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Evaluation of CropSyst for simulating the yield of flooded rice in northern Italy

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Abstract

Research on rice cropping systems carried out in Europe has to face the great variability of pedo-climatic conditions, and the linked abundance of cultivated varieties, characteristic of the high latitudes-temperate areas where rice is traditionally grown.

Dynamic simulation models can provide an useful tool for system analysis needed to improve the knowledge, the agronomic management and crop monitoring.

For calibrate and validate CropSyst (never used for rice), a process-based simulation model, for Indica-type and Japonica-type varieties, data obtained from five field experiments, carried out in Northern Italy between 1989 and 2002, were used.

Plants were sampled during the life cycle from rice plots of five cv Loto, Cripto, Ariete, Drago, Thaibonnet and Sillaro, maintained at potential production, to determine some important crop variables and parameters such as aboveground biomass (AGB), leaf area index, specific leaf area, harvest index, the date of the main phonological stages.

At the end of the calibration process to the parameters (the others were set to the default value, taken from the Literature or measured) optimum mean daily temperature for growth, specific leaf area (for Japonica varieties), stem/leaf partition coefficient (empirical), leaf duration, were assigned the following values: 28 and 27 °C respectively for Japonica and Indica varieties, 27 and 29.5 $m^2\,kg^{-1}$ respectively for Japonica early and medium-late varieties, 4.5, 3, 1.5 for Japonica early, medium-late and Indica varieties, 700, 850, 950 °C-days for the three groups of varieties.

The assessment of model performances has shown average RRMSEs of 20 and 22% at the end of calibration and for the validation process; the modelling efficiency is always positive and the coefficient of determination always very close to 1. General improvements will be achieved by the model by considering the thermal profile (strongly influenced by flooding water at mid latitudes) evolving in and over the canopy.

Keywords: *Oryza sativa* L.; Simulation model; Aboveground biomass

1. Introduction

Rice (*Oryza sativa* L.), the staple food of about one-half of the world population, providing 35–60% of the dietary calories consumed by 3 billion people,

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is arguably the most important crop worldwide. Although total rice production has more than doubled since 1965, problems about food security still persist (Cassman et al., 1997), so that it appears crucial to increase rice production through an increase in yield from rice-cultivated land because an expansion of irrigated areas probably will not be realizable (Mae, 1997).

With 3 million tonnes per year, the EU production of rough rice ranks 17th (0.5%) among main world producers, whereas with a consumption of 3.5 million tonnes (rough rice) the EU ranks only 19th. Rice is produced in very specific areas in France, Greece, Italy, Portugal and Spain. The main producers are Italy and Spain, which together represent 84% of the total area of about 400,000 ha, located in the Po Valley (mainly in the western part of it), and in the two delta Rivers areas (Ebro and Guadalquivir) in Spain. The rice cropping system tends to create everywhere a sort of “district regional structure”. Vercelli or Lomellina (Pavia Province), Camargue (France), Ebro (Spain), are clear examples of the concentration of activities, all related to only one crop so that whole the area seems strictly linked to rice from different point of views: agronomy (specialization, simplification); landscape (crop specific: “rice landscape”); natural resources (intensification of the resource use); economy; culture (traditional festivals, traditional recipes, movies). On the other hand this regional concentration and specialization can create also a high impact agricultural activity that, starting from the single field and the cropping system, can involve, at a large scale, the farming and the agricultural system of the region.

Modern rice-culture, facing both food and environmental security, requires sustainable and environmentally sound management analysis, both at farm and regional scale, integrating our knowledge of pedoclimatic conditions, crop production physiology, and agrotechniques for analysing agro-ecosystem. Dynamic simulation models could provide the technical support for analysing system for better planning, management, and monitoring.

Bouman et al. (1996) distinguished three major modeling groups: (i) the USA one in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project (Uehara and Tsuji, 1993) which produced the CERES-family models; (ii) the Australian group which is developing the Agricultural Production system SIMulator (APSIM) system (McCown et al., 1995); (iii) the group working in The Netherlands at Wageningen which has developed the family of models described by Van Ittersum et al. (2003).

Both the Wageningen and the CERES approaches are very detailed in describing crop physiology and, 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 and Bechini, 2004), it’s known that the calibration process becomes more complex as the number of parameters or, in general, the level of detail 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 larger spatial variability. Mahmood (1998) underlined that the detailed input data set required by the CERES level in simulating plant growth may be an impediment for its extensive use. For these reasons many of these models are described in the literature but very few have been used to successfully solve management problems (Monteith, 1996). Small appetite for data and simplicity are considered fundamental features of operative models also by Passioura (1996).

Moreover, CERES-Rice belongs to a family of models where each member is able to simulate only one crop behaviour, creating problems for cropping systems simulations.

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).

In the last years, a model which does not belong to the groups of models described by Bouman et al. (1996) has been increasingly used. CropSyst (Stöckle and Nelson, 1999; Stöckle et al., 2003) is a process-based simulation 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 processes (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, 2004). For these considerations, CropSyst can be considered a management-oriented model. 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, 2004), it is 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 socio-economic heterogeneity which characterises the Continent. It is possible to distinguish two main groups of varieties: Japonica and Indica types. The first one refers generally to some traditional 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 is characterised 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 objective of this work was to calibrate and validate CropSyst crop parameters for Indica type varieties, Japonica type early varieties and Japonica type medium-late varieties.

2. Materials and methods

2.1. Experimental data

Experimental data were collected in five experiments (Table 1) carried out between 1989 and 2002 in northern Italy.

For experiments 1–4, daily meteorological data (rainfall, maximum and minimum air temperature and global solar radiation) were collected with automatic weather stations near the fields. For the first locality of the fifth experiment (Vignate), daily temperature data 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 sensor undisturbed (Confalonieri et al., 2002).

For all the experiments, the soils were sub-acid, with medium-low cation exchange capacity (CEC). Plant samples were stored in oven until constant weight to determine the dry matter weight of aboveground biomass (AGB) which will be always expressed as dry matter in this text.

For experiments 3–5, plant N concentration was determined with a calibrated automatic NIR analyzer. For experiment 5, leaf area index (LAI) was obtained by measuring the area of leaves and stems with a software for graphical elaboration and specific leaf area (SLA) by dividing leaves area by leaves weight. For the same experiment, soil nitrogen concentration was determined on an aggregated sample (two sub-samples per plot), by analyzing the soil layer 0.00–0.10 m with a continuous-flow analyzer.

For experiments 2–4, the soils were characterized by medium nutrients availability; the first and the fifth experiment soils had high phosphorous content while low (the first) and medium (the fifth) potassium content. All the soils had sufficient organic matter content, except for experiment 1 (low content).

For experiments 1 and 2, the system was maintained at potential production level (Van Ittersum and Rabbinge, 1997).

For all the experiments the harvest index (HI) and the phenological stages of emergence, flowering and maturity (respectively codes 10, 65 and 89 of the BBCH scale for rice) were determined and initial condition of soil profiles (soil water content [$m^3\,m^{-3}$], soil N-NH_4 and N-NO_3 concentration [kg N-NH_4 ha^{-1}; kg N-NO_3 ha^{-1}]) were measured.

Only the fifth experiment was carried out for the specific purpose of parameterising the model.

The seven locations where the data sets have been collected can be considered representative of the “Italian rice belt” (provinces of Vercelli, Pavia, Novara, Milano, Alessandria) where the almost whole Italian rice production (>95%) is concentrated. This area provides also for the 60% of the European rice production.

2.2. Simulation model

CropSyst (Stöckle et al., 1994, 2003; Stöckle and Nelson, 1999) 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,

Table 1
Data sets used

Experiment no.	Location	Latitude Longitude	Years	Soil texture	Experimental design (treatments)	Replications	Measured variables	Sampling frequence	Sample size
1	Gudo Visconti (Ml[a])	45°22′N, 9°00′E	1989, 1990	Sandy-loam	Complete randomized block (3 Japonica varieties with different cycles (Loto [early], Cripto [medium-late], Europa [late]))	4	AGB[b], LAI[c]	10^{-15} days	0.03 m^2 (5 plants plot^{-1})
	Vercelli (Ml[a])	45°19′N, 8°25′E	1989, 1990	Sandy-loam			AGB[b]	10^{-15} days	
2	Castello d’Agogna (PV[d])	45°14′N, 8°41′E	1994, 1995	Silty-clay	Complete randomized block (6 varieties (Thaibonnet [Indica, medium-late], Loto (Japonica, early], Cripto, Carnaroli, Aritete, M203 [Japonica, medium-late]))	4	AGB[b]	14 days until flowering, 7 days after flowering	018 m^2 (0.18 m × 0.5 linear m)
3	Castello d’Agogna (PV[d])	45°14′N, 8°41′E	1996	Silty-clay	Split-split-plot (plot Japonica variety [Loto, early; Drago, medium-late]; subplot: N level [urea; 60, 120, 180 kg ha^{-1}], sub-subplot: fertilizing event [1, 2 or 3 events])	3	AGB[b], plant N concentration	6 sampling events during the crop cycle	0.09 m^2 (018 m × 0 5 linear m)
	Mortara (PV[d])	45°14′N, 8°41′E		Sandy-loam					
4	Velezzo Lomellina (PV[d])	45°9′N, 8°44′E	1999, 2000	Sandy-loam	Complete randomized block (the variety Thaibonnet (Indies) was grown; 2 N fertilizers [urea, calcium cyanamide]; 4 N levels [0, 40, 80, 120 Kg N ha^{-1}];1 or 2 fertilizing events)	3	AGB[b], plant N concentration	6 sampling events during the crop cycle	0.07 m^2 (20 plants plot^{-1})
5	Vignate (Mr) Opera (Ml[a])	45°29′N, 9°22′E	2002	Sandy-loam	Complete randomized block (the variety Siilaro [Indica] was grown; 3 N levels [urea; 0, 70, 150 kg N ha^{-1})	3	AGB[b] plant, N concentration, LAI[c], SLA[e]	6 sampling events during the crop cycle for AGB and plant N concentration, 4 for SLA[c] 3 for LAI	0.1 m^2 (20 plants plot^{-1})
				Loam	Complete randomized block (the variety Thaibonnet [Indica] was grown; 3 N levels [urea; 0, 50, 110 kg N ha^{-1})	3	Soil N-NH$_4$ content, soil N-NO$_3$ content, BD[f], Ksat[g]		0.06 m^2 (20 plants plot^{-1})

[a] Province of Milan.

[b] Aboveground biomass.

[c] Leaf area index.

[d] Province of Pavia.

[e] Specific leaf area.

[f] Bulk density.

[g] Saturated hydraulic conductivity.

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 thermal time accumulated between a base temperature (T_{base}) and a maximum temperature (T_{cutoff}). 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:

$$B_{\mathrm{PT}} = \frac{\mathrm{BTR} \times T_{\mathrm{act}}}{\mathrm{VPD}} \tag{1}$$

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:

$$B_{\mathrm{Rad}} = \mathrm{LtBC} \times 0.5 \times \mathrm{Rad} \times (1 - \mathrm{e}^{-k \times \mathrm{LAI}}) \times T_{\mathrm{lim}} \tag{2}$$

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 $0.5 \times \mathrm{Rad}$ being an estimate for PAR), $(1 - \mathrm{e}^{-k \times \mathrm{LAI}})$ 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 $T_{\mathrm{a}} \le T_{\mathrm{base}}$; 1 if $T_{\mathrm{a}} \ge T_{\mathrm{opt}}$), 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:

$$\mathrm{LAI} = \frac{\mathrm{SLA} \times B}{1 + \mathrm{SLP} \times B} \tag{3}$$

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 Eqs. (1) and (2)), N and water limitations 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. Potential crop evapotranspiration is determined by multiplying reference potential evapotranspiration by a crop coefficient K_{C}.

$$K_{\mathrm{C}} = \begin{cases} 1 + (K_{\mathrm{C}}^{\mathrm{I}} - 1)\frac{\mathrm{LAI}}{3} & K_{\mathrm{C}}^{\mathrm{I}} > 1;\ \mathrm{LAI} < 3 \\ K_{\mathrm{C}}^{\mathrm{I}} & \text{otherwise} \end{cases} \tag{4}$$

where K'_{C} is the input parameter ET crop coefficient at full canopy.

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 through the soil profile is simulated with a simple mass-balance approach.

2.3. Model parameterization and validation

CropSyst version 3.02.23 (January 8, 2002) was used. Potential evapotranspiration was calculated with the Priestley–Taylor equation. The default value of 1.26 was used for the Priestley–Taylor constant. Soil water

Table 2
Data sets used for calibration and validation of crop parameters

Experiment	Locality	Year	Group of varieties	Considered variables	Activity
1	Vercelli	1989	Japonica, medium-late	AGB, D	C
1	Gudo Visconti	1990	Japonica, early	AGB, D, LAI	C
1	Gudo Visconti	1990	Japonica, medium-late	AGB, D	V
1	Vercelli	1990	Japonica, early	AGB, D	C
1	Vercelli	1990	Japonica, medium-late	AGB, D	V
2	CaateHo d’Agogna	1994	Japonica, medium-late	AGB, D	V
2	CasteHo d’Agogna	1995	Japonica, early	AGB, D	V
2	Castello d’Agogna	1995	Japonica, medium-late	AGB, D	C
3	CaateUo d’Agogna	1996	Japonica, early	AGB, D	V
3	Castello d’Agogna	1996	Japonica, medium-late	AGB, D	C
3	Mortara	1996	Japonica, medium-late	AGB, D	V
4	Velezzo Lometlina	1999	Indica	AGB, D	C
5	Vignate	2002	Indica	AGB, D, PNC, SNC, LAI	C
5	Opera	2002	Indica	AGB, D, PNC, SNC, LAI	V

In the column “Activity” C means data set used for calibration, V for validation. Variables abbreviations: AGB: aboveground biomass, D: phenological stage, LAI: leaf area index, PNC: plant nitrogen concentration and SNC: soil N-NH_4, N-NO_3 concentration.

redistribution was simulated with the Richard’s equation solved using a finite difference method.

Three crop parameter sets have been calibrated and validated. The first, defined 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; the cultivars Cripto, Ariete and Drago were grouped in this family of varieties. The third group, called Indica (I), refers to the Indica type varieties Thaibonnet and Sillaro.

Data from the five experiments were divided in two independent groups of data sets for the activities of calibration and validation of crop model parameters (Table 2). A sensitivity analysis allowed to select four parameters for calibration (SLA, SLP, T_{opt}, leaf duration). The other crop model parameters were set to values found in literature or derived from local experience (Table 3). For the group of variety I, measured values of SLA were available. The correspondent CropSyst parameter (specific leaf area) was initialized 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.

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, $-\infty/+\infty$, 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.

3. Results and discussion

3.1. Experimental results

Maximum daily temperature is usually lower than T_{cutoff} in the considered Region and meteorological data collected during the experiments confirm it. The average number of days in which minimum daily temperature was lower than T_{base} during the rice cycle is 33 (maximum: 44 days in 1990 both for Gudo Visconti and Vercelli; minimum: 17 days in 1994 at Mortara).

Data of AGB accumulation at production level 1 are shown in Figs. 1 and 2. In general, with the vari-

Table 3
Crop model parameters for rice and source of information

Parameter group of variables	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 root 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		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 maximum 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 far 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 (T_{base})		E		12	11	12	°C
Cutoff temperature (T_{cutoff})		L			42		°C
Unstressed harvest index		M		0.6	0.48	0.48	–
Maximum N concentration during early growth	E	E	M	0.050	0.050	0.036	kg N kg AGB^{-1}
Maximum N concentration at maturity	E	E	M	0.012	0.012	0.008	kg N kg AGB^{-1}
Minimum N concentration at maturity	E	E	M		0.007		kg N kg AGB^{-1}

C: calibrated parameters; L: literature; E: local experience; M: measured; D: default for other poaceae species; JE: Japonica, early; JM: Japonica, medium-late and I: Indica.

ety 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 t AGB ha^{-1} while the JM and the I groups of varieties produced average AGB values of, respectively, 14.6 and 15.6 t AGB ha^{-1}. The medium-late varieties showed low productions in 1990 and 1994, while higher values were reached in 1989, 1995 and 1996. Based on all available data, HI was 0.6 for cultivar Loto and 0.48 for all the others. Yields, for all the data sets, are comparable with what is usually obtained in the region, with values ranging between 6.5 and 8.0 t ha^{-1}. For the fifth experiment, measured agronomic N use efficiency was 25% and 21% for Vignate and Opera. Although these values appear low, they are in agreement with what is usually reported in literature (Cassman et al., 1993; Stutterheim et al., 1994; Singh et al., 1999).

3.2. *Model results*

3.2.1. *Calibration of crop model parameters*

Calibrated crop model parameters are shown in Table 3. T_{cutoff} 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 T_{base} is set up on 12 °C (11 °C for JM) basing on local experience. This value is in the range of values estimated by Sié et al. (1998) (9–12 °C) from experimental data collected for three Indica type varieties. The calibrated values for T_{opt} for Japonica cultivars (28 °C) is consistent with what reported by Casanova et al. (1998). This value was lowered to 27 °C for Indica varieties to increase crop growth rate by decreasing temperature limitation.

For radiation use efficiency (LtBC), the default value for other C3 species (3 g AGB MJ^{-1} intercepted

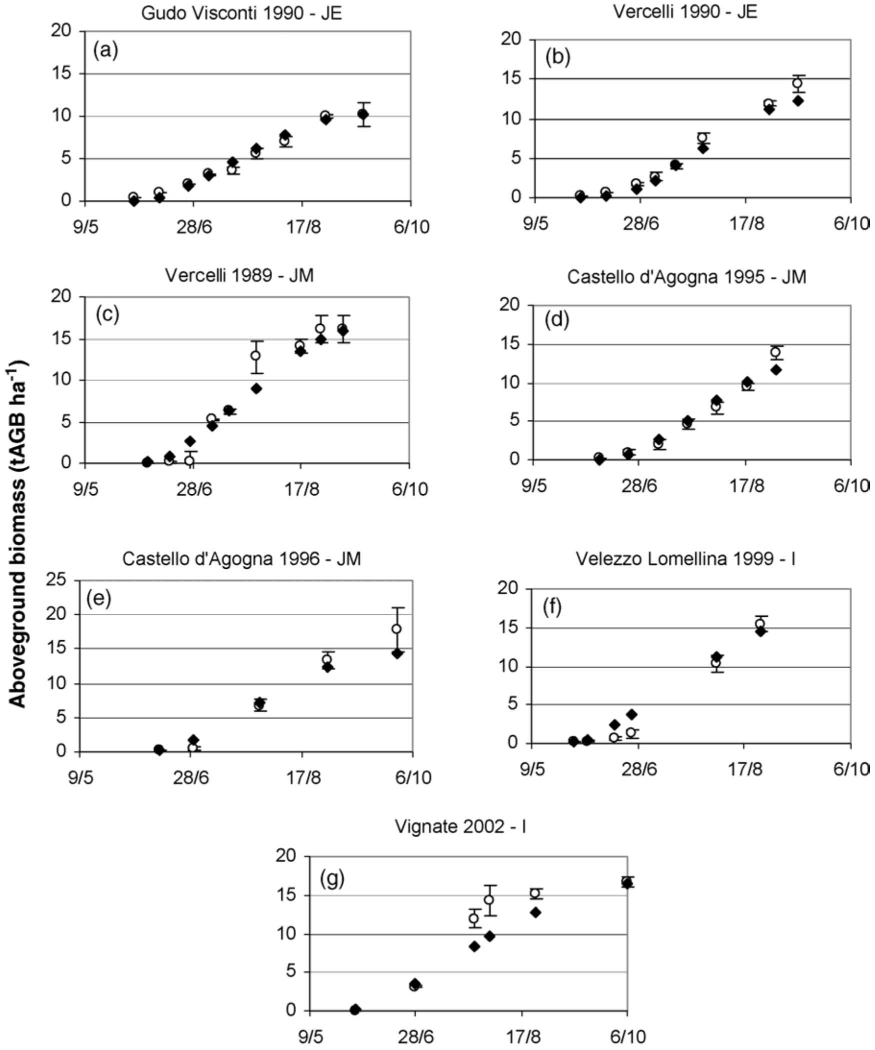

Fig. 1. Measured (○) and simulated (◆) aboveground biomass values. Calibration. JE: Japonica early; JM: Japonica medium-late; I: Indica. Date on the *X*-axes.

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 g AGB MJ^{-1} intercepted PAR and Horie and Sakuratani (1985) reported a value of about 2.78 g AGB 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 in agreement with the values reported by FAO (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 sowing 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

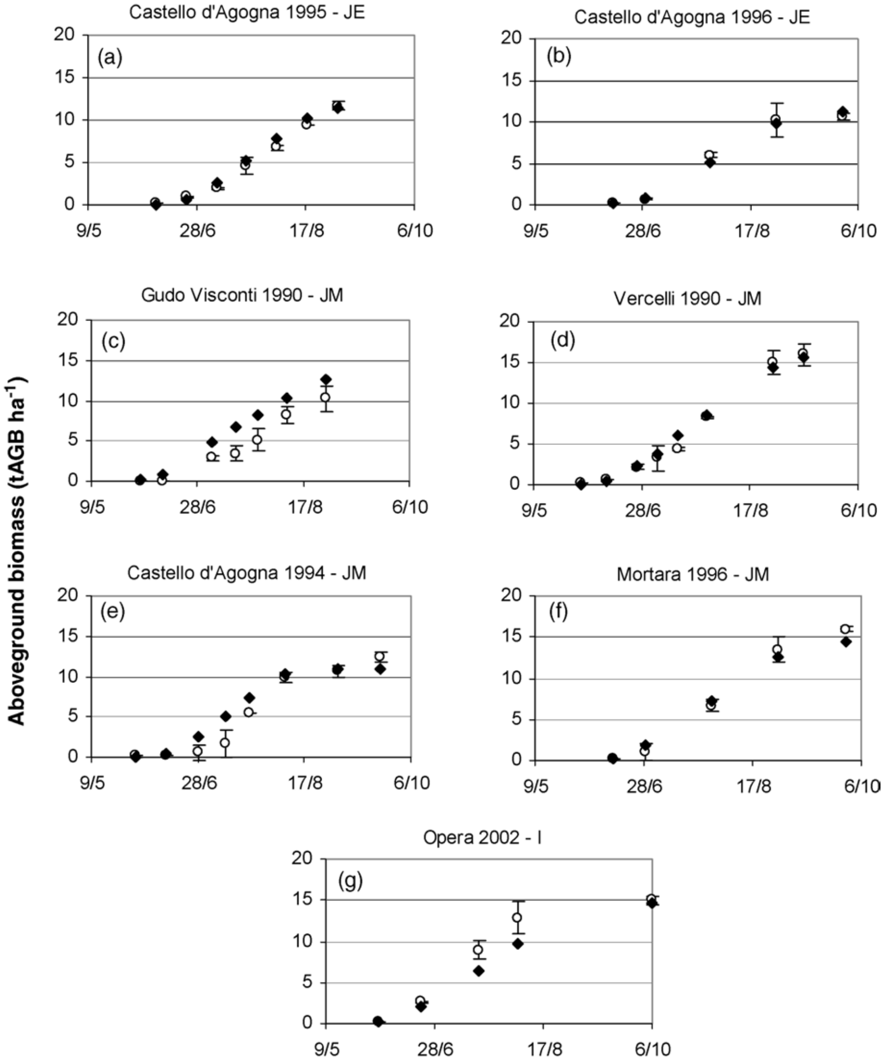

Fig. 2. Measured (○) and simulated (♦) aboveground biomass values. Validation. JE: Japonica early; JM: Japonica medium-late; I: Indica. Date on the *X*-axes.

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 Fig. 1 and in Table 4. 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 4: 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. 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 LAI measured in Vignate

Table 4
Indices of agreement between observed and simulated aboveground biomass values (t AGB ha^{-1})

	Locality	Year	Variety group	RRMSE	EF	CRM	CD	Slope	Intercept (t AGB ha^{-1})	R^2
Calibration	Gudo Visconti	1990	Japonica, early	11	0.98	−0.03	1.07	0.95	0.12	0 98
	Vercelli	1990	Japonica, early	18	0.96	0.13	0.84	1.10	0.24	0.99
	Vercelli	1989	Japonica, medium-late	20	0.93	0.07	0.75	1.15	−0.59	0.95
	Castello d'Agogna	1995	Japonica, medium-late	19	0.95	0.00	0.85	1.06	−0.34	0.95
	Castello d'Agogna	1996	Japonica, medium-late	22	0.94	0.07	0.64	1.24	−1.23	0 98
	Velezzo lomellina	1999	Indica	29	0.95	−0.15	0.86	1.07	−1.06	0.97
	Vignate	2002	Indica	25	0.84	0.17	0.82	1.11	0.78	0.92
Validation	Castello d'Agogna	1995	Japonica, early	12	0.98	−0.06	1.08	0.96	−0.06	0.99
	Castello d'Agogna	1996	Japonica, early	10	0.99	0.01	1.03	0.98	0.18	0.99
	Gudo Visconti	1990	Japonica, medium-late	52	0.62	−0.45	1.73	0.82	−0.80	0.98
	Vercelli	1990	Japonica, medium-late	11	0.99	−0.02	0.93	1.03	−0.33	0.99
	Castello d'Agogna	1994	Japonica, medium-late	33	0.88	−0.16	0.80	1.09	−1.37	0.92
	Mortara	1996	Japonica, medium-late	12	0.98	0.02	0.77	1.14	−0.82	0.99
	Opera	2002	Indica	23	0.88	0.17	0.89	1.07	0.91	0.96

AGB: aboveground biomass

(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.

3.2.2. *Validation of crop model parameters*

Fig. 2 and Table 4 show the results of crop parameters test. In general, CropSyst simulates accurately AGB values. For Gudo Visconti—1990 data set, Fig. 1 shows an evident and inexplicable overestimation during the whole crop cycle. The fitting indices calculated for the JE variety are better than the ones calculated for the other variety groups. Also during the validation the model has shown to be able to reproduce growth and development of different varieties under different conditions.

3.2.3. *The importance of modelling the influence of flooding water on vertical thermal profile*

The introduction in CropSyst of new algorithms connected with two important aspects of flooded rice may be suggested to improve the model for rice simulation. 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 presents 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 driving variable may lead to improve the simulations of many processes related to the crop–soil system. Confalonieri et al. (2002) have studied this problem by collecting water and air temperature data (at different height from water surface) and by developing a mechanistic model for water and near 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. In fact, temperature stress during the pre-flowering period may cause floral sterility and a remarkable yield reduction. In northern Italy this occurred, for example, in 2000, causing important economical damage to rice growers.

4. Conclusions

With the present work CropSyst has been calibrated and validated for the simulation of rice in the heterogeneous cultivars and pedo-climatic conditions which characterize Italian rice cultivation. To reach this aim, the cultivars grown in Europe were grouped 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, which represents more that the 95% of the total Italian area 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 for large-scale simulations of rice growth in Italy.

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