positive indicates model underestimation) and the parameters of the linear regression equation between observed and predicted values.

6.4. Results and discussion

6.4.1. Experimental results

6.4.1.1. Crop growth and development

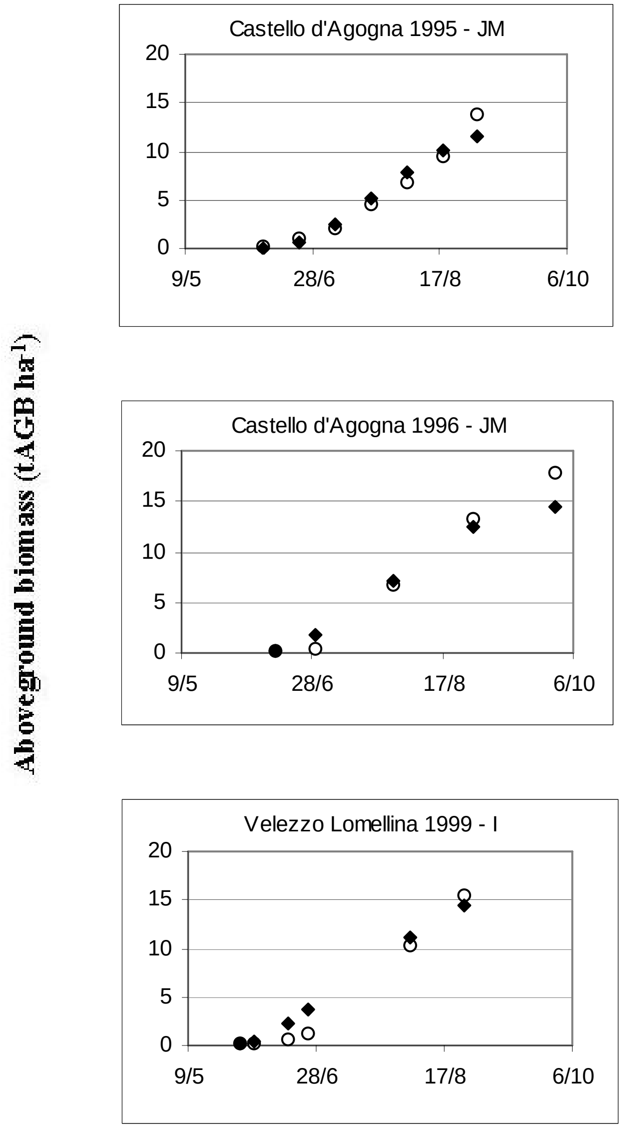
Data about AGB accumulation at production level 1 are shown in Figure 1 and 2. In general, with the variety Loto (JE), lower AGB values were reached, compared with the ones obtained with the other varieties for all the three years in which it was grown (1990, 1995 and 1996). Average AGB at maturity for Loto was 11.2 tAGB ha^{-1} while the JM and the I groups of varieties produced average AGB values of, respective, 14.6 tAGB ha^{-1} and 15.6 tAGB ha^{-1}. The medium-late varieties showed low productions during 1990 and 1994 while higher values were reached in 1989, 1995 and 1996. For the selected data set the value of HI for each variety was almost constant for all years and localities studied (0.6 for Loto and about 0.48 for the others varieties). Yields, for all the data sets, are comparable with what is usually observed in our region, with values ranging between 6.5 and 8.0 t ha^{-1}. For the fifth experiment N use efficiency was measured, obtaining values of 25% and 21% for Vignate and Opera. Although these values appear to be low, they are in agreement with what is usually reported in literature (Cassman et al., 1993; Stutterheim et al., 1994; Singh et al., 1999).



a

b

c


Aboveground biomass (tAGB ha-1)
Castello d'Agogna 1995 - JM
20
15
10
5
0
9/5
28/6
17/8
6/10
Castello d'Agogna 1996 - JM
20
15
10
5
0
9/5
28/6
17/8
6/10
Velezzo Lomellina 1999 - I
20
15
10
5
0
9/5
28/6
17/8
6/10

d

e

f

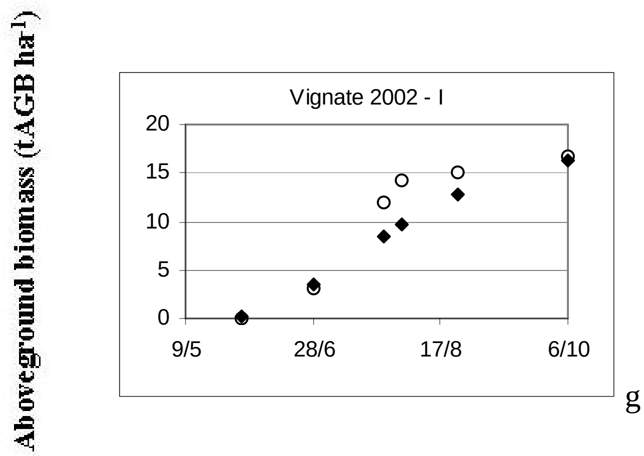


Figure 1 – Measured (o) and simulated (♦)AGB values. Calibration

6.4.1.2. Soil water infiltration and soil nitrogen content

During the fifth experiment, K_{sat}, was measured. For the first locality (Vignate) a value of 0.082 m day^{-1} was found. This value is high compared with the ones usually reported for north-Italian paddy fields because in this case the field was not puddled. For the second locality (Opera), the observed value of K_{sat} was 0.020 m day^{-1}. The value measured for Vignate is consistent with the one reported by Liu et al. (2001) for the same soil type while the same Author reports, for the Opera soil type, a value higher than the one we have observed, probably because the soil of the experiment was puddled. In fact, the relative difference between the value reported by Liu et al. (2001) for a loam soil and the value observed in the field of Opera (about 50%) is consistent with the relative difference between K_{sat} values measured for the same field in non-puddling and puddling conditions by other Authors (Bajpai and Tripathi, 2000; Kukal and Aggarwal, 2002).

BD (g cm^{-3}) was measured during the fifth experiment for both the localities (Figure 3). The first value measured in Vignate is very low compared with the others measured for the same field, probably because of the successive compression due to the flooding water hydrostatic pressure. The last values measured for both the fields are low compared with previous ones. A possible explanation is connected with the de-compressing effect of roots, above all in the soil layer 0.00 – 0.10 m.

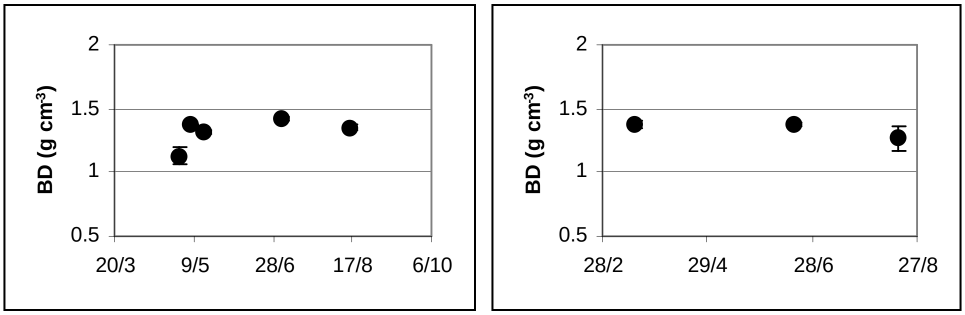
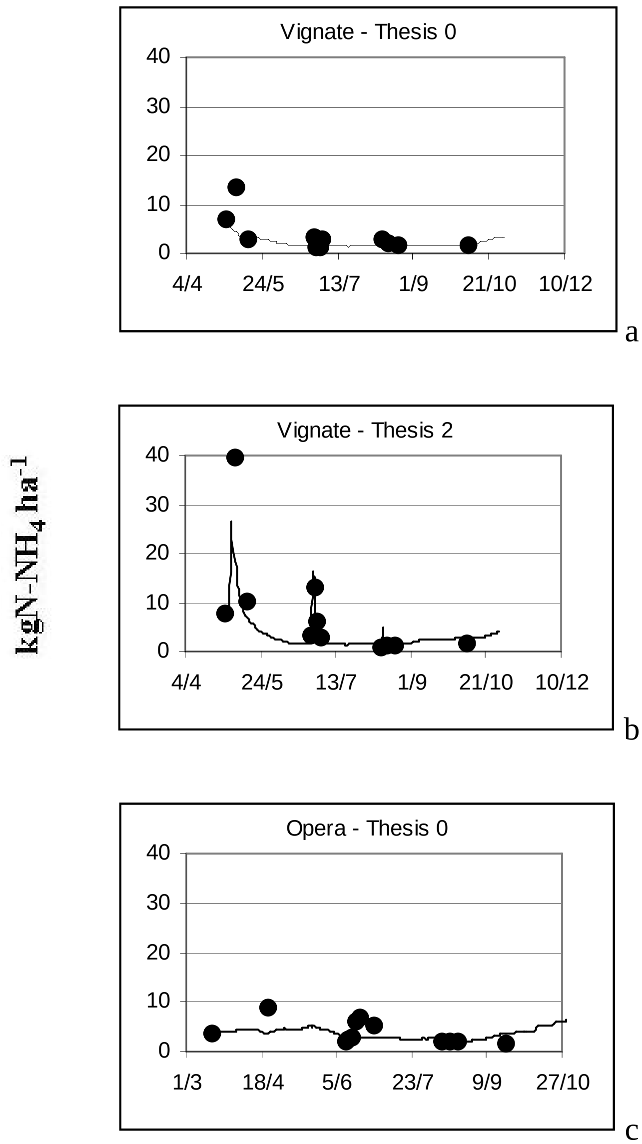


Figure 3 – Measured k_{sat} values for the fifth experiment. a. Vignate; b. Opera

SNCs measured during the fifth experiment are shown in Figure 4 and 5. Looking at Figure 4, it's possible to notice that ammonification, nitrification, denitrification, leaching, volatilization and crop uptake lead to an equilibrium concentration for N-NH_4 of about 2 kgN-NH_4 ha^{-1} for Vignate and 3-4 kgN-NH_4 ha^{-1} for Opera. When the soil-crop system receives N (topdress fertilizations), the soil N-NH_4 concentration immediately increases reaching a maximum value and comes back to the original value in about a week. The second value measured at Vignate for the thesis 0 is influenced by N horizontal movements from the near fertilized plots. Figure 5 shows that the soil N-NO_3 concentration is very low when the field is submerged because of (i) low nitrification rates, (ii) leaching (high infiltration rates were measured for both the localities) and (iii) denitrification. The rapid decrease in soil nitrate content shown for Vignate between the first and the second sampling events is mainly due to nitrate leaching occurred in occasion of the first real submersion of the not-puddled field.


Vignate - Thesis 0
40
30
20
10
0
4/4
24/5
13/7
1/9
21/10
10/12
a
kgN-NH4 ha-1
Vignate - Thesis 2
40
30
20
10
0
4/4
24/5
13/7
1/9
21/10
10/12
b
Opera - Thesis 0
40
30
20
10
0
1/3
18/4
5/6
23/7
9/9
27/10
c

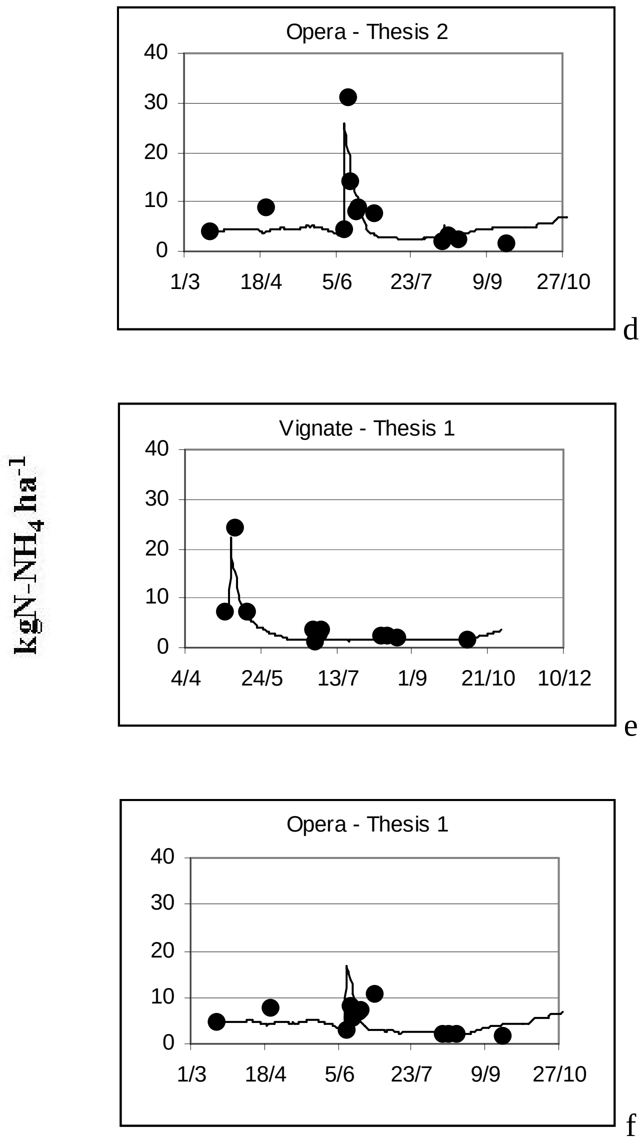
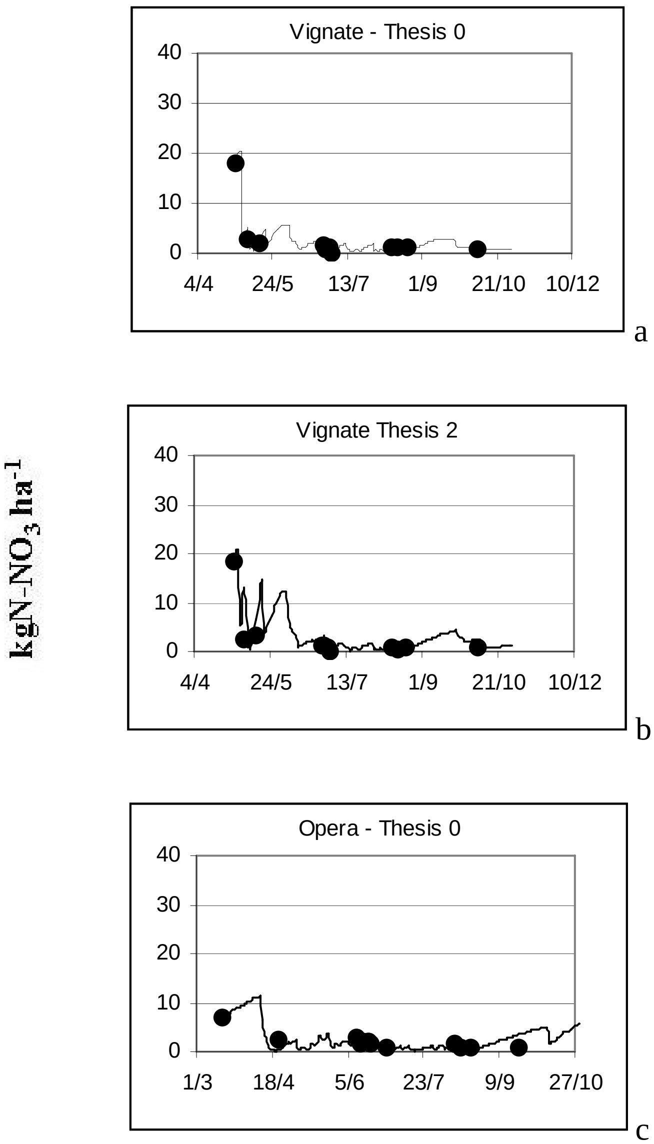


Figure 4 – Measured and simulated values of soil N-NH_4 content. Figures from 4.a to 4.d show the results of calibration; figures 4.e and 4.f show the results of the test of the calibrated parameters


Vignate - Thesis 0
40
30
20
10
0
4/4
24/5
13/7
1/9
21/10
10/12
a
kgN-NO3 ha-1
Vignate Thesis 2
40
30
20
10
0
4/4
24/5
13/7
1/9
21/10
10/12
b
Opera - Thesis 0
40
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20
10
0
1/3
18/4
5/6
23/7
9/9
27/10
c

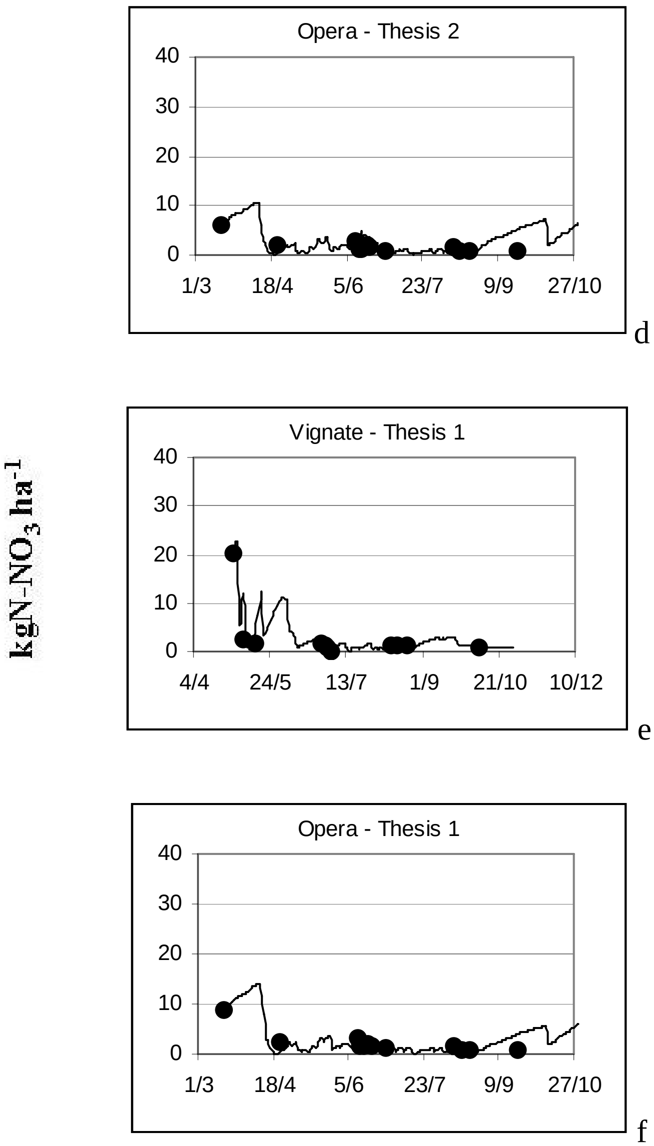


Figure 5 – Measured and simulated values of soil N-NO_3 content. Figures from 4.a to 4.d show the results of calibration; figures 4.e and 4.f show the results of the test of the calibrated parameters

6.4.2. Model results

6.4.2.1. Calibration of crop model parameters

Calibrated crop model parameters are shown in Table 2. Tc is initialized for all the groups of varieties to the value reported by Yin and Kropff (1996) and already used by Kropff et al. (1994) for the ORYZA1 model while Tb is set up on 12 °C (11 °C for JM) basing on local experience. This values are comprised in the range of values estimated by Sié et al. (1998) (9 – 12 °C) from experimental data collected during an experiment with three Indica type varieties. Topt was calibrated starting from the value found by Ellis et al. (1993) which showed different temperature responses on foliar (Topt = 26 °C) and floral (28 °C) development in cv. IR36 rice. The same value is reported for Japonica cultivars by Casanova et al. (1998). This value was lowered to 27 °C for I varieties to increase crop growth rate by decreasing temperature limitation.

For radiation use efficiency (LtBC), the default value for other C3 species (3 gAGB MJ^{-1} intercepted PAR) was used. This value is defined by CropSyst for optimal temperature conditions but in field conditions, efficiency may be limited by temperature. This is why lower values were found in literature by different authors: Kiniry et al. (2001) found a value of 2.39 gAGB MJ^{-1} intercepted PAR and Horie and Sakuratani (1985) reported a value of about 2.78 gAGB MJ^{-1} intercepted PAR. The value of 0.5 for the solar radiation extinction coefficient for PAR is consistent with what reported by Dingkuhn et al. (1999), as mean for many *O. sativa* (Indica and Japonica), and *O. glaberrima* varieties and by Casanova et al. (1998).

The value for the ET crop coefficient at full canopy (1.05) is consistent with the values reported by FAO (Allen et al., 1998) and by Tyagi et al. (2000).

The values of SLA for the three groups of cultivars enter in the range of values reported by other authors: Asch et al. (1999) for the first 30 days after soaking measured values from about 27 to about 60 m^2 kg^{-1} for Indica and Japonica type cultivars differing in early vigor; Dingkuhn et al. (1998) found values between about 20 and 36 m^2 kg^{-1} during the 30 days after sowing in an experiment with different cultivars grown under different N levels and climatic conditions.

The agreement between observed and simulated AGB values after the calibration is shown in Figure 1 and in Table 3. In general, CropSyst is accurate in simulating AGB accumulation. The model overestimates the last AGB value of the year for the data set of Vercelli – 1990, Castello d'Agogna – 1995 and Castello d'Agogna – 1996, while for the other data sets crop growth is well simulated. This is confirmed by the fitting indices shown in Table 3: the values of RRMSE are low, except for the data set of Velezzo Lomellina – 1999, EF and CD are always close to one and CRM is close to zero for all the simulations. The best values of the fitting indices were calculated for the Japonica type varieties, in particular for the JE varieties. For the data set of Gudo Visconti 1990, LAI values were measured until flowering. The simulated values of LAI are close to the measured ones (RRMSE = 17%, EF = 0.94, CD = 1.44): this confirm the goodness of the combination of crop parameters chosen for the JE varieties. The same consideration is possible for the LAI measured in Vignate (I): the values of the fitting indices (RRMSE = 9%, EF = 0.99, CD = 1.05), with a maximum measured LAI of 12.2 $m^2\ m^{-2}$ consistent with the values reported by Kiniry et al. (2001), confirm the goodness of calibrated parameters.

Table 3 – Indices of agreement between observed and simulated AGB values

		Variety group	**RRMSE (%)**	**EF**	**CRM**	**CD**	**Slope**	**Intercept (t AGB ha^{-1})**	**R^2**
Calibration	Gudo Visconti 1990	JE	11	0.98	-0.03	1.07	0.95	0.12	0.98
	Vercelli 1990	JE	18	0.96	0.13	0.84	1.10	0.24	0.99
	Vercelli 1989	JM	20	0.93	0.07	0.75	1.15	-0.59	0.95
	Castello d'Agogna 1995	JM	19	0.95	0.00	0.85	1.06	-0.34	0.95
	Castello d'Agogna 1996	JM	22	0.94	0.07	0.64	1.24	-1.23	0.98
	Velezzo Lomellina 1999	I	29	0.95	-0.15	0.86	1.07	-1.06	0.97
	Vignate 2002	I	25	0.84	0.17	0.82	1.11	0.78	0.92
Validation	Castello d'Agogna 1995	JE	12	0.98	-0.06	1.08	0.96	-0.08	0.99
	Castello d'Agogna 1996	JE	10	0.99	0.01	1.03	0.98	0.18	0.99
	Gudo Visconti 1990	JM	52	0.62	-0.45	1.73	0.82	-0.80	0.96
	Vercelli 1990	JM	11	0.99	-0.02	0.93	1.03	-0.33	0.99
	Castello d'Agogna 1994	JM	33	0.88	-0.16	0.80	1.09	-1.37	0.92
	Mortara 1996	JM	12	0.98	0.02	0.77	1.14	-0.82	0.99
	Opera 2002	I	23	0.88	0.17	0.89	1.07	0.91	0.96

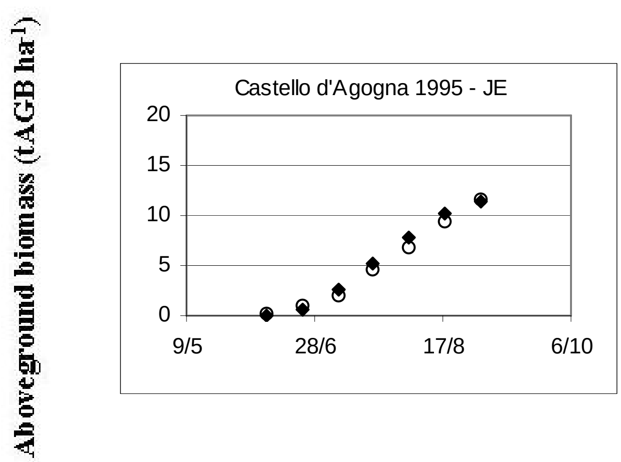
For the parameters involved with the simulation of PNC, we have not conduced a real calibration process because only measured values have been used. The test of these parameters has given the results shown in Table 4. The fitting indices shows that the models is able to correctly simulate PNC.

Table 4 – Indices of agreement between observed and simulated values of PNC

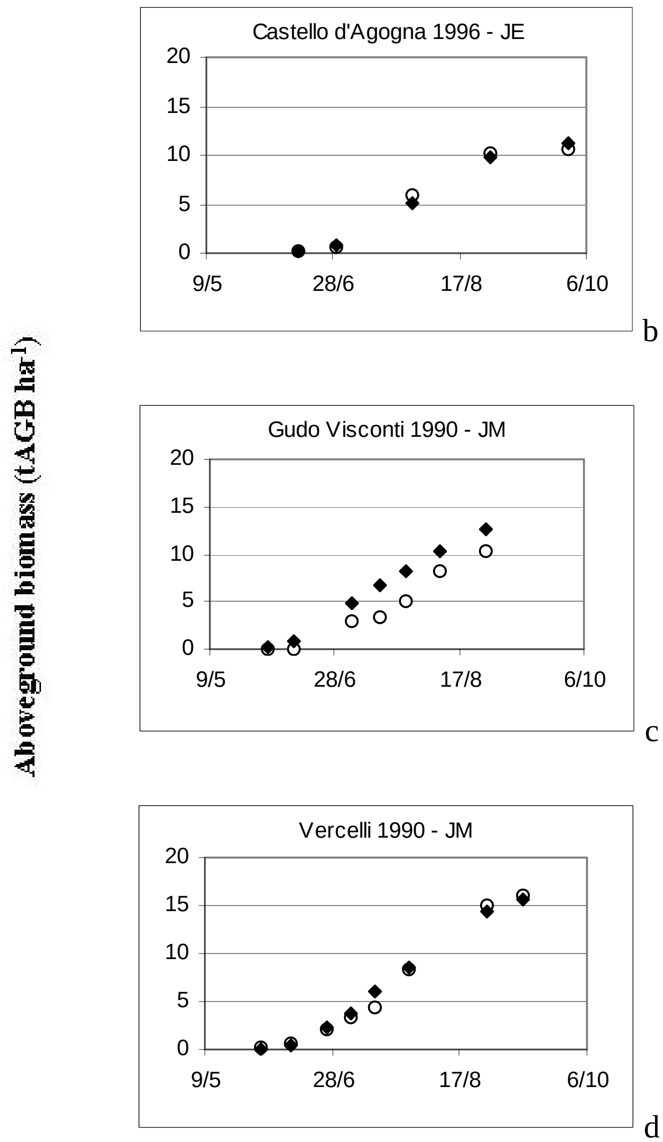
Locality	Thesis	RRMSE (%)	EF	CRM	CD	Slope	Intercept (t AGB ha^{-1})	R^2
Vignate 2002	0	19	0.90	-0.10	0.97	0.96	0.00	0.93
	1	23	0.86	-0.18	0.87	0.94	0.00	0.95
	2	15	0.91	-0.06	0.80	0.87	0.00	0.94
Opera 2002	0	21	0.86	0.19	1.15	1.15	0.00	0.99
	1	30	0.70	0.24	1.11	1.13	0.00	0.90
	2	24	0.77	0.21	1.08	1.13	0.00	0.96

6.4.2.2. Validation of crop model parameters

Figure 2 and Table 3 shows the results of crop parameters test. In general, CropSyst simulates accurately AGB values. For Gudo Visconti – 1990 data set, Figure 1 shows an evident and inexplicable overestimation during the whole crop cycle. The fitting indices calculated for the JE variety are better than the one calculated for the other variety groups. Also during the validation the model has shown to be able to reproduce the variability between years, soils and varieties.



a


Aboveground biomass (tAGB ha-1)
Castello d'Agogna 1996 - JE
20
15
10
5
0
9/5
28/6
17/8
6/10
b
Gudo Visconti 1990 - JM
20
15
10
5
0
9/5
28/6
17/8
6/10
c
Vercelli 1990 - JM
20
15
10
5
0
9/5
28/6
17/8
6/10
d

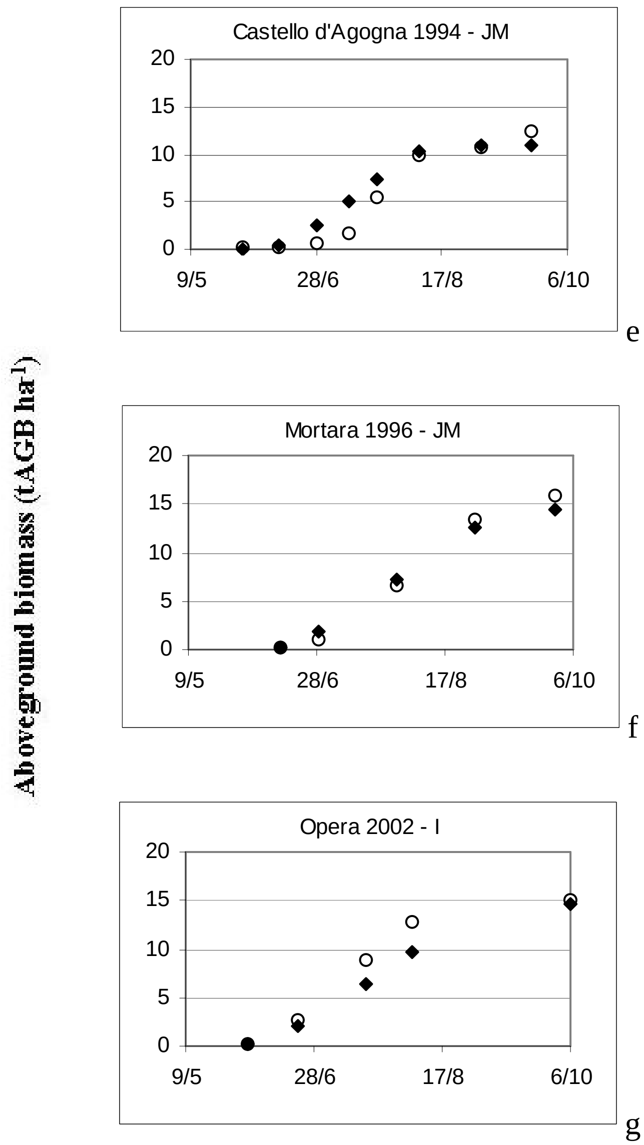


Figure 6 – Measured (o) and simulated (♦)AGB values. Validation

6.4.2.3. Soil nitrogen content

For both the soils, K_{sat} and BD was initialized with measured values. Calibrated parameters involved with the transformation of SNC are exposed in Table 5. The values of the parameters reflect the peculiar conditions, typical of paddy fields, caused by reduced oxygen availability: high and medium-low values for, respective, denitrification and nitrification rates (Focht, 1979). The difference between NRA values for the two soils is probably due to the fact that the Vignate field was not puddled. In fact, in this locality, the water level was usually lower than the one normally observed in north-Italian paddy fields. This probably caused a higher oxygen availability for the oxidation of N-NH_4. Measured and simulated values of N-NH_4 and N-NO_3 will always be referred to the soil layer 0.00 – 0.10 m in this section.

Table 5 – Parameters involved with soil nitrogen transformation for the two localities of the fifth experiment

Parameter	**Value**		**Units**	**Range**
	Vignate	**Opera**		
MRA	1.3	1.3	/	0-2
NRA	0.4	0.2	/	0-2
DRA	1.9	1.9	/	0-2

The agreement between measured and simulated values of N-NH_4 is shown in Figure 4 and in Table 6. After the calibration, the model has shown to be able to simulate the evolution of soil N-NH4 content (Figure 4.a – 4.d) for both the localities, reproducing (i) the effects of the pre-seeding (Vignate) and the top-dressing (both the localities) fertilizations and (ii) the almost constant low N-NH_4 content measured for the thesis 0. For the second sample collected in Vignate, CropSyst underestimates the value measured for the thesis 2 (Figure 4.b) while the overestimation reported in Figure 4.a (thesis 0) is probably due to horizontal movements of N from the fertilized plots. Also the results of the test of model parameters (Figure 4.e and 4.f) may be considered satisfactory.

Table 6 – Indices of agreement between measured and simulated values of SNC

		Locality	Thesis	RRMSE (%)	EF	CRM	CD	Slope	Intercept (t AGB ha^{-1})	R^2
N-NH$_4$	Calibration	Vignate	0	36.75	0.67	-0.18	1.23	0.83	0.05	0.79
			2	118.37	-0.66	-0.43	4.68	0.45	1.97	0.90
		Opera	0	64.74	-5.18	-0.12	8.50	0.20	2.13	0.33
			2	47.27	0.76	0.02	0.98	0.89	1.10	0.77
	Validation	Vignate	1	75.21	0.53	-0.39	2.46	0.64	0.42	0.96
		Opera	1	86.14	-0.27	0.17	0.41	0.20	5.21	0.01
N-NO$_3$	Calibration	Vignate	0	32.81	0.97	0.05	0.86	1.06	-0.04	0.97
			2	80.52	0.66	0.38	0.77	1.03	1.56	0.73
		Opera	0	75.62	0.49	-0.20	0.79	0.85	-0.03	0.54
			2	83.31	-0.06	0.31	0.54	0.61	1.59	0.15
	Validation	Vignate	1	76.25	0.76	0.28	0.77	1.04	1.02	0.80
		Opera	1	70.07	0.58	-0.02	0.78	0.87	0.25	0.60

Figure 5 and Table 6 show the agreement between measured and simulate values of N-NO$_3$. The values of the parameters at the end of the calibration (Figure 4.a – 4.d) allow the model to correctly simulate the course of nitrate in the soil for both the localities although the model overestimates the value of the last sample of Opera (Figure 4.c and 4.d). The test of calibrated parameters (Figure 5.e and 5.f) has confirmed the goodness of model performances although some of the values assumed by the fitting indices (above all RRMSE) may appear unencouraging (Table 6). In fact, the means of the measured values of all data sets are low, with a minimum corresponding to 1.38 kgN-NO$_3$ ha^{-1} (Opera – thesis 0) and a maximum to 4.44 kgN-NO$_3$ ha^{-1} (Vignate – thesis 2). This is why RRMSE values are high (RRMSE is calculated dividing RMSE for the observed mean), although the figure shows satisfactory correspondence between measured and simulated values. In fact, the average of the RMSE values for N-NO$_3$ simulations is only 2.06 kgN-NO$_3$ ha^{-1}, which may be considered relatively low thinking about a possible use of the model for management purposes or, for example, to evaluate groundwater pollution due to nitrate leaching. In fact, most of the values calculated for the other fitting indices are satisfactory (EF negative only in one case, CD almost always close to 1). The same considerations about the values of RRMSE may be valid also for the simulation of N-NH$_4$, although the values of the other indices confirm the lower precision of the model in simulating this variable.

For five days after the first top-dressing fertilization (thesis 2), CropSyst has simulated an average nitrification rate of 2.49 kgN ha^{-1} day^{-1} at Vignate and 1.87 kgN ha^{-1} day^{-1} at Opera. These values are consistent with what reported by Reddy (1982) (about 2.8 kgN ha^{-1} day^{-1}). The average simulated denitrification rates after the first top-dressing fertilization (0.07 kgN ha^{-1} day^{-1} for Vignate and 0.04 kgN ha^{-1} day^{-1} for Opera) are low compared with what reported by Reddy (1982 and 1989) (about 0.5-1.1 kgN ha^{-1} day^{-1}) but consistent with the value measured by Majumdar et al. (2000) (0.06 kgN ha^{-1} day^{-1}). A possible explanation of the low simulated denitrification rate is connected with the relatively high water infiltration rates measured in our experiment which may have caused higher nitrate leaching and, therefore, low N-NO_3 availability for denitrification.

6.5. Conclusions

With the present work CropSyst has been parameterized and tested for the simulation of rice in the heterogeneous cultivars and pedo-climatic conditions which characterize European rice cultivation. To reach this aim, we grouped the cultivars grown in our continent by defining three crop parameters sets, corresponding to Japonica early and medium-late and Indica varieties. The crop parameters were calibrated and validated by using data collected between 1989 and 2002 in north Italy in order to take into account the different pedo-climatic situations in which rice is grown.

CropSyst, after this parameterization, is able to simulate accurately the growth of these rice cultivars types. The exploration of different meteorological conditions allows to exclude that the presented parameters sets include errors due to particular meteorological situations. Therefore, the three parameters sets calibrated for Japonica early and medium-late and for Indica varieties may be used to simulate crop growth in Europe.

The results obtained during the test of the model for soil nitrogen content show that, for the analyzed soil types, CropSyst has been able to reproduce soil mineral nitrogen concentration for the studied period, indicated nitrification and denitrification rates similar to the ones we have found in literature. The test has been conduced only with two data sets, collected in two locations during the same year. Moreover, measured leaching data was not available. For these reasons, it's impossible, at the moment, to make definitive considerations about the model adequacy for the simulation of N balance under flooding conditions. The interest about the low N use efficiency in rice fields is justified by its economic and environmental impact. Therefore, further tests of the model for N balance simulation are needed and the collection of field specific data is the *sine qua non* condition to reach this aim.

The introduction in CropSyst of algorithms connected with two important aspects of flooded rice may be suggested to improve the model for rice simulations. One is related to the possibility of simulating the effect of flooding water temperature (very important at mid latitudes) on crop growth and development and on soil chemical transformations. For a big part of rice growth cycle, the meristematic apex (one of the parts of the plant which present high temperature sensitivity) is below water surface. Moreover, near-water air temperature is highly influenced by water temperature. Therefore, the use of water and near-water temperature instead of air one as guide variable may lead to improvements for the simulations of many processes related with the crop-soil system. Confalonieri et al. (2002) have studied this problem by collecting water and air temperature data (at different distances from water surface) and by developing a mechanistic model for water temperature estimation starting from air maximum and minimum daily temperatures. Another suggestion is related to the possibility of introducing sensitivity to temperature stress in particular phenological phases (temperature stress during the pre-flowering period may cause floral sterility and a consequent a remarkable yield reduction).

ANALYSIS AND MODELLING OF WATER AND NEAR WATER TEMPERATURES IN FLOODED RICE (*Oryza sativa* L.)

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Submitted to: Ecological Modelling (2003)

7.1. Abstract

The knowledge of micrometeorological conditions in flooded rice fields is crucial for better modelling the behaviour of the crop in mid and high latitudes, where the thermal mitigation provided by water layer is significant against the climatic risk of low temperatures in spring and early summer.

Two micrometeorological models (a mechanistic and an empirical one) for the simulation of thermal profile related to water and near water temperatures were calibrated and validated with data gauged in some rice fields located near Milano (Italy). The results show that the models could improve the performances of crop simulation models physically based, currently used for crop growth, development and production analysis.

Keywords: *Oryza sativa* L., paddy rice, flooded field temperature profile, model

7.2. Introduction

In almost every pedoclimatic condition occurring in the agroecological zones, where rice is cultivated, the interaction between the rice plant and the water stand deeply characterizes the biochemical and physical structure of the entire cropping system. In many cases the modern rice agroecosystems have replaced ecosystems naturally submerged such as humid areas, marsh and swampy regions. The heritage of the typical, original flora/fauna equilibriums often still remains in the rice districts which are concentrated in particular regions where rice is the predominant or sole crop, giving to the landscape its mark. More similar the agro ecosystems to the natural original one are, the higher level of sustainability (Gliessman, 2002). Those features, as a whole, make the rice environments in Europe so valuable that most of them are located inside National or Regional Parks (e.g. Parco Agricolo Sud Milano, Parco della Mesola, Camargue, Ebro etc.) and it seems suitable to save these agroecosytems as they are, without changing the irrigation system, strictly related to environmental equilibrium. Moreover, the water stand at mid or high latitudes such as those of the Po Valley (45 N) affects the temperature profile providing a floating bio-mechanism, mitigating extreme daily-night temperatures fluctuations. In fact, cold shocks or strong changes between day and night temperatures can affect negatively rice cycle and production, particularly when it occurs during emergence and in pre-flowering phases. Rice growers working at high latitude (North Italy, North Japan, North Corea, North China, South Australia) consider water an important tool during this phases (Confalonieri et al., 2002) and increase the water layer height when the risk of temperature fall increases. Figure 1 shows the increasing smoothing effect of water on temperature with increasing water height: maximum and minimum air daily temperatures are quite far from water ones. The water layer affects the crop behaviour in several ways as pointed out by many studies carried out in the last years (e.g. Hanson et al., 1990; Jearakongman et al., 1995; Boonjung and Fukai, 1996).

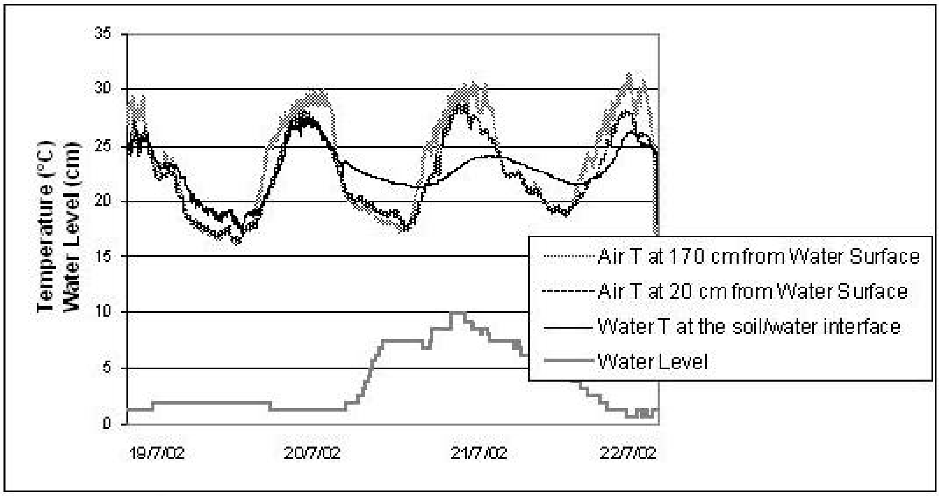

Figure 1 Water level measurements and hourly temperatures gauged at soil/water interface (water temperature), at 20 cm and at 170 cm from water surface (air temperature). Data from rice field of Vignate

Water availability mainly affects the crop productivity and a sub-optimal water supply, more than for the other cereal crops, can significantly affect plant growth and reduce yields (Inthapan and Fukai, 1988). The peculiar sensitivity for water stress observed on the rice crop is related to rice plant shallow root system and its consequent low ability to extract water from depth (Puckridge and O'Toole, 1981). Other important aspects are connected with the interaction between water and nitrogen availability (O'Toole and Padilla, 1984) and with the negative correlation found between weed growth and water depth (De Datta et al., 1973).

Flooding water temperature is important also for the influence on the temperature-dependent soil bio-chemical transformations and for the important role in the life cycles of all the species leaving in paddy fields. In fact, the development of the aquatic stages of mosquito species directly depends from surface water temperature which determines the number of emerging adult (Jetten and Takken, 1994; Lucassen, 1996).

Yokohari et al. (1997; 2001) have underlined that the effect of water on near-water temperature is interesting also for urban planning purposes in those areas where cities and paddy fields have to interact strictly, presenting interesting considerations about the effect of paddy fields on summertime air temperature in residential Tokyo. In Italy, this situation is common in Milan Province.

Temperature is one of the most important driving variables for models simulating crop growth and soil nutrient cycles. The rice crop growth models simulates the plant behaviour base on the air temperature even when the vegetative apex, sensitive to temperature's driving effect, is located under the water (so affected by the water, not air temperature) or pollen mother cells are under the influence of the interaction water temperature × air temperature. As previously stressed, the rice system is always affected by water temperature and also the crop models have to take into account properly this tremendous influence. A micrometeorological model able to estimate water and near - water temperatures in flooded rice fields from air temperatures gauged by standard meteorological stations could significantly improve the accuracy and realism of those models and consequently the performances of operational crop simulation models currently used for crop growth, development and production analysis.

The present study aims at i) improving the knowledge of the paddy field temperature profile by collecting temperature data registered at different heights from the soil-water interface, ii) analyzing and formalizing the knowledge thru two physical models to use as modules for improving the performances of the crop growth models. The results obtained with two models, one empirical and one mechanistic, are here presented and discussed.

7.3. Materials and methods

7.3.1. Field measurements

The study of the processes related to the influence of water on air temperature in paddy fields was initially based on data sets of water and air temperature collected during previous experiments (Bocchi, 1992). The main limit of these data sets was represented by the availability of only two levels of measurement (soil-water interface and air temperature at 1.80 m). For this reason, from the beginning of the 2002 rice field campaign, a monitoring activity was started, based on (i) an automatic floating station measuring temperature into the water (bottom and surface), into the canopy layer and above it and (ii) an automatic system for the continuous water level measurement.

Data for models calibration and validation were gauged in paddy rice fields near Milan (45.10 °N, 9.40° E), in the medium plain of the Po valley, during the growing season 2001 and 2002 (table 1 and figure 2). Mean yearly values (precipitation = 900 mm, air temperature = 13°C, evapotranspiration from reference crop = 1100 mm, Johannson index = 28) qualify this climate as sub-continental.

Table 1 Datasets collected for calibration and validation of rice micrometeorological models

Dataset	Year	Rice variety
Milano - Ripamonti	2001	Thaibonnet
Vignate	2002	Sillaro
Opera	2002	Thaibonnet

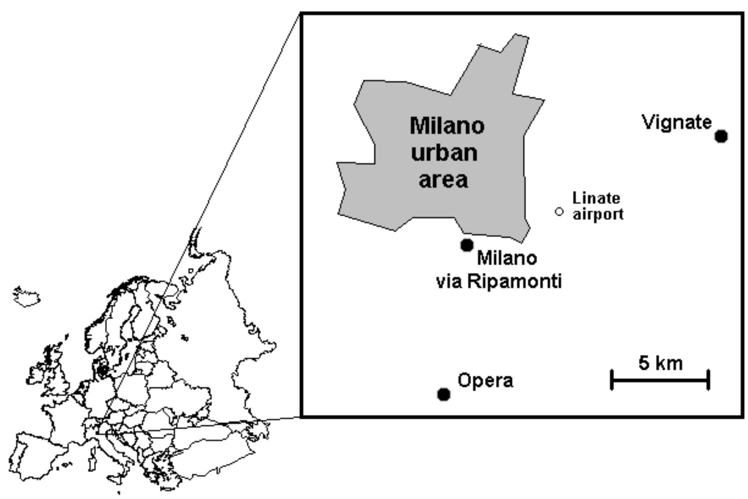

Figure 2 Localisation of rice fields of Opera, Vignate and Milano – via Ripamonti

As compared to the long term values (climatic normal) measured at Linate airport (5 – 15 km from the study sites) the 2001 growing season was warmer by about 2°C (on average) and drier (by 120 mm) and the 2002 growing season was warmer by about 2°C (on average) and wetter (by 60 mm) (table 2).

Table 2 Mean values for the period 1 May – 30 September (data from the synoptic station of Milano Linate Airport)

	Total rainfall (mm)	Tx (°C)	Tn (°C)
2001	270	28	16
2002	442	27	17
Normal	386	26	15

Rice fields of Milano – Ripamonti and Opera were equipped with the following instruments:

- thermometer (thermoresistance) for water temperature at bottom of the water;
- thermometer (thermoresistance) for air temperature located in a white weather shelter house;
- pyranometer (silicon cell-photo-diode) for global radiation;
- pyranometer (silicon cell-photo-diode) for albedo.

Rice field of Vignate was equipped with a floating station and a Davis low cost electronic meteorological station.

The rice weather station, developed at the Crop Science Department (Confalonieri et al., 2002) is able to float in the middle of the paddy field in very shallow water bodies, carrying steel stems holding thermometers above, below and on air-water interface. This is projected for getting measurements as function of their distance from water surface. The sensors are sufficiently far from the parts of the structure, which can disturb the micro-environmental variables that we need to measure. Thermometers (thermoresistances) are located inside radiation screens. The Davis weather station was located at the border of the field and was equipped with a cup anemometer for the measurement of horizontal wind speed at 2 m of high, a pluviometer, a termoresistance for air temperature and a film capacitor element for relative humidity.

Whole meteorological variables were measured at least every 1 min and averaged for 1 h. The 1 h averages were used for the following computations.

7.3.2. Thermal Profile Modelling (TPM)

The thermal profile modelling was approached by adopting two different strategies: an empirical one, developed on the estimation of the water temperature on the basis of the air temperatures of some past days and a mechanistic one founded on the resolution of the energy balance equation adopting as storage term the heat accumulation into the water.

7.3.2.1. Description of the mechanistic algorithm

Simulation of temperature of water surface

The energy balance of a water surface (Oke, 1978) can be approximated as:

$$Rn + G + H + L \cdot E = 0 \qquad [\mathrm{J\ m^{-2}\ h^{-1}}] \qquad [1]$$

Where the flux terms are respectively the net radiation (Rn), the heat stored into the water (G), the latent heat (L·E) and the sensible heat flux. The storage term G acts as practically only source of energy at night and a considerable sink of energy during daytime (Geiger, 1961).

In equation [1] the term H can be expressed as:

$$H = h_u \cdot (T_s - T_a) \qquad [\mathrm{J\ m^{-2}\ h^{-1}}] \qquad [2]$$

Were T_s [°C] is water surface temperature, T_a [°C] is air temperature and h_u is the transfer coefficient of sensible heat, which value was expressed by Penman (Penman, 1948) as a function of wind velocity with the following equation (van Keulen and Wolf, 1986):

$$h_u = a_u \cdot (1 + b_u \cdot u_{med}) \qquad [\mathrm{J\ m^{-2}\ h^{-1}\ °C^{-1}}] \qquad [3]$$

where u_{med} is the mean hourly wind velocity [m s^{-1}]; a_u and b_u are empirical coefficients. In this study the values proposed by Frere and Popov

(Allen et al., 1998) for flat surfaces and wind speed measured at 2 m of high (a_u = 6.4·10^5/24 J m^{-2} h^{-1} °C^{-1}; b_u = 0.54 s m^{-1}) were adopted.

Substituting equation [2] in equation [1] we obtain:

$$T_s = T_a + \frac{(L \cdot E + G + R_n)}{h_u} \qquad [°C] \qquad [4]$$

In this equation the term R_n was obtained from:

$$R_n = R_g \cdot (1 - albedo) - R_L \qquad [J\ m^{-2}\ h^{-1}] \qquad [5]$$

where R_g is the global solar radiation approximated on the base of the air temperature by means of an algorithm proposed by Campbell – Donatelli (Bechini et al., 2000). In absence of a significant canopy effect, a constant value of 0.08 was adopted for the albedo, as suggested for shallow water by Uchijima (Uchijima, 1976).

R_L is the net outgoing long wave radiation obtained with Brunt's semi-empirical solution of the Stefan – Bolzmann's law (Sutton, 1953).

$$R_L = \sigma \cdot (T_a + 273.02)^4 \cdot \left(1 - a - b \cdot e_a^{\ 0.5}\right) \cdot (1 - an \cdot co) \qquad [J\ m^{-2}\ h^{-1}] \qquad [6]$$

where σ is the Stefan - Bolzmann constant, e_a is the vapour pressure, values of 0.44 and 0.080 were adopted for a and b parameters and a value of 0.65, typical of cumulus clouds, was assigned to *an* parameter.

Daily value of cloud coverage co (that varies in the range 0-1 with 1 is for overcast sky) was obtained from the ratio between the current simulated value of R_g and the maximum possible for the selected day.

The term G was estimated on the base of net radiation R_n by means of the following empirical equation (1):

$$G = -3600 \cdot \left(-51 + 0.41 \cdot \frac{R_n}{3600}\right) \qquad [J\ m^{-2}\ h^{-1}] \qquad [7]$$

Evaporation term E is simulated adopting the following approach, proposed by Penman in 1948 (6):

$$L \cdot E = \frac{1}{\Delta + \gamma} \cdot \left(\Delta \cdot R_n + h_u \cdot \left(e_s - e_a \right) \right) \qquad [\text{J m}^{-2}\ \text{h}^{-1}] \qquad [8]$$

Were e_s and e_a [hPa] are the vapour pressures respectively referred to water surface and air (vapour pressure of water surface is considered equal to saturated vapour pressure e_s), γ is the psicrometric constant (0.66) and Δ is the slope of the saturation vapour pressure curve between the average air temperature and dew point.

Relative humidity (RH), necessary to obtain water vapour pressure e_a, was modelled with the algorithm described by Mc Vicar & Jupp (Mc Vicar and Jupp, 1999), based on the assumption that minimum air temperature is equal to dew point temperature and that the mixing ratio remain constant during the day.

Simulation of canopy variables

The algorithm adopted for canopy simulation is based on the following assumptions: (i) rice canopy is considered as a multilayer pattern with layers of constant depth of 10 cm; (ii) the number of layers increases with the age of the crop; (iii) leaf area index (LAI) is homogeneously subdivided among the layers.

The effect of canopy on the physical properties of boundary layer is considered significant from 10 of June, when an high of 10 cm is imposed. The high of the canopy is obtained adopting the following very simplified linear equation:

$$hcanopy = 10 + 2 \cdot \left(pjd_{today} - pjd_{10\,June} \right) \qquad [\text{cm}] \qquad [9]$$

where pjd is the pseudojulian date (1 = January 1; France and Thornley, 1984). The maximum value that can be attained by canopy is 100 cm, according to what is possible to observe in our region. Leaf area index (LAI) and cultural coefficient (Kc) are obtained with the following equations:

$$LAI = \frac{hcanopy}{15} \qquad [\text{cm}] \qquad [10]$$

and

$$Kc = \frac{LAI}{6} \qquad \text{[cm]} \qquad [11]$$

The quote of solar radiation reflected by canopy (albedo) is calculated with the following linear model described by Uchijima (1976):

$$albedo = 0.32 - 0.0027 \cdot b \qquad [\%] \qquad [12]$$

where b is the angle of solar elevation calculated with classical trigonometric functions. The quote of solar radiation absorbed by the canopy is obtained with the following equation defined by Ross (Burba et al., 1999).

$$assorb = \left(1 - \exp\left(-k_e \cdot LAI\right)\right) \qquad [\%] \qquad [13]$$

where the extinction coefficient k_e is obtained with the formula:

$$k_e = G_{\mathrm{om}ega} \cdot sin(b) \qquad [14]$$

where a spherical leaf angle distribution is considered and therefore G_{omega} was initialised to 0.5.

The outgoing long wave radiation R_L is obtained with the above described Brunt equation [6] and the quote intercepted by different layers is estimated with Lambert Beer law modified by Monsi e Saeki, with an extinction coefficient k_e = 0.65.

Wind speed for different canopy layers is calculated with the following exponential equation (Uchijima, 1976):

$$u_z = u_h \cdot \exp\left(-a \cdot \left(1 - \frac{z}{h}\right)\right) \qquad [\mathrm{m\ s^{-1}}] \qquad [15]$$

where h is the top of the canopy and a value of 2.2 was adopted for the extinction coefficient h.

ET0 (subdivided in the two terms radiation driven and aerodynamic driven) is simulated with the Penman – Monteith equation (7) and ETM is obtained multiplying for Kc.

The radiation driven quote of ETM (ETm_RadT) id subdivided among the different layers in proportion with the quote of R_g absorbed; the aerodynamic-driven quote (ETm_aeroT) is subdivided among layers in proportion with the contribution of each layer to the total wind velocity.

Leaf temperature is estimated with the following equation:

$$Rn + H + L \cdot E = 0 \qquad [16]$$

where the physical storage term is neglected (Oke, 1978).

In this equation the H term is expressed in the following way (Bonan, 2002):

$$H = \rho \cdot Cp \cdot \frac{T_1 - T_a}{3600 \cdot \frac{rb}{2}} \qquad [\mathrm{J\ m^{-2}\ h^{-1}}] \qquad [17]$$

where ρ is the air density, Cp is the thermal capacity of air (1005 J kg^{-1} $°C^{-1}$), T_l is the leaf temperature [°C] and rb is the leaf boundary layer resistance, expressed in function of wind velocity u by means of the following equation:

$$rb = aa \cdot \left(\frac{dd}{u}\right)^{0.5} \qquad [\mathrm{J\ m^{-2}\ °C^{-1}\ s^{-1}}] \qquad [18]$$

where a value of 200 was adopted for the coefficient aa and a value of 0.04 m was adopted for the mean leaf dimension.

The balance equation becomes:

$$T_1 = T_a + (Rn + L \cdot E) \cdot \left(\frac{rb}{3600 \cdot 2 \cdot ro \cdot Cp}\right) \qquad [°C] \qquad [19]$$

where E (mm = kg * m^{-2}) is the transpired water.

Other details about simulation with mechanistic algorithm

The algorithm was developed in standard PASCAL code, adopting an hourly time step.

Hourly values of R_g, T_a, RH were estimated on the base of standard daily data (daily total R_g, maximum and minimum air temperature (T_x, T_n) and relative humidity (RH_x, RH_n)) adopting a standard generator (Denison and Loomis, 1989). The same model was used for the generation of hourly values of wind speed, considering a mean daily value of 0.7 m s^{-1}, characteristic of Milano area.

In the case of Vignate dataset, the experimental filed was surrounded by rows of poplars (*Popolus nigra ssp. italica*) with significant microscale effects on meteorological variables. Only the effect of this shield on R_n was described considering:

- the reduction of the daily amount of direct solar radiation due to the presence of an apparent horizon;
- the reduced amount of outgoing long wave radiation due to the limited sky view factor.

7.3.2.2. Description of the empirical algorithm

The empirical model simulates minimum daily water temperature by solving the equation below:

$$TnW = \left[\left(Tn_{D-1} \cdot 0.2\right) + \left(Tn_D \cdot 0.6\right) + \left(Tn_{D+1} \cdot 0.2\right)\right] + 3 \qquad [20]$$

where: TnW [°C] is the minimum water temperature of the day D; Tn_{D-1} [°C] is the minimum air temperature of the day D-1; Tn_D [°C] is the minimum air temperature of the day D and Tn_{D+1} [°C] is the minimum air temperature of the day D+1. This algorithm reproduces the flooding water smoothing effect on temperatures by means of a Gaussian filter applied to the air temperatures gauged in a standard weather station. Moreover the energy storage effect of water was simulates by adding a constant to the values calculated with the Gaussian filter.

The empirical algorithm for the simulation of daily maximum water temperature is based on the following equations:

$$TxW = \begin{cases} \left[(Tx_{D-1} \cdot 0.2) + (Tx_D \cdot 1.1) + (Tx_{D+1} \cdot 0.2) \right] - 6 & DOY < 164 \\ \left\{ \left[(Tx_{D-1} \cdot 0.2) + (Tx_D \cdot 1.1) + (Tx_{D+1} \cdot 0.2) \right] \cdot 0.75 \right\} - 2 & 164 \leq DOY < 200 \\ \left[(Tx_{D-1} \cdot 0.27) + (Tx_D \cdot 0.36) + (Tx_{D+1} \cdot 0.27) \right] + 1 & 200 \leq DOY < 213 \\ \left\{ \left[(Tx_{D-1} \cdot 0.2) + (Tx_D \cdot 1.1) + (Tx_{D+1} \cdot 0.2) \right] \cdot 0.4 \right\} + 8 & DOY \geq 213 \end{cases} \quad [21]$$

where: TxW [°C] is the maximum water temperature of the day D; Tx_{D-1} [°C] is the maximum air temperature of the day D-1; Tx_D [°C] is the maximum air temperature of the day D; Tx_{D+1} [°C] is the maximum air temperature of the day D+1 and DOY is the day of the year. Also in this case the water smoothing effect on temperatures is simulated by using a Gaussian filter.

7.3.2.3. Data sets for calibration / validation

The only input data for both mechanistic and empirical model is represented by air temperature gauged at 1.80 m at the border of the field.

Calibration and validation of mechanistic and empirical models were carried out with reference to data collected in Vignate, Milano – Ripamonti and Opera. For the databases of Opera and Milano – Ripamonti, temperatures measured at the bottom of the vertical profile were considered in place of water surface temperature; this introduce an error that can be considered relatively small due the substantial isothermal conditions that characterise water reservoirs with deepness of 10-20 cm (Geiger, 1961).

Mechanistic model was calibrated by using datasets of Vignate and Milano – Ripamonti; validation was referred to Opera dataset.

For the mechanistic model, calibration was carried out acting only on the empirical parameter cf1 that modulates evaporation from water surface. This solution was adopted on the base of a sensitivity analysis (results not discussed here).

The parameter cf1 was introduced in equation [4] that assumed the following structure:

$$T_s = T_a + \frac{L \cdot E \cdot cf1 + G + Rn}{h_u} \qquad [°C] \qquad [22]$$

After calibration the final values adopted for cf1 were 0.6 for LAI <= 3, 0.8 for LAI between 3 and 6 and 1.2 for the following period.

Empirical model was calibrated with datasets of Opera and Milano – Ripamonti, working on coefficients of equations [20] and [21]. Validation was referred to Vignate data – set.

7.3.2.4. Statistical analysis

Measured and simulated data have been compared by using the fitting indices proposed by Loague and Green (Loague and Green, 1991): the relative root mean square error (RRMSE, 0-100%, optimum = 0%), the coefficient of determination (CD, 0-1, optimum = 1, which indicates whether the model reproduces the trend of measured values or not), the modelling efficiency (EF, $-\infty \div +\infty$, optimum = 1; if positive, the model is a better predictor than the average of measured values), the coefficient of residual mass (CRM, 0-1, optimum = 0; a positive sign indicates model underestimation).

7.4. Results and discussion

Figure 3 shows some examples of temperature of water surface simulated with the calibrated mechanistic model for the station of Opera and figure 4 presents the behaviour of air temperature Ta, canopy (45 cm high) and water surface for the station of Vignate.

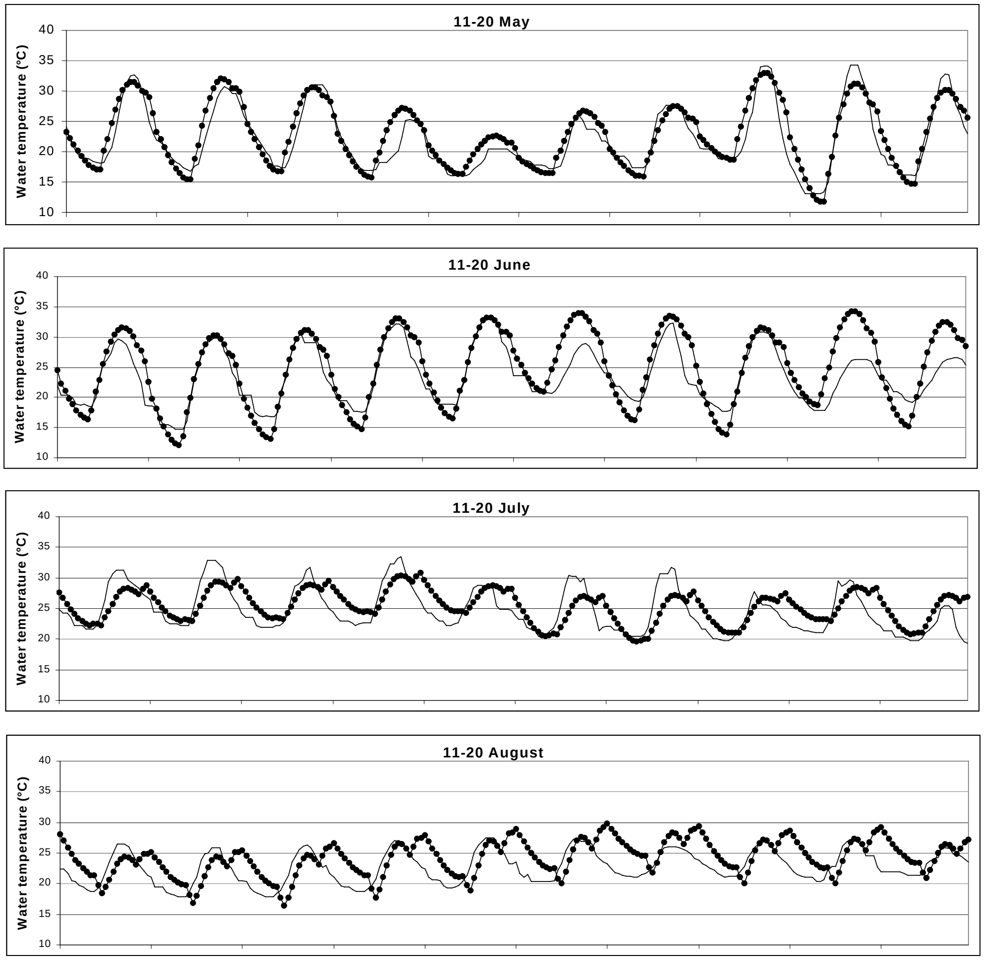

Figure 3 Surface water temperature for the second decade of May, June, July and August for rice field of Opera; values measured and values simulated with the mechanistic model (line with dots). The substantial reduction of the thermal daily excursion in July and August decades is the effect of the canopy

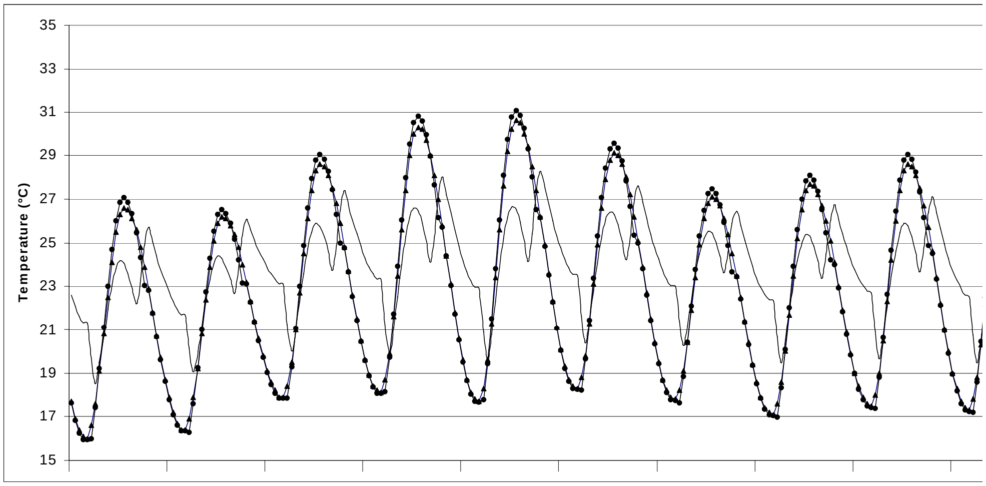

Figure 4 Hourly temperatures for air (line with triangles), for canopy layer 70-80 cm (line with dots) and for water surface (normal line) simulated by the mechanistic model (station of Vignate / period 25 July – 4 August 2002)

7.4.1. Performance analysis of mechanistic model

The results of performance analysis carried out on data of water surface temperature simulated by mechanistic model are presented in table 3 and 4.

Table 3 Results of the match of simulated hourly values of water surface temperature with measured ones (whole growing period)

Site	Period	RRMSE (%)	EF	CRM	CD
Opera	29/5/2002 - 12/9/2002	11	0.48	-0.06	0.76
Ripamonti	12/5/2001 - 12/9/2001	17	0.34	-0.06	0.90
Vignate	29/5/2002 - 24/9/2002	16	0.25	-0.11	0.81

Table 4 Results of the match of simulated hourly values of water surface temperature with measured ones (flowering period)

Site	RRMSE (%)	EF	CRM	CD
Opera 2002	7	0.35	-0.01	0.67
Ripamonti 2001	11	0.51	-0.02	1.97
Vignate 2002	13	-0.07	-0.09	0.57

Table 3 is referred to the whole period, table 4 only to the flowering period (period between 20 July and 10 August).

The model has shown to be able to simulate water temperatures. The values of the fitting indices are satisfactory. The model accuracy in the simulation process is evident, looking at the low values of RRMSE and at the values of CD close to one.

We can observe that the model presents a good degree of realism in particular during the flowering period, where the climatic risk of low temperatures is relatively high.

7.4.2. Performance analysis of empirical model

The comparison between measured and simulated values at the end of the calibration is shown in figure 5, 6 and in table 5.

Table 5 Measured and simulated minimum water temperatures. Opera, 2002

	Dataset	Variable	RRMSE (%)	EF	CRM	CD
Calibration	Ripamonti, 2001	TNW	4	0.67	0.02	1.44
	Opera, 2002	TNW	6	0.90	-0.01	0.94
	Ripamonti, 2001	TNX	11	0.46	0.01	1.10
	Opera, 2002	TNX	5	0.88	0.00	0.86
Validation	Vignate, 2002	TNW	9	0.79	0.06	0.75
	Vignate, 2002	TNX	10	0.70	0.05	0.57

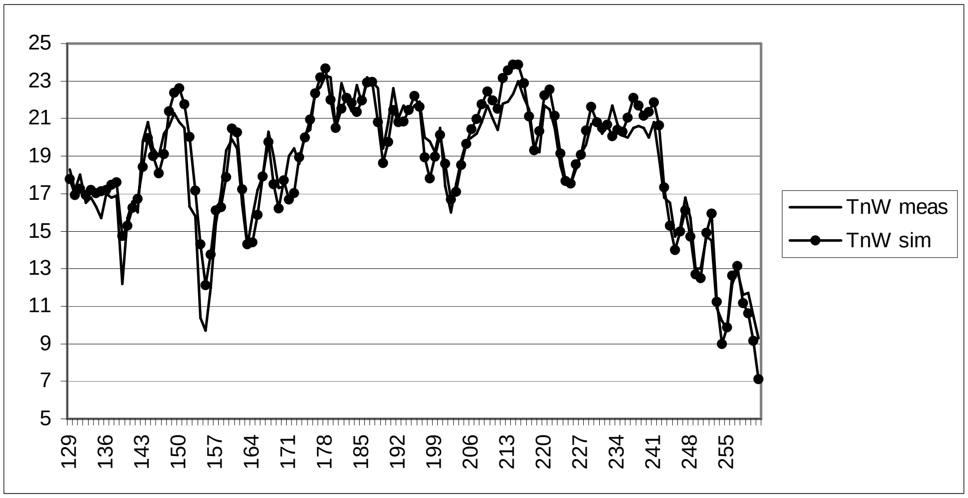

Figure 5 Measured and simulated minimum water temperatures. Ripamonti, 2001

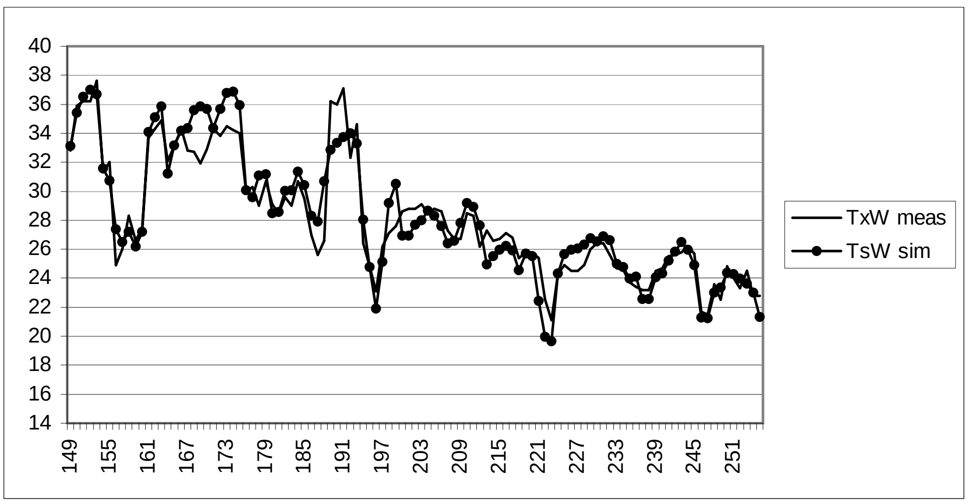

Figure 6 Measured and simulated minimum water temperatures. Opera, 2002

The model has shown to be able to simulate water temperatures. The values of the fitting indices are satisfactory, both for calibration and validation. The model accuracy in the simulation process is evident, looking at the low values of RRMSE and at the values of CD close to one.

7.5. Conclusion

A fundamental question is: why use thermal data produced by a micrometeorological simulation model instead of air temperature? A quantitative answer to this question is given by the following table, which represents how air temperature is able to describe water temperature.

We can observe that for all data sets the fitting indices presents worst values if compared with values obtained for the results of presented models (Table 3, 4 and 6).

Table 6 Results of the match of measured hourly values of water surface temperature with measured air temperatures

Site	Period	RRMSE (%)	EF	CRM	CD
Opera	29/5/2002 - 12/9/2002	30	-0.89	-0.08	1.34
Ripamonti	9/5/2001 - 12/9/2001	29	-0.36	-0.08	1.19
Vignate	29/5/2002 - 24/9/2002	23	-0.20	-0.03	1.11

The availability of models which can produce reliable estimates of physical variables into the canopy layer is crucial for modern agriculture, especially when precision farming practices are needed both for the enhancement of quali-quantitative aspects of crop production and for environment presenrvation.

In this paper were presented and discussed the results obtained with two models developed with the aim to describe temperature conditions in rice crop canopy layer.

Results obtained show that a micro-meteorological approach can give an important tool for agrometeorological monitoring, useful for farmers, crop physiologists and crop modellers.

The future works:

- prosecution of data collection with an improvement of the technology of micrometeorological analysis;
- validation of simulation model for canopy layer;
- release of a micrometeorological module for rice simulation models.

7.6. Acknowledgements

We would like to acknowledge Gabriele Cola for the help in the calibration phase and Enrico Confalonieri for the help in projecting and constructing the floating station.

ANALYSIS OF TEMPERATURES PROFILE IN FLOODED RICE FIELD. PRELIMINARY RESULTS

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Published in: International Rice Research Notes 27 (2002), 39-40

8.1. Abstract

This paper presents some preliminary results of a modelling process that describes a temperature profile (soil, water, canopy and air), using temperature data collected in a standard weather station in 1989-91, in a rice field in Italy during a period in which the field was not completely covered by the canopy. The method used to collect data after the closed canopy stage in 2002 is described.

8.2. Article

Po valley is one of the uppermost northern areas in the Boreal hemisphere for rice crop. At these extreme latitudes, water submerging rice field plays an important driving effect on the meteorological variables. In particular, water affects soil and canopy temperature, by smoothing the differences between thermal extremes (figure 1). Cold shocks or strong changes between day and night temperatures can affect negatively rice cycle and production particularly when occur during emergence and in pre-flowering phases. For this reason European rice growers traditionally consider water level as the most important tool during these phases. Few studies have been carried out for improving knowledge on the influences of water on temperature of canopy. Rice growth and development models, nowadays available to simulate the behavior of rice crop, require as daily input only air temperature, while the meristhematic apex and the global plant behavior depend on water temperature, at least up to stem elongation phase.

This note presents 1) some preliminary results of a modeling process which describes temperature profile in paddy rice field (in the period in which the field is not completely covered by the canopy) by using temperature data collected in a standard weather station in the period 1989-1991 and 2) the description of a new method used to collect data after the close canopy stage in 2002. In temperate (mid latitudes) rice areas, the proposed model would be useful to predict crop phenological stages, strongly influenced by water temperatures (Confalonieri et al., 2001).

Moreover water temperature influences life cycles of all the species leaving in paddy rice fields. For example, mortality and development of the aquatic stages of mosquito species (Aedes, Culex, Anopheles, etc.) are strongly influenced by surface water temperature which determines the number of emerging adult (Jetten and Takken, 1994; Lucassen, 1996).

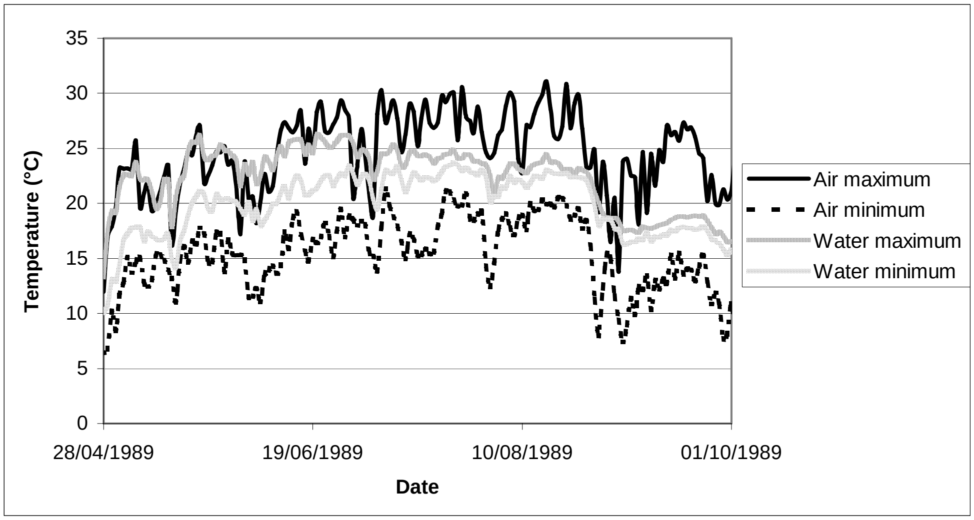

Figure 1 – Daily data showing water smoothing effects on temperature during the crop cycle (data collected in Rosate in 1989)

Experimental data were collected in Rosate (Milan province - Italy) in three seasons (1989, 1990, 1991) with a standard agrometeorological station (Bocchi, 1992). Air temperature at 1.5 m above soil surface, water temperature at the contact with soil, global solar radiation and albedo were recorded. At the moment the course of water temperature between the sowing and the “close canopy” (the canopy completely cover the water – soil) is modeled using two different approaches: empiric and mechanistic. The empiric model simulates temperature at the bottom of the water profile as a function of air temperature of the last 5 days. The mechanistic approach simulates hourly values of surface water temperature by solving the equation of surface energy balance.

Table 1 – Indices of agreement between observed and simulated values. Tn represents the daily minimum temperature and Tx the maximum daily temperature

Parameter	RRMSE (%)	EF	CRM	CD	Slope	Intercept	R2
TwB Min (empiric model)	7	0.71	0.03	0.93	0.87	2.63	0.78
TwB Max (empiric model)	4	0.81	0.01	0.81	0.84	3.86	0.85
TwB Min (mechanistic model)	12	0.56	-0.02	1.48	0.93	0.95	0.58

The comparison between measured and simulated data with the empiric model is shown in table 1. The fitting indices are the one proposed by Loague and Green (1991): the relative root mean squared error (RRMSE, 0-100%, optimum=0%), the coefficient of determination (CD, 0-1, optimum=1, indicates whether the model reproduces the trend of measured values or not), the modelling efficiency (EF, $-\infty \div +\infty$, optimum=1, if positive, indicates that the model is a better predictor than the average of measured values), the coefficient of residual mass (CRM, 0-1, optimum=0, if positive indicates model underestimation) and the parameters of the regression equation between observed and predicted values. The low values of RRMSE and the values of CD close to one show that the model is quite accurate. Table 1 shows also some preliminary simulation results of the mechanistic model. The fitting indices indicate that the model is able to simulate the considered processes in a paddy rice field and they encourage the future activities of development, calibration and validation.

In order to model the temperature profile in the period after the “close canopy” stage, data collected inside the canopy layer (at different heights) and over it are required. For this reason we have built a floating structure (figure 2) with stems holding thermometers into the canopy (at 20 and 60 cm from water surface), on the water surface, on the bottom of the paddy rice field and over the canopy (at 150 cm from water surface). The structure is so light that it is able to float and maintain the system undisturbed near sensors. The structure can float in very shallow water bodies (about four - five centimeters deep) and it is able to follow the water level, variable in function of weed management, fertilizing strategies and crop development. The structure is made of aluminum pipe connected by aluminum or plastic hand made structures. The floats are little slabs of polyurethane. Temperature data loggers (external sensor; 12 bit version) are located inside radiation screens (Micros technologies). In figure 3 some results are shown.

Figure 2 – The floating station (details are in the text)

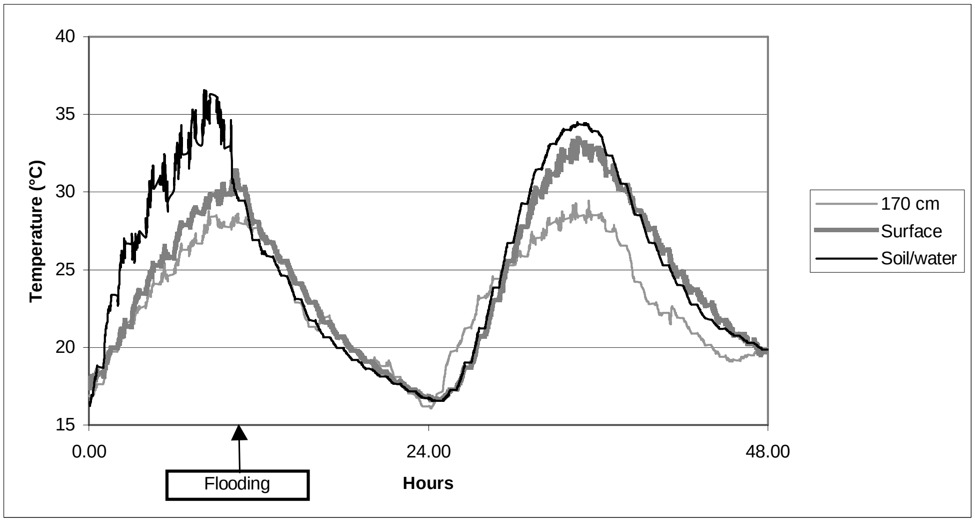

Figure 3 – Temperature measured at different levels with the floating station (Vignate (MI); 48 hours starting from June 1 2002; 6.00 am) at the soil/water interface, on the surface and at 150 cm from water surface. The flooding effect on water temperature is evident in the second day, when water produces a significant delay in the afternoon temperature decrease

CONSTRUCTION AND USE OF A WATER LEVEL SENSOR TO ESTIMATE WATER INFILTRATION RATE IN PADDY RICE FIELDS

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Submitted to: Computers and Electronics in Agriculture (2003)

9.1. Abstract

In the last years, the conflict for water use is becoming a very important topic because of the increasing urban needs which often subtract sources from countryside. For this reason, water management has to be optimized through an accurate monitoring activity of incoming and outcoming water. In case of not-puddled rice fields, infiltration rates can be estimated by measuring water level because in this case evapotranspiration can be neglected. Most of the commercial water level sensors are not suitable for field use and most of them are not accurate for measuring water level when vegetation completely covers the water surface. For these reasons, a new kind of water level sensor based on mechanical principle was developed and it was tested for infiltration rates measurements in two paddy fields during 2002 and 2003 seasons.

Keywords: Water level, paddy fields, rice, infiltration rate, sensor

9.2. Introduction

Flooding water is very important in paddy rice fields for several reasons. It supplies water for the crop and, especially at mid latitudes, it influences water temperature profile by smoothing thermal extremes (Confalonieri et al., 2002). It's also important in relation to weeds and pests management (De Datta et al., 1973), to nutrient cycles and, last but not least, to solutes transport in the soil. Moreover, from an ecological point of view, flooding water is very important for ecological and environmental conservation (Chen and Liu, 2002).

In many parts of the world, increasing urban and industrial water demand (Borrel et al., 1997) are leading to conflicts for water use between countryside and city. In several regions, therefore, water is becoming a precious resource and its management has to be optimized, by limiting water losses from soil – water system. For all this regions, water management is going to be a very important topic in rice research.

In this note, we present (i) a new tool we have developed to measure and record water level in paddy rice fields, (ii) the performances of the sensor at extreme temperatures and (iii) the way we have used it to estimate the infiltration rate in a paddy rice field.

Water level can be measured by using different principles, for example basing on the hydrostatic pressure, either on the optical surface reflection or on ultrasonic waves. The tools developed basing on the first principle are usually not accurate when working in very shallow water bodies (few centimeters height) with high variation in water level, or in case of dirty water. On the other side, the last two mentioned technologies can be affected by errors when hindered by obstacles not present at the moment of sensor establishment (e.g. growing leaves and seaweeds). Moreover, many available sensors are not suitable for outdoor use; in fact most of them cannot work with batteries and/or solar panels or are not sufficiently robust for field activity.

9.3. Materials and methods

Our sensor (figure 1) is based on a mechanical principle, connecting a polyurethane float and a lead counterbalance with a toothed belt which transfers the float vertical movement to a pulley connected to a precision potentiometer (Spectrol Reliance, model 534), so that level differences are traduced in different voltages. In order to kept the belt tensed, the float needs to be weighted down with a lead ballast proportional to the counterbalance. The use of a toothed belt instead of a simple belt allows to avoid misalignment between the pulley and the belt caused by non ordinary and unexpected movement of the belt caused, for example, by birds. The vertical parts of the toothed belt are distanced by two ball bearings located at the sides of the pulley, avoiding physical interference between the counterbalance and the float, which necessarily needs to be flat and large: flat to reduce the draught and to reduce the exposition to wind, and large to support the ballast. A 8 bit, ultra low cost logger (HOBO H8 4-channel External) records the voltage outcoming from the potentiometer, which is connected to a tension generator powered by a rechargeable – replaceable battery. The whole sensor is protected by a case resistant to intense field activities. A 4.5 Ah 6V battery is sufficient for measuring water level for more than 10 days. With the exception of substituting the battery, our sensor doesn't need any maintenance for long periods.

Figure 1. The water level sensor (with opened case)

During 2002 and 2003 seasons, our water level sensor has been tested in two paddy fields near Milan to estimate water infiltration rate. In our application, the evapo-transpired water quantity has been considered negligible (the maximum evapo-transpiration rate at our latitudes is about 6 mm day^{-1}) compared with observed water level decrease. If daily meteorological data are available, the error introduced by evapotranspiration (ET) can be reduced through the application of one of the available equations for ET estimation (e.g. Priestley-Taylor, Penman-Monteith). The advantage of measuring infiltration rate through level measurement is related to the fact that, if the water level is measured before it gets lower than the soil surface roughness, the obtained measure is surely the average value of the whole field. On the contrary, infiltrometers need measurement replications in many parts of the field because the infiltration rate is highly variable from a point to another.

In order to estimate the infiltration rate without influences due to other water inputs or outputs, we have selected 3 and 5 sub-data sets respectively for the 2002 and 2003 seasons corresponding to days in which (i) no rainfall has been observed and (ii) no water input or output took place through canals (figure 2). To obtain the infiltration rate measure, we have found the slope of the straight lines interpolating the curves shown in figure 3.

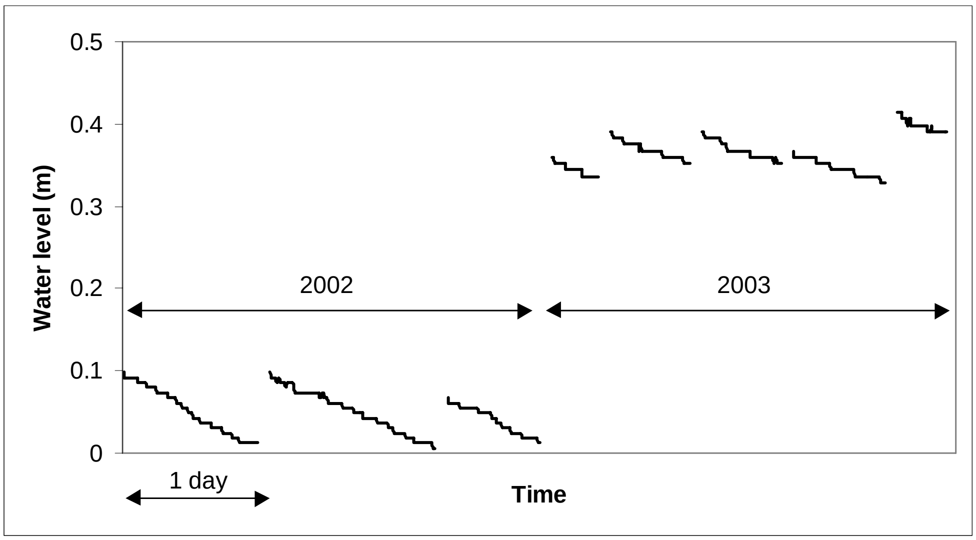

Figure 2. The 3 and 5 sub-data sets used, respectively, to estimate water infiltration rate in 2002 and 2003 seasons

9.4. Results and discussion

Table 1 shows the infiltration rate calculated on the 2002 and 2003 sub-data sets. It's possible to notice that the coefficient of variation (standard deviation / mean value) is very low (9 % for 2002 and 5 % for 2003). This allows to consider sufficiently precise the proposed method. In fact, the differences between levels measured in different points of the field (also if it has been leveled) is usually more than the standard deviation we have obtained (0.008 m for 2002 and 0.004 for 2003).

Table 1. Measured water infiltration rate

Year	Infiltration rate (m day^{-1})					mean (m day^{-1})	standard deviation (m day^{-1})	coefficient of variation (%)
	1st curve	2nd curve	3rd curve	4th curve	5th curve			
2002	0.095	0.083	0.079			0.086	0.008	9
2003	0.075	0.071	0.077	0.070	0.067	0.072	0.004	5

The sensor has shown to be sufficiently precise. It measures water level with a 6 mm resolution, due to the logger resolution. In figure 3 the calibration graph of the sensor for the 2002 season is shown. The precision of the sensor is demonstrated by the R^2 of linear regression (between meters and voltage) very close to 1. Therefore, the inverse of the linear regression equation is used to convert values recorded by the logger into meters.

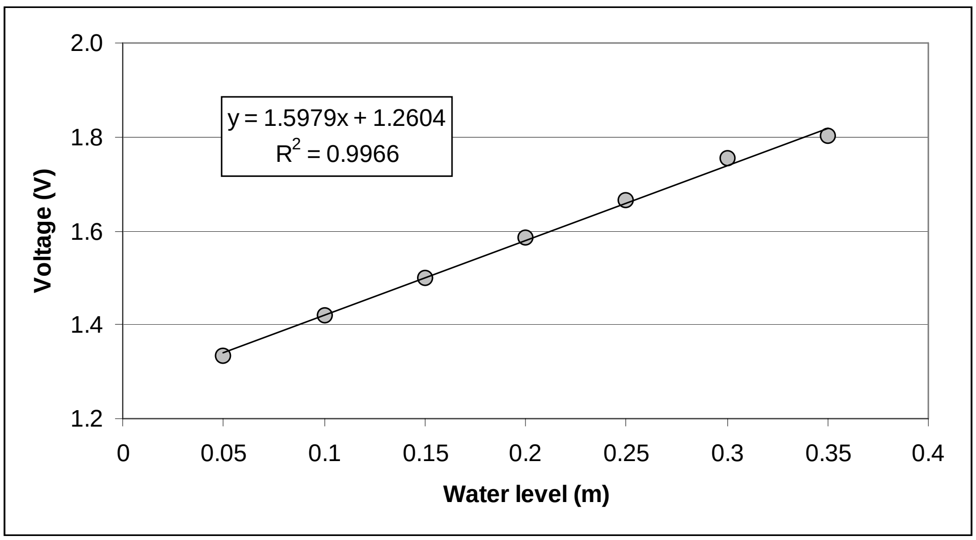

Figure 3. Sensor calibration graph for 2002 season

Although the electronics of the sensor is quite simple, it has not demonstrated to be sensible to extreme temperatures. The calibrations carried out with air temperatures of 5, 27 and 60 °C (a range wider than the one which can be observed in field conditions) resulted in the same equation.

However, an improvement of the sensor is going on by adopting more sophisticated electronics. This will lower the resolution threshold and will increase the utilization range (actually of 1.5 m).

The flat float and the thin belt allow to neglect errors due to oscillations caused by wind; moreover, except for the first part of crop cycle, the growing vegetation shields both the belt and the float.

9.5. Conclusions

The sensor has shown to be adequate for our purposes. The installation of the sensor in the field and the process of extracting and analyzing data are very easy. Moreover, the robustness and the simplicity of the structure make the sensor remarkably reliable.

The proposed method is useful in case of high water infiltration rates because of the assumption of neglecting evapotranspiration. These high rates are usually observed in case of not puddled fields or in case of delayed flooding, very common situations in northern Italy and in other European countries (e.g. Liu et al., 2001).

9.6. Acknowledgments

We would like to acknowledge Enrico and Lorenzo Confalonieri for the help given for constructing the sensor.

CONCLUSIONS

Agroecological indicators and simulation models have shown to be powerful tools for evaluating the environmental impact of agrotechniques. The firsts provide qualitative and synthetic indications about important topics of nowadays agriculture, although the need of few information for the calculation.

On the other side, simulation models need lots of precise information to run and, before being used, they need an accurate work of calibration and validation. Although their application at regional scale is often prevented by the impossibility of recovering sufficient data, they have demonstrated to be able to quantitatively describe the system they are projected for. In particular, CropSyst has confirmed to be successfully adaptable for the simulation of processes related to growth and development of different herbaceous crops and to water and nitrogen balances in the plant-soil system.

The study of complex systems (agroecosystems) has implied a cascade process which, starting from a problem belonging to a particular aspect of research, has leaded to find solutions in fields belonging, in some cases, to other disciplines. This is why, during this thesis, new technologies and tools were projected and developed, such as, for example, instrumentation for micrometeorological monitoring. This has allowed to collect original and high quality experimental data.

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SUMMARY

In many intensified agroecosystems the efficiency of the production factors (i.e. water, fertilizers, pesticides) is often low, and this corresponds to a high risk of pollution. European Community policy has been training and supporting farmers with several documents/laws aiming at reducing negative effects on the environment of agricultural activities and setting alternative to intensive farming system.

Tools are needed nowadays to evaluate the achievement of objectives and/or for monitoring adequately and globally farmer activities at regional scale. Direct measurement at field scale can be too costly and time consuming. For this reason, in the last years, new tools have been developed: agroecological indicators and simulation models.

Both these tools have to be parameterized and tested before being used. This thesis aims to setting up and/or developing tools for the evaluation of agroecosystems efficiency in the Po Valley. In particular, the objectives of this work are:

- the calibration of the model CropSyst for the simulation of growth and development of alfalfa, winter wheat and rice;
- the parameterization of CropSyst for the simulation of the processes related to water and nitrogen balances in the plant-soil system;
- the setting-up of indicators involved with crops rotation, crops spatial heterogeneity and yield gap;
- the evaluation of the technical adequacy of the calibrated tools for agricultural and environmental investigations.

The results of the experiences to meet these objectives are presented in Chapters 2 – 6. Chapter 7 – 9 are about three works aiming at improving rice simulations and about new technologies developed during the research.

Appendixes 1 – 3 present additional tools developed and used during this thesis.

Bockstaller et al. (1997) proposed a set of agroecological indicators (AEIs), calculated with data available on farm and expressed on a scale between 0 and 10. These AEIs match the criteria provided by OECD (1999) for the ideal indicator (simple, representative of environmental conditions, allowing comparisons, theoretically well founded, with a threshold or reference value). The indicators of crop diversity and crop sequence were parameterized by adapting them to the study area and tested (Chapter 2) on 50 farms belonging to the municipalities of Corbetta and Rosate. The crop diversity indicator assigns higher values to farms with "smaller" plots and where more species are cultivated. The other one parameterizes the effects of a crop on the following one (including effects on soil structure, diseases, parasites, weeds, nitrogen in residues) and the number of crops in rotation in the last four years. At Rosate crop rotations are relatively simple and frequently include several years of rice followed by few years of other crops (e.g. maize). On average, crop diversity indicator is lower at Rosate than at Corbetta, where water availability and coarse soils do not allaw rice to be calculated as at Rosate. The crop sequence indicator allows to consider more diversified the rotations at Rosate. Both the indicators have shown to be able to characterize qualitatively the agroecosystems by needing very few input data

In several regions of northern Italy, the increasing dimension of urban areas leads to conflicts in water use between countryside and city, particularly where rice is traditionally cultivated in flooded conditions. Sometimes, regional Irrigation Boards are not able to assure sufficient amounts of water for rice paddies determining decreases in yields. These losses have been so far estimated by agronomist and/or economist in a traditional way, basing on their own experience. In Chapter 3, the simulation model CropSyst and the indicator Yield gap were used to quantify rice yield losses occurred in 2001 in some rice farms of southern Milan (Italy) due to insufficient water availability. The indicator compare the potential production (simulated by the model) that would be obtained with an optimized management with the actual one. This study encourages the developement of a new integrated methodology aiming at assessing the economical damage due to insufficient water availability. In this Chapter, the indicator has been tested in extreme conditions but it could also be used for evaluating the efficiency in inputs transformation, by comparing potential production with the one obtained with a not completely adequate crop management.

The need to set-up appropriate simulation models for scenario analysis of intensive forage cropping systems in northern Italy, where alfalfa plays a major role, is the object of Chapter 4. CropSyst was used to simulate aboveground biomass accumulation and soil water content for two alfalfa meadows seeded in 1996 and 1997 in Lodi (northern Italy). For most of the cuts, the model simulates appropriately the growth of the crop: the relative root mean squared error (RRMSE) between observed and measured aboveground biomass ranged between 3 and 6% after calibration and between 3 and 5% after validation. RRMSE for soil water content ranged between 13 and 21% after calibration and between 10 and 20% after validation. Even if some limitations are explicitly addressed, this crop parameter set can be already used for explorative scenario simulations in the study area. This work has demonstrated the robustness of the model for perennial forage crops simulations and has suggested some improvements of the model (automatic scheduling of cuts, role of crown reserves).

With the aim of extending the information available to run scenario simulations in northern Italy with the cropping systems simulation model CropSyst, we set-up crop parameters for winter wheat by deriving information from existing experimental data sets and literature (Chapter 5). The experiments, carried out in northern Italy between 1986 and 2001, quantified the dynamics of aboveground biomass (AGB), plant nitrogen (N) concentration (PNC) and nitrogen uptake (UPTK) by means of periodical measurements. Part of the calibration process was carried out on modules (crop development and growth) separated from the main model. The relative root mean squared error (RRMSE) obtained after calibration ranged between 9 and 30% for AGB, was 10% for PNC and ranged between 8 and 28% for UPTK. Corresponding RRMSE during validation ranged between 17 and 32% for AGB, 6 and 40% for PNC, 9 and 24% for UPTK.

Rice represents the staple food for more than half of the world's population and an increase in yield will be required in the next years, mainly through a better management of water and nitrogen. Although it has been already used for many herbaceous crops, CropSyst has not yet been parameterized for rice (*Oryza sativa* L.). In Chapter 6, CropSyst crop parameters were calibrated and validated for the simulation of the behavior of three groups of varieties (Japonica early, Japonica medium-late and Indica) by using data collected in different locations of northern Italy between 1989 and 2002. Moreover, the model has been tested for the simulation of soil nitrogen concentration under flooded conditions, by using measured data of crop nitrogen uptake, water infiltration rate and soil N-NH_4 and N-NO_3 concentrations, gathered during 2002 growing season at two experimental sites. The average relative root mean squared error (RRMSE) between measured and simulated values of aboveground biomass after the calibration and after validation was 20 and 22%. The model has simulated nitrification and denitrification rates similar to the ones found in literature for flooded soils and has reproduced with sufficient accuracy the soil nitrogen content during the season.

The knowledge of micrometeorological conditions in flooded rice fields is crucial for better modelling the behaviour of the crop at mid and high latitudes, where the thermal mitigation provided by water layer is significant against the climatic risk of low temperatures in spring and early summer. Two micrometeorological models (a mechanistic and an empirical one) for the simulation of thermal profile related to water and near water temperatures were proposed (Chapter 7), calibrated and validated with data gauged in some rice fields located near Milano. The results show that these models could improve the performances of the physically based crop simulation models currently used for crop growth, development and production analysis.

In order to develope micro-meteorological models like the ones just described, appropriate technologies are needed. In particular, to study the vertical thermal profile in paddy fields, a floating weather station able to measure temperature at different distance from water surface (above and below it) is needed. No commercial products exist for this objective. For these regions a floating weather station was developed and used (Chapter 8) to collect micro-meteorological data in paddy fields near Milano (Italy). The particular structure of the station has allowed to collect almost undisturbed data also inside the canopy.

In order to correctly interpret the data collected with the floating station, continuous data about the level of flooding water are needed. Moreover, continuous water level data can be used to easily estimate the high water infiltration rate observed in the study area because, in this conditions, evapotranspiration can be neglected. For these reasons, a water level sensor adapted for field activity was developed (Chapter 9). By using this tool, infiltration rates of 0.086 and 0.072 m day^{-1} were measured for two fields sited near Milano during 2002 and 2003 seasons.

Agroecological indicators and simulation models have demonstrated to be powerful tools for the analysis of agroecosystems. The firsts provide qualitative information by needing few data, the others are able to quantify several processes although they need to be accurately calibrated and validated before being used and they need lots of data to run. The study of the agroecosystem from different points of view has leaded to projecting and developing new technologies for the monitoring of particular aspects of the system.

Keywords:

micro-meteorological monitoring, sustainability, agroecosystem, agroecosystem efficiency, agroecological indicator, crop diversity, crop sequence, simulation model, yield losses, forage crops, growth and development, northern Italy, soil water content, plant nitrogen concentration, nitrogen uptake, aboveground biomass, flooded rice, nitrogen balance, water balance, CropSyst, paddy rice, flooded field temperature profile, model, water level, infiltration rate, sensor, floating weather station, alfalfa, rice, wheat.

RIASSUNTO

In molti agroecosistemi intensivi l'efficienza di trasformazione dei fattori di produzione (ad esempio acqua, fertilizzanti, fitofarmaci) è spesso bassa e questo corrisponde, in genere, ad un elevato rischio di inquinamento. La politica della Commissione Europea sta formando e supportando gli agricoltori con documenti/leggi atti a ridurre gli effetti negativi sull'ambiente delle pratiche agricole e individuare alternative all'agricoltura intensiva.

Sono necessari strumenti per valutare il successo di questi obiettivi e/o per monitorare adeguatamente e globalmente l'attività dell'agricoltore a scala territoriale. Le misure dirette a scala di appezzamento sono troppo costose e richiederebbero molto tempo. Per questi motivi, negli ultimi anni, sono stati sviluppati nuovi strumenti: gli indicatori agroecologici ed i modelli di simulazione.

Entrambi questi strumenti devono essere parametrizzati e testati prima di essere utilizzati. Questa tesi ha come scopo la messa a punto e/o lo sviluppo di strumenti per la valutazione dell'efficienza degli agroecosistemi nella pianura padana. In particolare, gli obiettivi sono:

- la calibrazione del modello CropSyst per la simulazione della crescita e dello sviluppo di erba medica, frumento tenero e riso;
- la parametrizzazione di CropSyst per la simulazione dei processi legati ai bilanci di acqua e azoto nel sistema suolo-coltura;
- la messa a punto di indicatori riguardanti la successione delle colture, l'eterogeneità delle colture in azienda e il deficit di resa;
- la valutazione dell'adeguatezza tecnica degli strumenti messi a punto per studi sulla produttività e sull'impatto dei sistemi agricoli.

I risultati del lavoro svolto al fine di raggiungere questi obiettivi è presentato nei capitoli dal 2 al 6. I capitoli dal 7 al 9 riguardano il

miglioramento dei processi di simulazione in ambiente di risaia sommersa e nuove tecnologie sviluppate nel corso della ricerca. Le appendici 1 – 3 presentano altri strumenti (tecnici e informatici) sviluppati ed utilizzati nel corso di questa tesi.

Bockstaller et al. (1997) hanno proposto un set di indicatori agroecologici (AEIs), calcolati con dati disponibili in azienda ed espressi in una scala da 0 a 10. Questi AEIs sono conformi ai criteri espressi da OECD (1999) per l'indicatore ideale (semplice, rappresentativo di condizioni ambientali, permette confronti, con robuste basi teoriche, con una soglia o un valore di riferimento). Gli indicatori di diversità colturale e di successione colturale sono stati parametrizzati adattandoli all'area di sudio e testati (capitolo 2) su 50 aziende appartenenti ai comuni di Corbetta e Rosate. L'indicatore di diversità colturale assegna valori alti ad aziende con campi "piccoli" e nelle quali sono coltivate molte specie. L'altro parametrizza gli effetti di una coltura su quella che segue (per quanto riguarda struttura del suolo, malattie, parassiti, malerbe, azoto nei residui) e il numero di colture in rotazione negli ultimi quattro anni. A Rosate, le successioni colturali sono relativamente semplici e frequentemente includono molti anni di riso seguiti da pochi anni di altre colture (ad esempio mais). In media, l'indicatore di diversità è più basso a Rosate che a Corbetta, dove la disponibilità idrica e le tipologie di suolo non consentono di coltivare il riso come a Rosate. L'indicatore di successione colturale considera le rotazioni di Rosate più diversificate. Entrambi gli indicatori hanno dimostrato di poter caratterizzare qualitativamente gli agroecosistemi a partire da pochissimi dati.

In molte regioni del nord Italia, le crescenti dimensioni delle aree urbane portano a conflitti per l'uso dell'acqua tra la città e la campagna, particolarmente dove il riso è tradizionalmente coltivato in sommersione. Non di rado, i consorzi di gestione dell'acqua non sono in grado di assicurare quantità di acqua sufficienti per le risaie con conseguenti decrementi nelle rese. Queste perdite sono da sempre stimate da agronomi e/o economisti in modo tradizionale, basandosi sull'esperienza di esperti del settore. Nel capitolo 3, il modello di simulazione CropSyst e l'indicatore

Yield gap sono stati utilizzati per quantificare le perdite verificatesi nel 2001 in alcune aziende risicole a sud di Milano dovute a insufficiente disponibilità idrica. L'indicatore confronta la produzione potenziale (simulata dal modello), che si sarebbe potuta ottenere ottimizzando la gestione, con quella reale. Lo studio incoraggia lo sviluppo di una nuova metodologia integrata, atta a valutare il danno economico dovuto ad insufficiente disponibilità idrica. In questo capitolo l'indicatore è stato testato in condizioni estreme ma può anche essere utilizzato per valutare l'efficienza di trasformazione degli input in azienda, attraverso il confronto tra produzioni potenziali e quelle ottenute con gestioni non del tutto adeguate.

La necessità di mettere a punto modelli di simulazione per analisi di scenari dei sistemi foraggeri intensivi nel nord Italia, dove l'erba medica gioca un ruolo importante, è oggetto del capitolo 4. CropSyst è stato utilizzato per simulare l'accumulo di biomassa aerea e il contenuto idrico del terreno di due medicai seminati nel 1996 e nel 1997 a Lodi (nord Italia). Per la maggior parte degli sfalci, il modello simula adeguatamente la crescita della coltura: l'errore quadratico medio relativo (RRMSE) tra i dati misurati e quelli simulati di biomassa aerea è tra 3 ed 6% al termine della calibrazione e tra 3 e 5% dopo la fase di validazione. Il valore dell'RRMSE per quanto riguarda il contentuo idrico del terreno è compreso tra 13 e 21% dopo la calibrazione e tra 10 e 20% dopo la validazione. Anche se sono state evidenziate alcune limitazioni, il set di parametri colturali può essere utilizzato per analisi di scenari nell'area di studio. Questo lavoro ha inoltre dimostrato la robustezza del modello per la simulazione di colture foraggere pluriennali ed ha suggerito diversi miglioramenti al modello (gestione automatica degli sfalci, ruolo delle riserve della corona).

Con lo stesso obiettivo, sono stati messi a punto i parametri colturali di CropSyst per il frumento tenero derivandoli da dati sperimentali e da letteratura (capitolo 5). Le sperimentazioni, condotte nel nord Italia tra il 1986 ed il 2001, quantificano le dinamiche della crescita della coltura, della concentrazione di azoto nella stessa e delle asportazioni di azoto. Parte del processo di calibrazione è stato condotto su moduli (crescita e sviluppo della coltura) separati dal modello principale. L'RRMSE ottenuto al termine della calibrazione è compreso tra 9 e 30% per la biomassa aerea, è pari a 10% per la concentrazione di azoto nella coltura e, per le asportazioni di azoto, è risultato tra 8 e 28%. I corrispondenti valori di RRMSE in fase di validazione sono risultati tra 17 e 32%, tra 6 e 40% e tra 9 e 24 %.

Il riso rappresenta l'alimento base per più di metà della popolazione mondiale e, nei prossimi anni, è richiesto un incremento produttivo, per lo più attuabile attraverso una migliore gestione delle risorse acqua e azoto. Sebbene CropSyst sia già stato utilizzato per diverse colture erbacee, manca una sua parametrizzazione per riso (*Oryza sativa* L.). Nel capitolo 6, sono stati calibrati e validati i parametri colturali del modello per tre gruppi di varietà (Japonica precoci, Japonica medio-tardive, Indica) utilizzando dati sperimentali raccolti in diverse località del nord Italia tra il 1989 ed il 2002. Il modello è stato inoltre testato per la simulazione del bilancio dell'azoto in condizioni di sommersione, utilizzando dati riguardanti l'azoto asportato, il tasso di infiltrazione dell'acqua nel suolo e le concentrazioni di azoto nitrico e ammoniacale nel terreno, raccolti nel 2002 in due località. L'RRMSE tra dati misurati e simulati di biomassa aerea a fine calibrazione è risultato compreso tra 20 e 22%. Il modello ha simulato tassi di nitrificazione e denitrificazione analoghi a quelli trovati in letteratura per suoli sommersi ed ha riprodotto con sufficiente accuratezza il contenuto di azoto nel corso della stagione.

La conoscenza delle condizioni micrometeorologiche in risaia sommersa è cruciale per meglio modellizzare il comportamento della coltura alle medie ed alte latitudini, dove la mitigazione termica dovuta all'acqua è importante contro il rischio climatico dovuto alle basse temperature che possono verificarsi in primavera ed estate. Sono stati proposti (capitolo 7) e calibrati con dati raccolti vicino a Milano due modelli micrometeorologici (uno empirico ed uno meccanicistico) per la simulazione del profilo termico in acqua e negli strati di aria immediatamente al di sopra della superficie dell'acqua. I risultati dimostrano che i modelli proposti possono migliorare le performances dei modelli meccanicistici attualmente usati per la simulazione della crescita, della produzione e dello sviluppo della coltura.

Al fine di sviluppare modelli micrometeorologici come quelli appena descritti, è necessaria una tecnologia appropriata. In particolare, per studiare il profilo termico verticale in risaia sommersa, è necessaria una stazione meteorologica galleggiante in grado di misurare la temperatura a diverse distanze dalla superficie dell'acqua (sopra e sotto di essa). Dal momento che non esisteva in commercio un'apparecchiatura che rispondesse a questi requisiti, è stata progettata ed utilizzata (capitolo 8) una stazione galleggiante per la misura di variabili micrometeorologiche. La particolare struttura della stazione ha permesso di raccogliere dati quasi indisturbati anche all'interno della canopy. Al fine di interpretare correttamente i dati raccolti dalla stazione galleggiante sono necessarie misure in continuo del livello dell'acqua. Questi dati possono essere inoltre utilizzati per stimare gli alti tassi di infiltrazione dell'acqua osservati nell'area di studio dal momento che, in queste condizioni, l'evapotraspirazione può essere considerata un output di acqua trascurabile. Per queste ragioni è stato sviluppato un sensore di livello adatto all'attività di campo (capitolo 9) con il quale, nel corso del 2002 e del 2003, sono stati misurati tassi di infiltrazione rispettivamente di 0.086 e 0.072 m giorno^{-1} in due località vicino a Milano.

Gli indicatori agroecologici ed i modelli di simulazione si sono rivelati strumenti potenti per lo studio degli agroecosistemi. I primi forniscono informazioni di tipo qualitativo necessitando di pochi dati, gli altri sono in grado di quantificare diversi processi anche se necessitano di molti dati in input e di essere accuratamente calibrati e validati prima di essere utilizzati. Lo studio dell'agroecosistema da diversi punti di vista ha inoltre portato alla progettazione e allo sviluppo di nuove tecnologie per il monitoraggio fisico del sistema.

Parole chiave:

monitoraggio micrometeorologico, sostenibilità, agroecosistema, efficienza dell'agroecosistema, indicatori agroecologici, diversità colturale, successione colturale, modello di simulazione, perdite di produzione, colture foraggere, crescita e sviluppo, nord Italia, contenuto idrico del terreno, concentrazione di azoto nella coltura, asportazioni di azoto, biomassa aerea, riso in sommersione, bilancio dell'azoto, bilancio idrico, CropSyst, risaia sommersa, sensore, stazione meteorologica galleggiante, erba medica, riso, frumento.

APPENDIX 1

COLIDATA: A SOFTWARE FOR THE STATISTICAL EVALUATION OF ANALYTICAL DATA

R. Confalonieri, B. Scaglia

Introduction

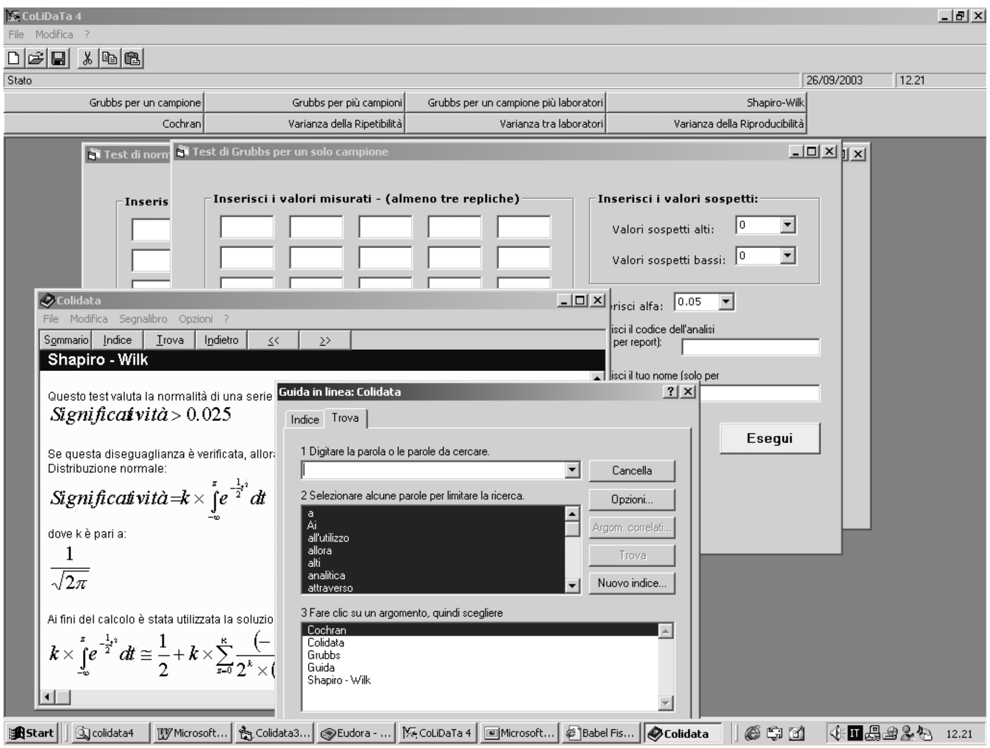


Figure 1. CoLiDaTa’s interface

CoLiDaTa is a software for the statistical evaluation of analytical data. It was originally developed for allowing the user to discard one or more outliers from a group of data. ISO 5725 defines the outliers as “entries among the original test results, or in the tables derived from that, that deviate so much from the comparable entries in the same table that they are considered irreconcilable with the other data”. After this definition, ISO 5725 adds that “experience has taught that outliers cannot always be avoided and they have to be taken into consideration in a similar way to the treatment of missing data”.

When someone have to analyze experimental results (with replications), it’s possible that some of the values of the replications appear “wrong” because they differ from the other replicated values. Very often, the experience is not sufficient for discarding reasonably the data which appear “strange”. Statistical tests are available for doing that but they need a lot of time to be executed by hand. For this reasons, CoLiDaTa can calculate Shapiro-Wilk normality test, Grubbs’ test for outliers (indicated by ISO 5725; valid if the distribution is normal) and the Dixon’s outliers test. This tests will be discussed later in this text.

Successively, other utilities was introduced in the software: Cochran’s test for the homogeneity of variances, procedures for evaluating the repeatability and reproducibility of a measurement method, procedure for regressions.

CoLiDaTa contains the tabulated values for the implemented tests: no reference tables are needed and it’s very easy to use the software. Two modalities for data input are available: a simple grid useful for executing tests on few values and the possibility of opening text files (derived, for example, from Excel files) when several data have to be analyzed. An online – Help is available with the documentation and the user’s guide.

In this text, only the utilities for the Shapiro-Wilk test, the Grubbs’ test, the Dixon’s test, the Cochran’s test and for the linear regression will be discussed: the other utilities were not used for the drawing up of this volume.

Documentation

Cochran's test (ISO 5725)

Given a set of p standard deviations s_i, all computed from the same number (n) of replicate results, Cochran's test statistic, C, is:

$$C = \frac{s_{\max}^2}{\sum_{i=1}^{p} s_i^2}$$

where s_{max} is the highest standard deviation in the set.

a) If the test statistic is less than or equal to its 5 % critical value, the item tested is accepted as correct.
b) If the test statistic is greater than its 5 % critical value and less than or equal to its 1 % critical value, the item tested is called a straggler and is indicated by a single asterisk.
c) If the test statistic is greater than its 1 % critical value, the item is called a statistical outlier and is indicated by a double asterisk.

Grubbs' test (ISO 5725)

Given a set of data x_i for $i = 1, 2, \ldots, p$, arranged in ascending order, then to determine whether the largest observation is an outlier using Grubbs' test, compute the Grubbs' statistic, G_p.

$$G_p = \frac{\left(x_p - \bar{x}\right)}{s}$$

where

$$\bar{x} = \frac{1}{p}\sum_{i=1}^{p} x_i$$

and

$$s = \sqrt{\frac{1}{p-1}\sum_{i=1}^{p}\left(x_i - \bar{x}\right)^2}$$

To test the significance of the smallest observation, compute the test statistic:

$$G_1 = \frac{\bar{x} - x_1}{s}$$

a) If the test statistic is less than or equal to its 5 % critical value, the item tested is accepted as correct.
b) If the test statistic is greater than its 5 % critical value and less than or equal to its 1 % critical value, the item tested is called a straggler and is indicated by a single asterisk.
c) If the test statistic is greater than its 1 % critical value, the item is called a statistical outlier and is indicated by a double asterisk.

Dixon's test

Dixon's test is generally used for detecting a small numbers of outliers. The τ statistic for the highest value is computed by using the following equations:

Observations

$$3-7 \qquad \tau = \frac{x_n - x_{n-1}}{x_n - x_1}$$

$$8-10 \qquad \tau = \frac{x_n - x_{n-1}}{x_n - x_2}$$

$$11-13 \qquad \tau = \frac{x_n - x_{n-2}}{x_n - x_2}$$

$$14-20 \qquad \tau = \frac{x_n - x_{n-2}}{x_n - x_3}$$

The τ statistic for the lowest value is computed by using the following equations:

Observations

$$3-7 \qquad \tau = \frac{x_2 - x_1}{x_n - x_1}$$

$$8-10 \qquad \tau = \frac{x_2 - x_1}{x_{n-1} - x_1}$$

$$11-13 \qquad \tau = \frac{x_3 - x_1}{x_{n-1} - x_1}$$

$$14-20 \qquad \tau = \frac{x_3 - x_1}{x_{n-2} - x_1}$$

The τ statistic is compared with a critical value at a chosen value of alpha. If the τ statistic is less than the critical value, the null hypothesis is not rejected, and the conclusion is that no outliers are present. If the τ statistic is greater than the critical value, the null hypothesis is rejected, and the conclusion is the most extreme value is an outlier.

Shapiro-Wilk test

This test evaluate the normality of a group of value through the following inequality:

$$S > 0.025$$

If this inequality is verified, the group of values is normally distributed. S is calculated from the normal distribution:

$$S = k \times \int_{-\infty}^{z} e^{-\frac{1}{2}t^2} dt$$

where:

$$k = \frac{1}{\sqrt{2\pi}}$$

To solve the equation, the following numerical solution was adopted:

$$S = k \times \int_{-\infty}^{z} e^{-\frac{1}{2}t^2} dt \cong \frac{1}{2} + k \times \sum_{z=0}^{k} \frac{(-1)^k \times z^{2k+1}}{2^k \times (2k+1) \times k!}$$

Linear regression

Given a set of *n* data points X(n), Y(n) with individual standard deviations Sig(n), this procedure fits them to the straight line

$$y = a + bx$$

by minimizing Chi^2.

The procedure returns a, b, and their respective probable uncertainties SigA and SigB, the chi-square, and the goodness-of-fit probability Q.

User's interface

In figure 2 the Grubbs' test form for the input of data related to one sample with more replications is shown. The data have to be ranked in ascending order. This modality of data input is the same for Dixon's and Shapiro-Wilk tests. For the Grubbs' test, the number of high or low suspected values have to be indicated.

The user can insert also a code for identify the analysis and his name. In this way, when the "Esegui" command is selected, the data are saved in a directory called "c:\colidata\vecchie analisi\" and it will be possible to open them later for other considerations. If the operator's name and the identifying code are specified, CoLiDaTa prints a report (figure 3) (it's possible to find it in the directory "c:\colidata\output\". If the operator's name and the identifying code are not specified, CoLiDaTa gives the results by using message boxes.

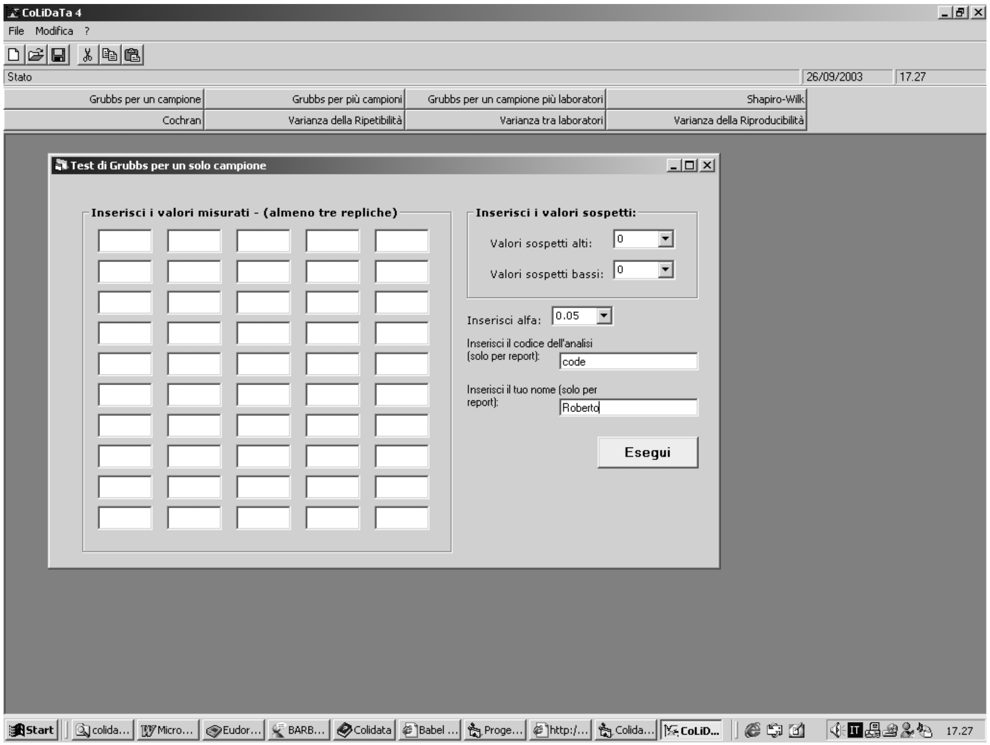


Figure 2. The Grubbs' test form for one sample and many replications

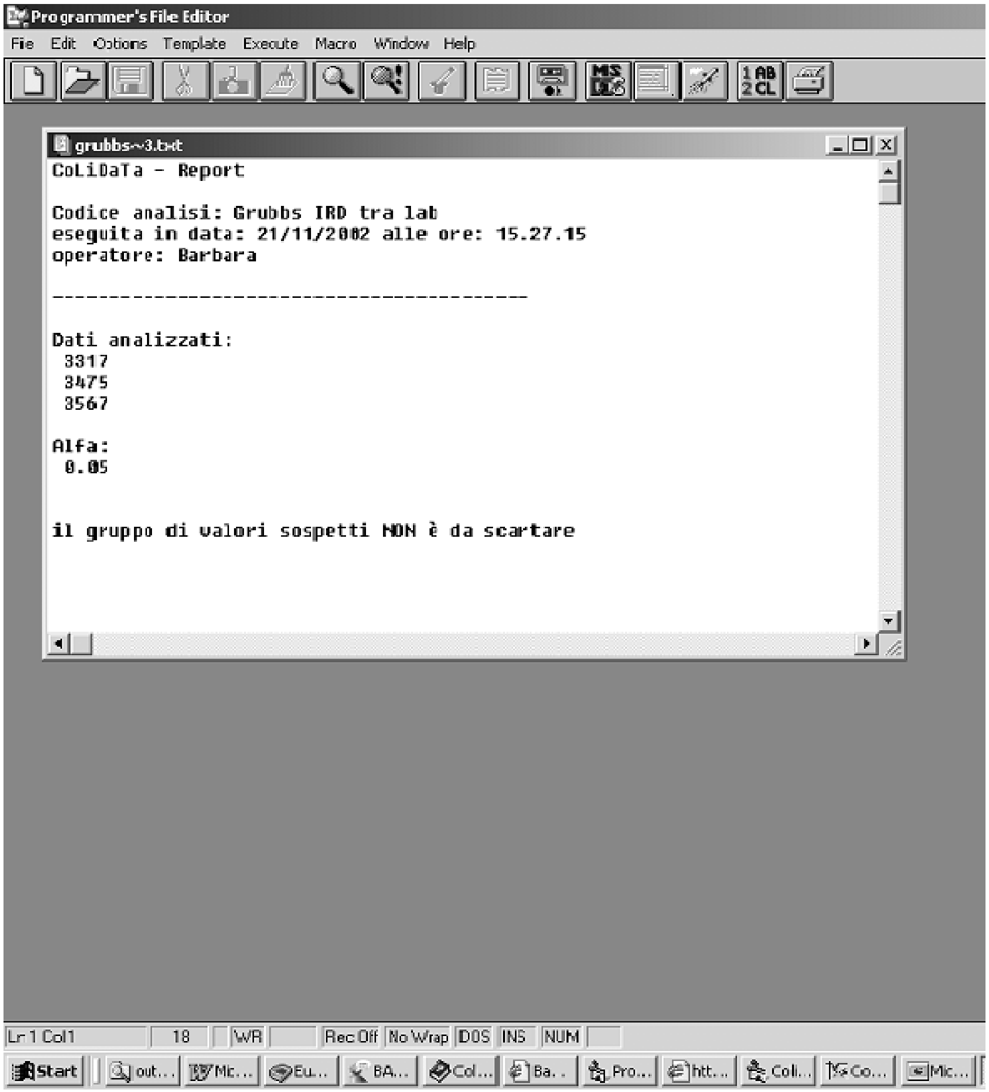
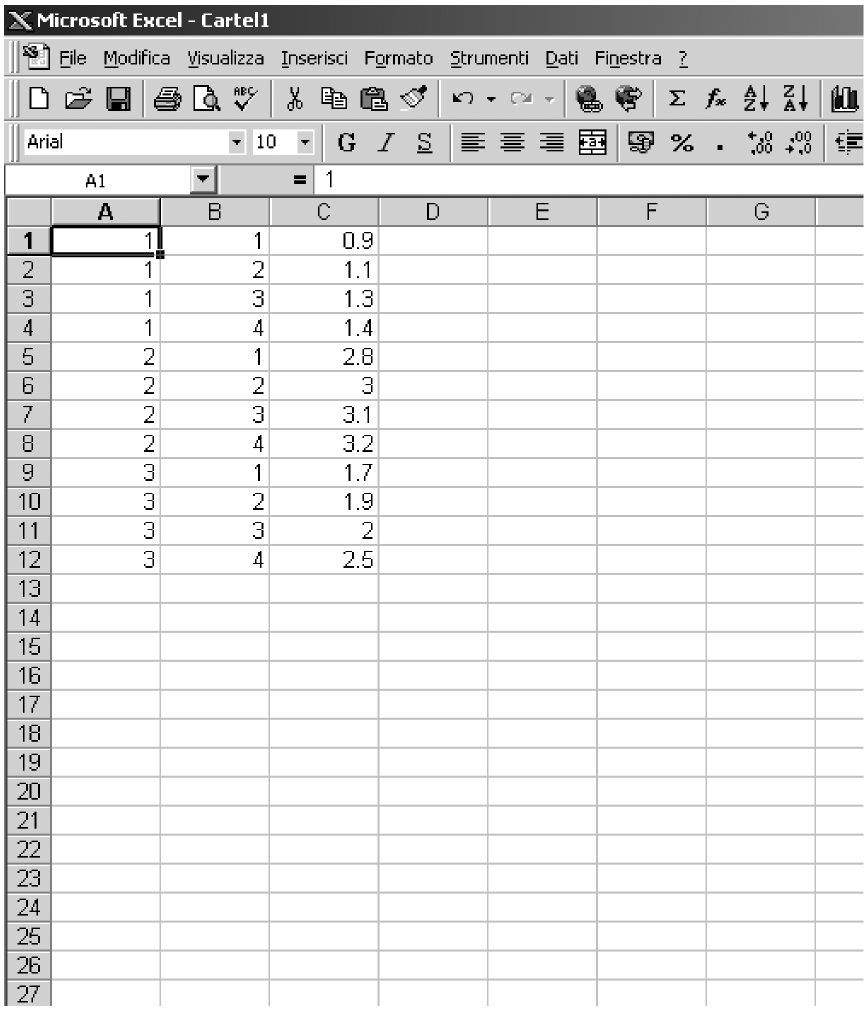


Figure 3. Example of report containing the results of the computations

In order to apply the Grubbs' test to many samples with many replications, it's recommended to insert the values in an Excel Data Sheet as indicated in figure 4.a. In the first column a sample ID is specified, in the second one a number for the identification of the replication is indicated and in the third the measured values are ranked. The table obtained in this way have to be saved as prn file.

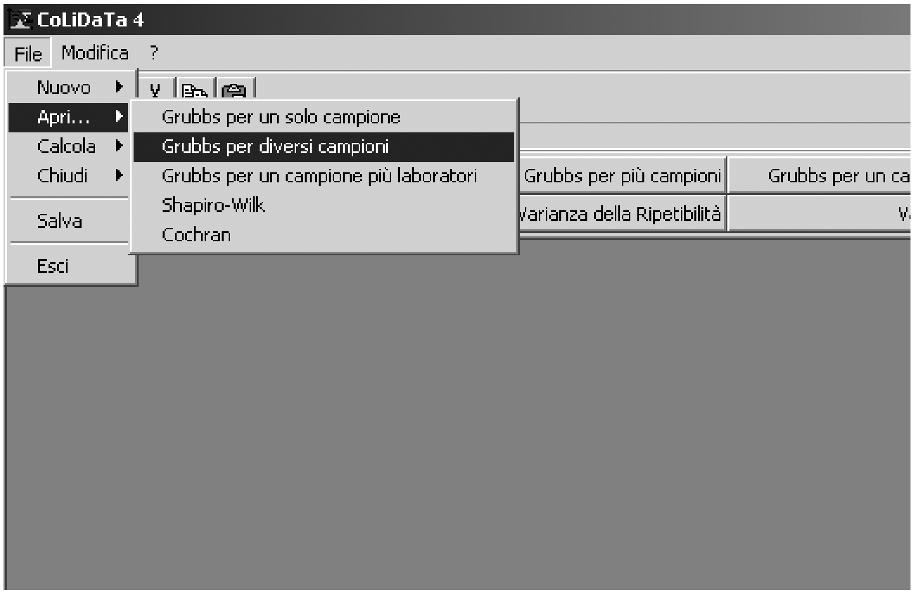
In order to open the prn file, select the command "File → Apri… → Grubbs per diversi campioni" (figure 4.b). CoLiDaTa will automatically apply the Grubbs' test to all the samples.

The procedure for applying Dixon's and Shapiro-Wilk tests are analogue to the one described for the Grubbs' test.



	A	B	C	D	E	F	G
1	1	1	0.9				
2	1	2	1.1				
3	1	3	1.3				
4	1	4	1.4				
5	2	1	2.8				
6	2	2	3				
7	2	3	3.1				
8	2	4	3.2				
9	3	1	1.7				
10	3	2	1.9				
11	3	3	2				
12	3	4	2.5				

a)



b)

Figure 4. How automatically apply the Grubbs' test to many samples

More details about how to use CoLiDaTa are described in the software's Guide.

APPENDIX 2

CONSTRUCTION OF A SOIL SAMPLER FOR PADDY FIELDS

R. Confalonieri

Introduction

In flooding conditions, oxygen availability for nutrients transformations is reduced to the superficial soil layer (about 10 cm). The classical soil samplers used for agronomic experimentation are often inadequate in flooding conditions because of the reduced soil consistency. For this reason, an original soil sampler was developed (figure 1 and 2).

Figure 1. Prototype of the soil sampler for paddy fields

Description of the sampler (figure 2 for the references)

The structure of the sampler consists of a cylinder (A) in which a piston (B) slides. The piston is made of nylon because this material is auto – lubricating and this is important for avoiding the seizing of the piston inside the cylinder due to soil particles. Two handles (C) are present at the upper extremity of the cylinder and another one (D) is connected to the piston by a pipe (E) in order to facilitate the movement of the piston inside the cylinder. A stopper at the upper extremity of the cylinder prevents the piston to exit from the cylinder.

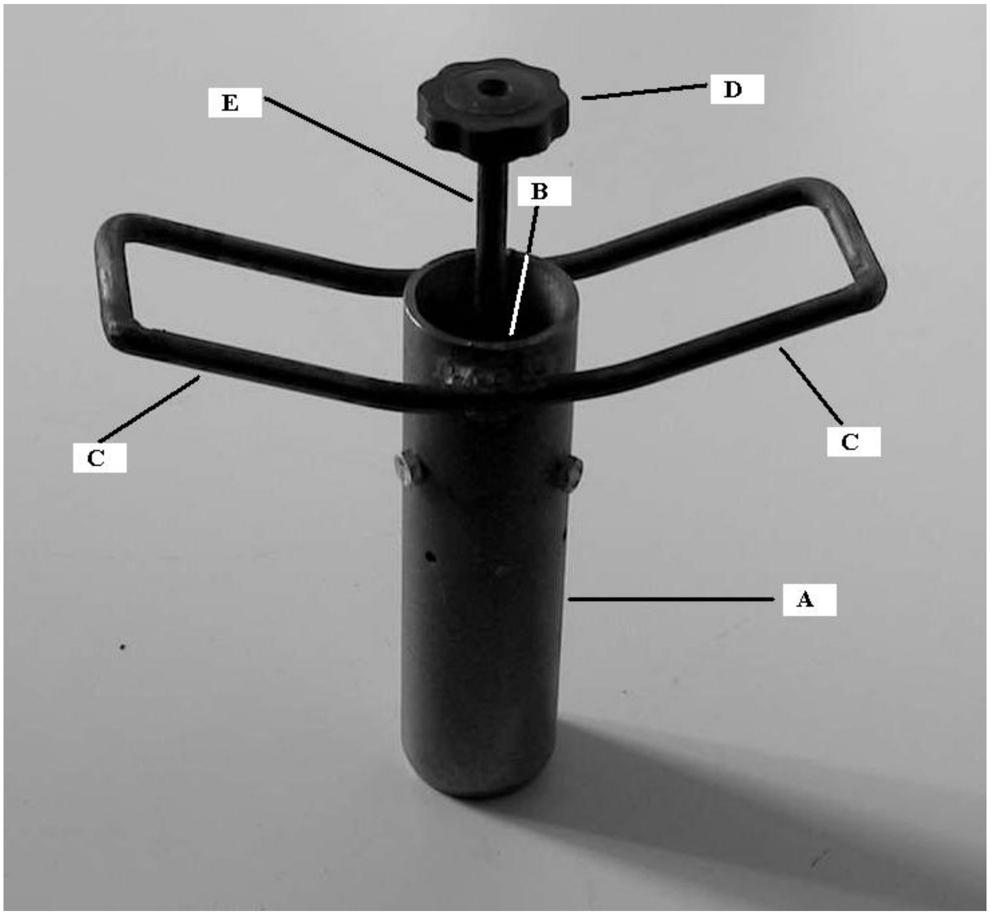


Figure 2. Details of the prototype (description in the text)

Use of the sampler

In order to use the soil sampler, its inferior extremity must be placed on the ground with the piston free to slip down to the bottom of the cylinder. The sampler must be pushed into the soil, by using the two handles connected to the cylinder, until the desired depth is reached. When the cylinder gets into the soil, the base of the piston remains above the ground. In order to extract the sample from the soil, it's sufficient to pull up the handle connected to the piston. The depression created inside the cylinder allows the sample to remain inside the cylinder. To extract the soil sample from the cylinder, it's sufficient to push the piston inside the cylinder.

APPENDIX 3

I.DA.: A SOFTWARE FOR THE INTERPOLATION OF METEOROLOGICAL DATA

Bechini, L., Confalonieri, R., Mariani, L.

Introduction

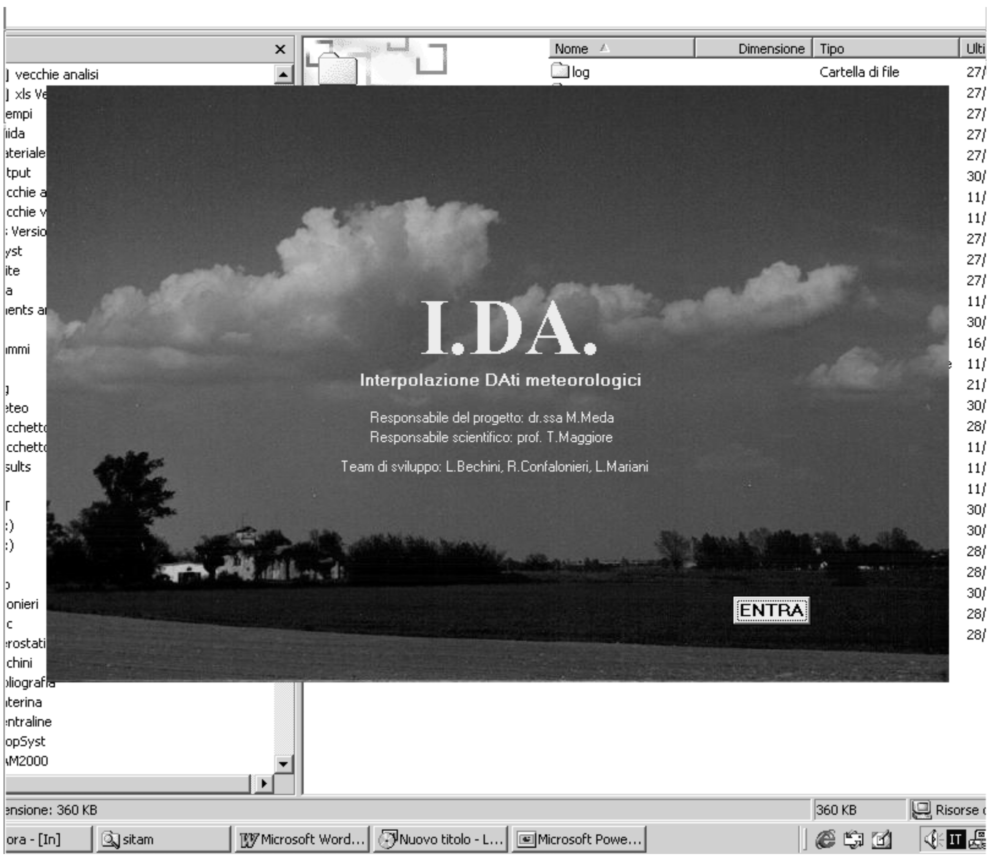
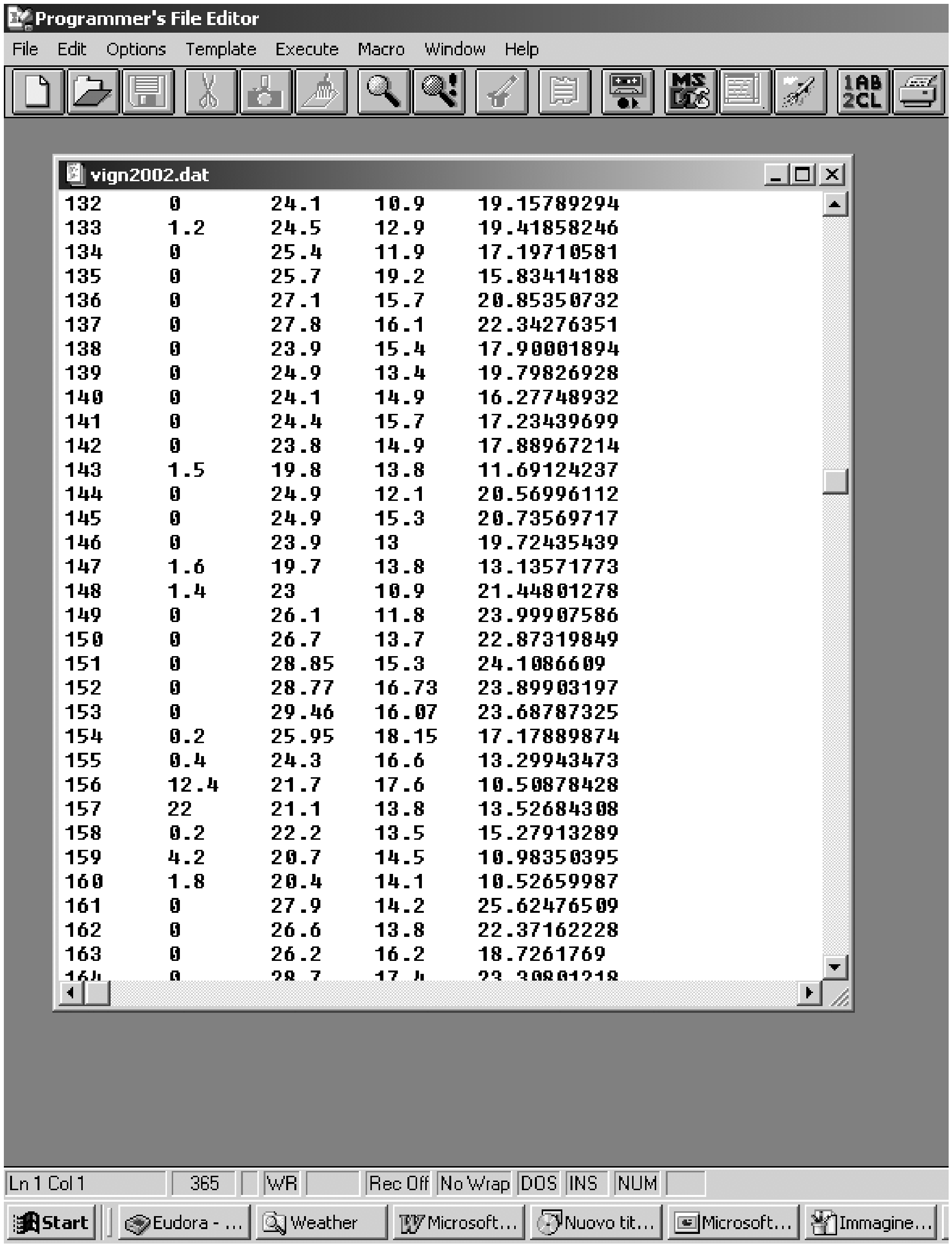


Figure 1. I.Da. – splash form

For agroecological studies, spatially distributed data are needed and, in many cases, this need has to do with series of historical data. Simulation models are probably the tools for which the historical series of daily meteorological data are most important. In fact, these data are irreplaceable guide variables for this kind of simulation models and they allow the models to evaluate the effects of tactical and strategic decisions taken at farm level on the environment (e.g. decision about irrigation methods, fertilizers distribution, treatments with chemical products, etc.).

Very often this data are not available. For this reasons, a software for the spatial interpolation of meteorological data was developed (figure 1 and 2).

I.Da. contains a database of geo-referenced meteorological data, which can be easily widened with new data, and uses this database to elaborate historical series of data in the desired location. In the actual database, meteorological data starting from 1951 are available. An user's guide with the documentation of the implemented algorithms and a software manual are available, although it's very easy to use I.Da. The program outputs are in the form shown in figure 2: in the first column the day of the year (DOY), in the second the rainfall (mm), in the third the maximum temperature (Tmax; °C), in the fourth the minimum temperature (Tmin; °C) and in the fifth the global solar radiation (rad, MJ m^{-2} day^{-1}).



132	0	24.1	10.9	19.15789294
133	1.2	24.5	12.9	19.41858246
134	0	25.4	11.9	17.19710581
135	0	25.7	19.2	15.83414188
136	0	27.1	15.7	20.85350732
137	0	27.8	16.1	22.34276351
138	0	23.9	15.4	17.90001894
139	0	24.9	13.4	19.79826928
140	0	24.1	14.9	16.27748932
141	0	24.4	15.7	17.23439699
142	0	23.8	14.9	17.88967214
143	1.5	19.8	13.8	11.69124237
144	0	24.9	12.1	20.56996112
145	0	24.9	15.3	20.73569717
146	0	23.9	13	19.72435439
147	1.6	19.7	13.8	13.13571773
148	1.4	23	10.9	21.44801278
149	0	26.1	11.8	23.99907586
150	0	26.7	13.7	22.87319849
151	0	28.85	15.3	24.1086609
152	0	28.77	16.73	23.89903197
153	0	29.46	16.07	23.68787325
154	0.2	25.95	18.15	17.17889874
155	0.4	24.3	16.6	13.29943473
156	12.4	21.7	17.6	10.50878428
157	22	21.1	13.8	13.52684308
158	0.2	22.2	13.5	15.27913289
159	4.2	20.7	14.5	10.98350395
160	1.8	20.4	14.1	10.52659987
161	0	27.9	14.2	25.62476509
162	0	26.6	13.8	22.37162228
163	0	26.2	16.2	18.7261769

Figure 2. Example of an output file by I.Da.

Historical series of meteorological data utilized for the interpolation

Actually, I.Da. generates the required historical series by using the data from the following series.

Milano Brera

The series has been homogenized: the thermal effects of the “urban heat island” are not taken into account. This series is very useful because it’s absolutely continuous from 1/1/1951 to 31/12/1998.

Linate

Station (sited near the Linate airport) of the Servizio Meteorologico dell’Aeronautica Militare. The series starts from 1/1/1951 and terminates in 31/12/2001. Some lacks are presents, above all after 1996.

Landriano

Station of the Azienda Didattico – Sperimentale A. Menozzi, of the University of Milan, managed by the University of Milan (Department of Crop Science) and by the Ente Regionale di Sviluppo Agricolo della Lombardia (ERSAL – Servizio Agrometeorologico). The series contains data from 24/11/1989 to 31/12/2001.

Lodi

Station of the Istituto Sperimentale per le Colture Foraggere. The series contains data from 1/5/1989 to 31/5/2000.

Method for the spatial interpolation

The temperature and rainfall data generator is based on a system of weighted means, with the weight inversely proportional to the square of the distances. The geography of the studied area does not present evident altitude differences: for this reason data about altitude and exposition are not taken into account.

The algorithm used for the computation is:

$$X_a = \frac{\sum_{i=1}^{n} \frac{X_i}{d_i^{\,2}}}{\sum_{i=1}^{n} \frac{1}{d_i^{\,2}}}$$

where:

X_a is the estimation of the X variable in the location *a* (location for which meteorological data are needed):

X_i is the variables measured by the meteorological station *i*;

d_i is the distance from the site *a* to the station *i*.

Estimation of the global solar radiation

The daily global solar radiation is estimated from maximum and minimum daily temperatures by using the method proposed by Donatelli and Campbell (1998) and used in north Italy by Bechini et al. (2000). This method is based on the estimation of the atmospheric transmission of the day *i* and therefore on the global solar radiation through the multiplication of the atmospheric transmission for the maximum radiation. The equation used for the computation is:

$$tt_i = \tau\left\{1 - \exp\left[-bf\left(T_{avg}\right)\Delta T_i^2 f\left(T_{\min}\right)\right]\right\}$$

where:

tt_i is the atmospheric transmission estimated for the day *i*;

τ is the atmospheric transmission at clear sky;

$\Delta T = T_{\max} i - \frac{T_{\min} i + T_{\min} i + 1}{2}$;

$f\left(T_{avg}\right) = 0.17 \exp\left(\exp\left(-0.53 T_{avg}\right)\right)$;

$T_{avg} = \frac{T_{\max} i + T_{\min} i}{2}$;

$f\left(T_{\min}\right) = \exp\left(\frac{T_{\min} i}{Tnc}\right)$;

T_{max} is the maximum daily temperature (°C);

T_{min} is the minimum daily temperature (°C);

Tnc is an empiric coefficient;

b is an empiric coefficient.

The estimation of the coefficient *b* and *Tnc* derives from the following equations:

$$X_t = (X - 360000)10^{-5}$$

$$Y_t = (Y - 4800000)10^{-5}$$

$$b(G) = 1.6 + 0.05X_t - 1.78Y_t - 0.173X_t^2 + 0.139X_tY_t + 0.739Y_t^2 + 0.029X_t^3 + \\ - 0.003X_t^2Y_t - 0.004X_tY_t^2 - 0.114Y_t^3$$

$$Tnc(G) = 137.9 + 101.1X_t - 156.7Y_t - 41.45X_t^2 - 54.57X_tY_t + 73.49Y_t^2 + \\ + 3.886X_t^3 + 11.397X_t^2Y_t + 7.511X_tY_t^2 - 11.957Y_t^3$$

where X and Y are the UTM (m) coordinates of the location for which meteorological data are needed.

References:

Bechini, L., Ducco, G., Donatelli, M., Stein, A., 2000. Modelling, interpolation and stochastic simulation in space and time of global solar radiation. Agriculture, Ecosystems and Environment, 81, 29-42.

Donatelli, M., Campbell, G.S., 1998. A simple model to estimate global solar radiation. In: Proceedings of the 5th Congress of the European Society for Agronomy, Nitra, Slovak Republic, pp. 133-134.

How to use I.Da

A simple interface allows the user to work with I.Da. without any difficulties (figure 3). The interface is divided into three areas:

- Location;
- Period;
- Coordinates of the location.

The first area allows the user to specify the locality for which the meteorological data are needed; the second one allows the user to define the period for which data are needed; the third is related to the geographical position of the location for which data are needed (coordinates must be expressed in UTM 32).

Figure 3. I.Da. – user’s interface

Location

The name of the generated files (one for each year) will be composed by:

- four letters indicating the location name (the first four letters of the specified location name);
- four numbers corresponding to the year for which data are needed.

The file extension is .dat.

Period

It’s possible to visualize the first and the last year for which data can be generated by pushing the “Visualizza le date disponibili” button.

Coordinates

I.Da. is valid for a large part of north Italy because this is the validity area of the implemented algorithm for the estimation of solar radiation. However, the data base of the historical series actually present in the software advises the user to use I.Da. only in the area of the Parco Agricolo Sud Milano.

I.Da. User's Guide

An online user's guide is available with the documentation of the algorithms used for the computations and the user's manual.

Log Files

I.Da. produces three kind of files with information recorded during the program execution:

- DATE.log: list of the meteorological files, initial and final dates, number of records;
- ERRORI.log: list of the errors with relative error codes;
- REPORT.log: list of peculiarities recorded during the program execution (for example, dates for which meteorological data of none station were available, etc…).

CURRICULUM VITAE

Roberto Confalonieri è nato l'8 maggio 1975 a Milano. Nel 1994 consegue la Maturità Scientifica presso il liceo "G. Peano". Il 10 maggio 2000 si laurea a pieni voti in Scienze Biologiche (indirizzo Ecologico) presso l'Università degli Studi di Milano con una tesi sperimentale dal titolo "Agroecosistemi della pianura lombarda: valutazione di alternative gestionali attraverso il modello di simulazione CropSyst", svolta presso il Dipartimento di Produzione Vegetale (Di.Pro.Ve.)

Dopo il conseguimento della laurea, continua l'attività di ricerca presso il Di.Pro.Ve. con una borsa di studio. Nell'ottobre del 2000 inizia il Dottorato di Ricerca in Ecologia Agraria presso lo stesso Dipartimento. Nel 2001 è vincitore del fondo "Giovani Ricercatori" con un progetto di ricerca dal titolo "Modellizzazione del profilo termico verticale in risaia".

E' stato correlatore di due tesi sperimentali e responsabile di diverse sperimentazioni in campo tra il 2001 e il 2003.

Nel 2002 ha progettato e sviluppato una stazione meteorologica galleggiante ed un sensore di livello per fluidi particolarmente adatto alla sperimentazione in campo (inventore nella domanda di brevetto numero MI2002A002399 depositata dall'Università degli Studi di Milano). Nel 2003 è stato invitato a presentare questi strumenti alla mostra sui brevetti europei organizzata dalla Provincia di Milano.

Editor degli Atti del convegno della Società Italiana di Agrometeorologia, tenutosi a Bologna nel 2003.

E' autore di CoLiDaTa, un software per la valutazione statistica dei dati sperimentali, e di Ida, software per l'interpolazione di dati meteorologici.

Attualmente impegnato nel miglioramento della simulazione di alcuni processi legati alla risaia sommersa e nello studio di un sistema di telerilevamento di precisione da pallone aerostatico da utilizzarsi a scala aziendale.

Ha svolto più di 120 ore di docenza tra corsi, master ed esercitazioni.

Lista delle pubblicazioni di Roberto Confalonieri:

21. Confalonieri, **R.**, Bechini, L., 2003. A preliminary evaluation of the simulation model CropSyst for Alfalfa. European Journal of Agronomy. In press.

20. Confalonieri, R., Mariani, L., Bocchi, S., 2003. Analysis and modelling of water and near water temperatures in flooded rice (*Oryza sativa* L.). Ecological Modelling. Submitted.

19. Confalonieri, R., Bocchi, S., Maggiore, S., 2003. Evaluation of CropSyst for flooded rice simulation and nitrogen balance in north Italy. European Journal of Agronomy. Submitted.

18. Adani, F., **Confalonieri, R.**, Tambone, F., 2003. Dynamic respiration index as a measure of biological stability of organic matrices. Journal of Environmental Quality. Submitted.

17. Confalonieri, R., Cola, G., Acutis, M., Mariani, L., 2003. Construction and use of a water level recorder to estimate water infiltration rate in paddy rice fields. Computers and Electronics in Agriculture. Submitted.

16. Bechini, L., **Confalonieri, R.**, Bocchi, S., Maggiore, T., 2003. Application of the simulation model CropSyst to winter wheat (*Triticum aestivum* L.) in northern Italy. European Journal of Agronomy. Submitted.

15. Confalonieri, R., Cola, G., Mariani. L., 2003. Tecniche di monitoraggio in ambiente di risaia sommersa per la messa a punto di modelli di simulazione. Le sfide dell'agrometeorologia. Atti della Società Italiana di Agrometeorologia, Bologna, 29-30 maggio 2003. In stampa.

14. Mariani, L., Bocchi, S., Cola, G., **Confalonieri, R.**, 2003. Analisi e modellizzazione della temperatura dell'acqua e delle sue vicinanze in risaia sommersa. Le sfide dell'agrometeorologia. Atti della Società Italiana di Agrometeorologia, Bologna, 29-30 maggio 2003. In stampa.

13. **Confalonieri, R.**, Mariani, L., Bocchi, S., 2003. Analysis and modeling of water and near water temperatures in rice fields. CD of proceedings of the 3rd International Temperate Rice Conference. 10-13 March, Punta del Este – Uruguay. Oral presentation.
12. **Confalonieri, R.**, Mariani, L., Bocchi, S., 2003. A simulation model and an agro-ecological indicator to assess rice yield losses. CD of proceedings of the 3rd International Temperate Rice Conference. 10-13 March, Punta del Este – Uruguay.
11. Bocchi, S., **Confalonieri, R.**, Genovese, G., Mariani, L., Martin, S., Orlandi, S., 2003. An integrated rice field forecasting system in Europe. CD of proceedings of the 3rd International Temperate Rice Conference. 10-13 March, Punta del Este – Uruguay.
10. Adani, F., **Confalonieri, R.**, Tambone, F., Genevini, P., 2003. Dynamic respiration index: a measure of biological stability for organic matrices. Proceeding of the workshop "The Role of Organic Matter in a Sustainable Agriculture", Lerici, 5-6 June, 2003, La Spezia, Italy, 174.
9. **Confalonieri, R.**, Mariani, L., Facchetti, M., Bocchi, S., 2002. Analysis of temperature profile in flooded rice field: preliminary results, International Rice Research Notes, 27(2): 39-40.
8. **Confalonieri, R.**, Bocchi, S., 2002. Studio dell'interazione fra colture agrarie e variabili ecologiche attraverso modelli di simulazione: il caso del riso, Genio Rurale 9: 27-33.
7. Bocchi, S., **Confalonieri, R.**, Mariani, L., Martin, S., 2002. Evaluation of growth and productivity model integrated with remote sensing techniques. Proceeding of the "CGMS International Expert Meeting", JRC – Ispra, 30 September – 1 October 2002, Italy.
6. **Confalonieri, R.**, Mariani, L., Bocchi, S., 2001. Analisi e modellizzazione della temperatura in risaia per la stima delle date di comparsa delle fenofasi – Risultati preliminari, Rivista di irrigazione e drenaggio, 2001, 48, **3**, 60-61.
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1. Mariani, L., Bechini, L., **Confalonieri, R.**, 2001. Cambiamento climatico e fabbisogni irrigui del mais nella pianura lombarda. Acqua e irrigazione. Atti della conferenza internazionale, Cremona, 25-26-27 settembre 2001. Italia, 294-296.