ESTIMATION OF PARAMETERS DESCRIBING MORPHO-PHYSIOLOGICAL FEATURES OF MEDITERRANEAN RICE VARIETIES FOR MODELLING PURPOSES

STIMA DI PARAMETRI MORFO-FISIOLOGICI DI INTERESSE MODELLISTICO PER VARIETÀ DI RISO MEDITERRANEE

Mirco Boschetti [1,2] *, Stefano Bocchi[2] , Daniela Stroppiana[1], Pietro Alessandro Brivio[1]

[1] *IREA-CNR, Institute for Electromagnetic Sensing of the Environment, National Research Council, Via Bassini 15, 20133 Milano, Italy.*
[2] *Department of Crop Science, University of Milano, Via Celoria 2, 20133 Milano, Italy*
** Corresponding Author : Tel. +39-02-23699297, E-mail: boschetti.m@irea.cnr.it, Fax: +39-02-23699300.*

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Abstract

This paper illustrates the estimation of parameters describing some morphological and physiological characteristics of Japonica-type and Indica-type rice varieties to be used for crop models parameterization. Seasonal variability of Specific Leaf Area (SLA; m^2 kg^{-1}) was determined from biomass and Leaf Area Index (LAI; m^2 m^{-2}) measurements. Coefficient of light extinction (k; -) was estimated by transmittance measurements recorded by LAI2000. Radiation Use Efficiency (RUE; g MJ^{-1}) was derived by regressive analysis between different above ground biomass measurements and corresponding cumulative Absorbed Photosynthetically Active Radiation (APAR; MJ m^{-2}). Results show that development stage determines more variability in SLA than cultivar typology. k parameter varies during the different plant developing stages in agreement with other published data; however, no significative difference is evident among the varieties, representative of different rice-group, when a mean seasonal value of 0.53 is derived. The analysis highlighted a sensible difference in RUE values between traditional tall Japonica variety (1.83 g MJ^{-1}) and new semi-dwarf Indica variety (3.14 g MJ^{-1}). A method to account for thermal limitations to RUE derived by field experiment is proposed. Applying this procedure, an unstressed RUE value (required by simulation models) for Japonica type medium late and Indica type early varieties was found to be respectively 2.69 and 3.25 g MJ^{-1}.

Keywords: *Oryza sativa L.*, coefficient of light extinction, radiation use efficiency, specific leaf area, above ground biomass, leaf area index, simulation model.

Riassunto

Il presente lavoro descrive le metodologie adottate per la stima di alcuni parametri morfo-fisiologici della coltura riso utili alla parametrizzazione di modelli di crescita e produzione. La sperimentazione ha permesso di calcolare per due gruppi di varità, tipologia Japonica e tipologia Indica, la variabilità stagionale dell' area specifica fogliare (SLA; m2 kg-1), come rapporto tra misure di indice di area fogliare (LAI; m2 m-2) e misure di biomassa e di stimare, grazie a misure di trasmittanza acquisite con lo strumento LAI2000, valori del coeffiente di estinzione della luce (k; -). Il parametro Radiation Use Efficiency (RUE; g MJ-1) è stato ottenuto con analisi di regressione tra periodici campionamenti di biomassa e relativi valori cumulati di Absorbed Photosynthetically Active Radiation (APAR; MJ m-2). I risultati mostrano che lo stadio di sviluppo determina una grande variabilità del parametro SLA per entrambi i gruppi di varietà analizzati. Il parametro k presenta una variabilità in funzione della varietà e dello stadio di sviluppo in accordo con altre pubblicazioni. Non si sono tuttavia evidenziate differenze significative tra le varietà nella stima di un valore medio annuo (0.53, -). La stima della RUE ha invece rilevato differenze sostanziali tra varietà tradizionali a tipologia Japonica (1.83 g MJ-1) e nuove varietà a profilo Indica (3.14 g MJ-1). Un metodo originale viene proposto nella stima della RUE basata su dati sperimentali di campo per compensare eventuali limitazioni termiche. Applicando tale procedura, sono stati ottenuti valori potenziali del parametro RUE, richiesti per la simulazione modellistica, per le varietà appartenenti alla tipologia Japonica con ciclo medio (2.69 g MJ-1) e a tipologia Indica a ciclo corto (3.25 g MJ-1).

Parole chiave: Oryza sativa *L., coefficiente di estinzione della luce, efficienza d'uso della radiazione, Area Specifica Fogliare, biomassa, Indice di Area Fogliare, modelli di simulazione.*

Introduction

Computer models can be efficiently used to simulate growth and yield of many crops since the 70s. Performances of these models depend on reliable parameterizations which require specific experiments to measure and estimate the proper crop parameters.

The WARM model (Confalonieri *et al.*, 2005) was developed in order to find the best balance between reliability and usability by reducing the number of parameters to a minimum directly measurable or derivable from measured data. The net photosynthesis is simulated on the basis of the Monteith's model (Monteith, 1977), also known as Radiation Use Efficiency (RUE), that defines the Above Ground Biomass accumulation (AGB, g m^{-2}) for a given time period as APAR multiplied by RUE coefficient. Light interception by the canopy is estimated, assuming a monolayer canopy, from LAI and k using the Lambert-Beer's law (Monsi and Saeki, 1953). Daily leaf area development is calculated as a function of the biomass partitioned to leaves each day and the development stage specific SLA.

In order to apply RUE-based models, such as WARM, for rice regional monitoring in Mediterranean-European environment, crop specific parameters are needed. No dedicated field studies have been carried out to measure the previous mentioned parameters for Mediterranean varieties. In particular, for RUE, Campbell *et al.* (2001) noted that *although rice is the most important food crop in the world, little field-scale, season-long research on RUE has been conducted.*

For these reasons the objective of this work was the estimation k, RUE, SLA, and Harvest Index (HI; -) to be used in crop modelling for regional estimates of rice production.

The variability of these parameters as a function of phenology and variety was analysed by collecting data in two field experiments carried out in 2003 and 2004. A method to estimate maximum potential RUE for modelling application not affected by temperature limitation was tested using also other available experimental field data set. Not all the parameters necessary to run complex explicative models were estimated, but only those usually considered the most important in describing LAI development and light harvesting in RUE-based approach. For all the estimated parameters, the group-of-varieties approach proposed by Confalonieri and Bocchi (2005) was followed, estimating specific sets of crop parameters for Indica type early varieties (IE), Japonica type early varieties (JE) and Japonica type medium-late varieties (JM).

Physiological and modelling meaning of the selected parameters

A short description of the physiological and modellistic meaning and importance of SLA, k, HI and RUE parameters are here presented

Specific Leaf Area

Specific leaf area is the leaf area (m^2) to leaf mass (kg) ratio. SLA values range between 15 and 40 m^2 kg^{-1} depending on crop typology but present also an intraspecific variability. Physiologically, high SLA values reduce the amount of assimilate required to produce a given leaf area, this results in an earlier ground cover and consequently a greater light harvest that produces a higher assimilation rate early in the season. It is one of the most important parameters in crop simulation models because it determines the amount of green area index (GAI; -) produced in a day.

Coefficient of light extinction

The coefficient of light extinction k describes the capacity of the canopy of light interception. k coefficient is crop specific but can differ also on the basis of cultivated varieties. The light extinction capacity depends on the plant morpho-physiological conditions and consequently it varies during the season dependently on plant development. As underlined by Kiniry *et al.* (2001) lower values of k allow a better light penetration into the canopy thus illuminating more leaf area that guarantee a more efficient light harvest. This characteristic is typical of plant with more upright leaves.

In crop modelling this parameter describes the light penetration through the canopy and is used to quantify, through the Lambert – Beer's law (Monsi and Saeki, 1953), the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) (equation 1). High k values determine strong light absorption while lower value determines a deeper light penetration in the canopy.

$$fAPAR = 1 - \exp^{-k*LAI} \qquad (1)$$

Wageningen models (e.g. WOFOST; Van Keulen and Wolf, 1986) requires different k values for different development stages. Other models such as CropSyst (Stöckle *et al.*, 2003) or WARM (Confalonieri *et al.*, 2005) use a mean k value for the entire crop cycle. For this reason k parameter variations were analysed along the season and a crop mean value was also estimated.

Harvest Index

The harvest Index describes the ratio between the commercial part (in case of cereals is grain) and the total above ground biomass at the end of the crop cycle.

The concept of HI was used during the cultivars selection to obtain better ratios between source-sink organs. The semi-dwarf cultivars have lower biomass production but a higher grains weight being also more resistant to lodging and more stable in terms of grains production over the years.

Before the Green Revolution, HI of many crops was 0.3 or less, and now it has been increased to about 0.5 in many cases. Modern high-yielding rice varieties can reach HI greater than 0.6. For some crop models once total biomass production is simulated, rice yield can be estimated by applying a specific HI. Italian varieties range from traditional low yielding cultivar (HI ≈ 0.38) to new high yielding (HI > 0.5).

Radiation Use Efficiency

The amount of CO_2 assimilated by the crop canopy and converted to dry biomass can be considered nearly stable per unit of intercepted/absorbed solar radiation under non stress condition (Monteith, 1977; Sinclair and Muchow, 1999). At canopy level, the saturation limiting processes that occur in leaf photosynthesis are far less pronounced so linear model can be used (Kiniry *et al.*, 1989).

RUE can be experimentally measured over a period of time as crop dry weight increases divided by APAR referred to the same period (Sinclair and Muchow, 1999). The amount of APAR used for RUE estimation depends

Tab. 1 – Rice parameters (SLA, k, RUE, max LAI and HI) values found in international literature.
Tab. 1 *– Valori pubblicati dei parametri della coltura riso (SLA, k, RUE, max LAI and HI) .*

Parameter	Value	Temp.var.	Location	Variety	Type	Reference
SLA (m^2 kg^{-1})	39	after 31 days	Italy	Gladio	semi-dwarf	Confalonieri and Bocchi, 2005
	27-60	after 30 days	-	-	-	Ash *et al.*, 1998
	35	after 31 days	Cote d'Ivore	-	Med. Tall	Dingkuhn *et al.* 1999
	26.6	after 46 days		-		
	23	after 64 days		-		
K (-)	0.4 -0.6	-	-	-	-	Kropff *et al.*, 1994*
	0.35	DVS<0.65	-	-	-	Casanova *et al.*, 1998
	0.49	0.65<DVS<1.0	-	-	-	
	0.61	1.0<DVS<2.0	-	-	-	
	0.65	-	-	-	-	Montheith 1969*
	0.35	DVS<0.53	-	-	-	Mitchell *et al.* 1998
	0.30 - 0.38	after 31 days	-	-	Med. Tall	Dingkuhn *et al.* 1999
	0.47	mean	-	-		
	0.38-0.40	range	Texas (US)	Jefferson	-	Kiniry et al; 2001
	0.45	mean		Cypress	-	
	0.42	mean		Lemont	-	
	0.68	mean	Texas (US)	Cypress	-	Cambpell *et al.*, 2001
RUE (g AGB MJ^{-1})	4.1	mean	-	-	-	Warren-Wilson, 1967*
	3.28	mean	-	-	-	Horie and Sakuratani (1985)**
	2.25	mean	-	-	-	Casanova *et al.*, 1998
	2.2	mean	-	-	-	Kiniry *et al.* 1989
	2.34	mean	Philippine	-	-	Mitchell et al, 1998
	2.37	mean	-	-	-	Charles-Edwards, 1982*
	2.41	mean	-	-	-	Horie *et al.*, 1997
	2.32	mean (1999)	Texas (US)	Jefferson	Early US var.	Kiniry et al; 2001
	2.46	mean (2000)				
	2.41	mean (1999)		Cocodrie	Early US var.	
	2.77	mean (2000)				
	2.09	mean (1999)		Cypress	Late US var.	
	2.59	mean (2000)				
	2.21	mean (1999)		Lemont	Late US var.	
	2.24	mean (2000)				
	5.09	mean (1998)	Texas (US)	Cypress	Late US var.	Cambpell *et al.*, 2001
	3.52	mean (1999)				
LAI (max)	> 5	-	Texas (US)	Cypress		Cambpell *et al.*, 2001
	> 7.0	-	Arkansass (US)	-	-	Grigg *et al.* 2000*
	5.7 - 8.2	-	Philippine	-	-	Ying *et al.* 1998a*
	6.7 - 10.4	-	China	-	-	
	6.0 - 7.0	-	Japan	-	-	Hasegawa and Horie, 1996
	> 7.0	-	Australia	Lemont	-	Borrell *et al.*, 1997*
	5.8	-	Australia	-	Tall	Prasertsak and fukai, 1997*
	3.0	-		-	semi-dwarf	
	5.3	-	Cote d'Ivore	-	traditional	Dingkuhn *et al.* 1999
	6.8	-		-	improved	
	11.2-12.7	-	Texsas (US)	Lemont		Kiniry et al; 2001
HI (-)	0.35 - 0.50	-	Philippine	-	-	Ying *et al.* 1998a*
	0.44-0.48	-	China	-	-	
	0.36-0.62	-	China	-	-	Berge *et al.*, 1997*
	0.40-0.55	-	India	-	-	
	0.35 -0.55	-	Philippine	-	-	
	0.42 - 0.57	-	Australia	-	-	

Developmet stage (DVS): Seeding DVS=0, flowering DVS=1, maturity=2. Intemidiate stage defined by linear model based on temperature (Van Keulen and Seligmanm 1987

* reference found in Kiniry *et al.*, (2001)

** reference found in Sinclair and Muchow (1999)

on two elements: the incoming PAR and the capacity (i.e. the fraction) of absorption by the crop (fAPAR). PAR can be measured directly with quantum sensor instruments or estimated as a proportion (~45-50%) of incoming global radiation measured by traditional meteorological station (Kiniry *et al.*, 1989). fAPAR can be directly derived by transmittance measurements or estimated from LAI measurements using a proper k in Lambert-Beer's law.

Other way to derived RUE is to convert measurements of carbon exchange (CE) between atmosphere and plants (Campbell *et al.*, 2001) in equivalent dry biomass value adopting crop specific coefficient of transformation; the estimated accumulated biomass along a period of time is then related to corresponding absorbed PAR to calculate RUE.

A high efficiency in radiation use is typical of efficient biological systems in terms of carbon fixation and therefore dry biomass accumulation. Much breeder's work was done to increase crop efficiency changing the plant *habitus* selecting dwarfness, erect leaves, high canopy LAI and biochemical photosynthetic efficiency. For this

Tab. 2 – Field data available for rice crop parameters estimation.
Tab. 2 *– Dati di campo disponibili per la stima dei parametric della coltura riso.*

Data set	**Culti-var**	**Group**	**Biomass**			**LAI**		**PAR transmision *****		**Meteo**		**Parameter est.**			
			# re-plic.	*Fert*	*# samp.*	*# samp.*	*Method*	*# samp.*	*Method*	*# samp.*	*Par.*	SLA	K	HI	RUE
Opera 2004	Gladio	I	4	(T2*) PL1	7	7 and 10	D & L	4 time x 4 replic		daily	T & GR	ok	ok	ok	ok
	Volano	JM	-	-	-	-	-	4 time x 4 replic				-	ok	ok	-
Besate 2003	Volano	JM	4	(T2**) PL1	4	7 and 3	D & L	-	-	daily	T & GR	ok	-	-	ok
Opera 2002	Thai-bonet	I	3	LP1	4	3	D	-	-	daily	T & GR	-	-	-	ok
Vigna-te 2002	Sillaro	I	3	LP1	4	3	D	-	-	daily	T & GR	-	-	-	ok
Rosate 1990	Loto	JE	4	LP1	7	5	D	-	-	daily	T & GR	-	-	-	ok
	Cripto	JM	4	LP1	7	5	D	-	-	daily	T & GR	-	-	-	ok
	Europa	JM	4	LP1	7	5	D	-	-	daily	T & GR	-	-	-	ok

L = LAI2000 D = destructive; GR=global radiation; T= temperature

T2* 80 + 80 Kg ha^{-1} *** LAI2000 (DIFN)
T2** 140 Kg ha^{-1} LP1 Production Level 1 (de Wit and Penning de Vies, 1982)

reason new rice varieties present in general higher RUE values with respect to traditional ones.

Consideration related to RUE estimation

Radiation use efficiency as a crop model parameter should represent a potential maximum value for the crop. External factors that reduce crop RUE in specific conditions (development stage, level of irradiance, temperature, damages for cold and disease) should be simulated by the model. In this way it is guaranteed the general validity of the model in situation that differs from that of the experimental data used for the calibration. While in field experiments management tries to prevent stresses (i.e. water needs, weeds and pests presence) only rarely researches are carried out in non-limiting temperature conditions. Temperature represents indeed a limiting factor that affect RUE estimation (Prince 1991; Stöckle *et al.*, 2003), especially when a macrothermal crop (such as rice) is grown in temperate environment.

Kiniry *et al.* (2001), reporting the results of RUE estimation of US rice cultivars, underline that the difference in RUE observed in two subsequent field experiment, year 1999 and 2000, were related to temperature changes. The Authors showed that the higher value estimated in 2000 correspond to summer average higher temperatures recorded from May to July. Similar results can be derived by analysing data published by Campbell *et al.* (2001): seasonal rice RUE derived from the 1998 field experiment was higher than that for 1999 data (Tab. 3, Campbell *et al.*, 2001) as a consequence of mean higher seasonal temperature (Tab.1, Cambpell *et al.*, 2001).

For these reasons, Tao *et al.* (2005) derived a potential RUE value for Maize to be used in CASA model (Potter *et al.*, 1993) for regional applications considering both temperature and moisture down-regulator. The first factor takes into account physiological reduction of RUE when temperatures are higher or lower than the optimal thermal range for growth. The latter factor is used to compensate for potential water stress. Recently, Ahl *et al.* (2004) adopted a similar approach to calculate RUE, for different forest species, considering air and soil temperature constraints in order to derive the cumulative growing season APAR that effectively influenced plant growth.

Materials and methods

Field experiments

Data for parameters' estimation come from two field experiments. A summary of the data sets used in relation to the parameters estimated is reported in table 2.

The 2004 experiment was conducted in Opera (Milano Province; Lat 45° 23', Long 9° 11'). Cultivars Gladio (Indica type, early, IE) and Volano (Japonica type, medium-late, JM) were sown in May 24 and grown under flooded conditions. The two varieties were chosen because belonging to different morpho-physiological group. Gladio is the most cultivated variety in Italy (23.26% of total rice, Statistics from Ente Nazionale Risi-ENR) and Volano is the second Japonica – medium cycle variety cultivated, after Balilla (6.82% of total rice). The experimental factors (variety and N fertilization) were arranged in a completely randomized block design with four replicates to obtain a total of 40 elementary 35 m^2 (7×5 m) wide plots. The fertilization was applied in two doses of 80 kg N ha^{-1} (urea) at the tillering stage (June 22; code 25 of the BBCH scale for rice; Lancashire *et al.*, 1991; 0.25 of the development stage code (DVSC) proposed by Van Keulen and Seligam (1987)) and at the beginning of the stem elongation phase (July

20; code 34 of the BBCH; 0.53 of DVSC). Ten indirect LAI2000 measurements were acquired for all the studied plots during the growing season. Destructive AGB and LAI samplings were conducted seven times only for Gladio on the plots which received the maximum nitrogen dose (Production Level 1 (PL1), de Wit and Penning de Vries, 1982).

In the 2003 experiment, cultivar Volano was sown on April 28 and grown under flooded conditions in a completely randomized block design with four replicates. The experimental factor was the top-dressing nitrogen fertilization (urea), applied at the beginning of the stem elongation phase on June 27 (BBCH code = 30; DVSC = 0.42). Nitrogen levels were 0, 70 and 140 kg N ha^{-1}. Seven LAI2000 acquisitions and three destructive biomass and LAI measurements were performed during the season for PL1 plots (Table 2). For both the experiments, field management allowed to prevent water stress, weeds and pests.

Daily global radiation and temperature data were acquired in both the years using a standard weather station positioned close to the field. Data set acquired in 1990 and 2002, presented in Confalonieri and Bocchi (2005), were used to calculated radiation use efficiency for Indica and Japonica type varieties.

Parameters determination

Specific Leaf Area

SLA values were calculated as the ratio between destructive LAI and biomass. Destructive LAI was measured in laboratory for a sample of six plants per plot: leaf blade and stem (culm and sheath) were separated and laid on a flat surface to acquire digital photographs. Leaf area (i.e. leaf blade; Yoshida, 1981) of all the harvested plants was determined by digital image analysis (Stroppiana *et al.*, 2006). Samples were then dried in an oven at 70 °C until constant weight and subsequently leaf and stem dry biomass was determined. SLA value for Volano and Gladio were derived respectively from the 2003 and 2004 LAI and leaf biomass data.

Coefficient of light extinction

The LAI2000 estimates light transmitted by the ratio of radiative measurements below and above the canopy (LI-COR, Inc., Nebraska, USA). PAR transmittance can be derived multiplying the instrument output DIFN (DIFfuse Not Intercepted) by a value of 0.94 assuming only 6% of visible light reflected by green canopy (Dingkun *et al.*, 1999). The reliability of this assumption was confirmed by the analysis of spectral reflectance data obtained by field spectroradiometer, data not showed, (Stroppiana *et al.*, 2005).

Light extinction coefficient k is then calculated inverting Lambert-Beer's law as:

$$k = -\ln(PAR_{transm}) * LAI^{-1} \quad \text{(eq. 2)}$$

Representative values of k for the two cultivars at different development stages were in both cases derived by regressing of –ln(PAR$_{transm}$) vs LAI (Casanova *et al.*, 1998; Dingkuhn et al 1999). LAI values were obtained by LAI2000 instrument excluding in the calculation the 5th ring (Stroppiana *et al.*, 2006).

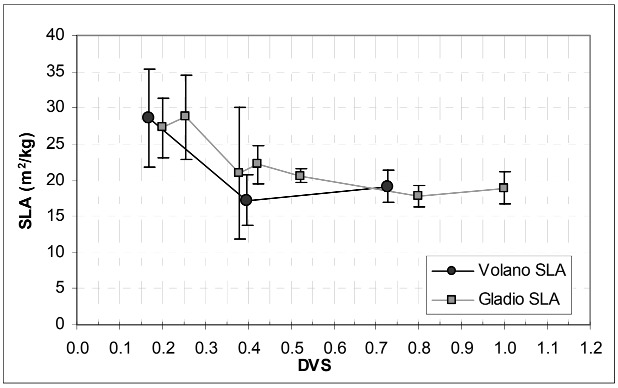

Fig. 1- Mean SLA values for the different sampling date as a function of development stage (DVSC code), one standard error bars are also presented. Gladio data are derived from 2004 experiment; Volano from 2003.

***Fig. 1**- Valore medio di SLA per differenti date di campionamento rappresentate in funzione dello stadio di sviluppo (codici DVSC); le barre indicano il valore di deviazione standard. I dati per la varietà Gladio derivano dall'esperimento del 2004 mentre per il Volano da quello del 2003.*

HI

In the 2004 experiment, at physiological maturity, all the plants in half square meter for each PL1 plots were harvested to calculate HI. Weight of the total AGB and grain were dried in oven and measured. Grains were subsequently separated from the panicles and weighted; HI was calculated for each variety as the ratio between the two measurements.

Radiation Use Efficiency

RUE was calculated as the slope of the linear regression between values of above ground biomass and cumulated APAR (calculated using Eq. 3) (Sinclair e Muchow, 1999). PAR was derived as the 45% of incoming global radiation measured by the weather station (Kiniry *et al.*, 1989) while daily fAPAR time series were estimated by Lambert-Beer formula (Monsi and Saeki, 1953) using the k values previously derived. The daily green LAI time series were obtained interpolating the field LAI measurements, derived by LAI2000, of each experimental data set using a sigma function.

$$APAR_d = PAR_d \times fAPAR_d \quad (3)$$

In the equation the subscript letter *d* refers to the daily value.

Estimation of Potential Radiation Use Efficiency

Potential RUE (or RUE$_{max}$) was calculated taking into account the constraints to biomass accumulation due to suboptimal thermal conditions by multiplying the daily APAR values for a temperature-dependent limiting factor (T$_{lim}$) (eq. 4). T$_{lim}$ was derived using a beta function drawn by three cardinal temperatures as suggested by Yan and Hunt (1999) (eq. 5).

$$APAR_d eff = PAR_d \times fAPAR_d \times T_{\lim} \quad (4)$$

$APAR_{eff}$ is the APAR that effectively influence the crop growth

$$T_{\lim} = \left[\left(\frac{T_a - T_b}{T_{opt} - T_b} \right) \cdot \left(\frac{T_c - T_m}{T_c - T_{opt}} \right)^{\frac{T_c - T_{opt}}{T_{opt} - T_b}} \right]^c \quad (5)$$

In Eq. 5, T_a (°C) is the average air daily temperature, T_b (°C) is the base temperature for rice growth, T_{opt} (°C) is the optimum temperature for growth, and T_c (°C) is the cutoff temperature for growth.

The C parameter of equation 5 was set to 1.92 by assuming $T_{\lim} = 0.5$ when mean temperature is equal to 20 C°. T_b, T_c and T_{opt} are set to 11, 42 and 28°C, respectively, based on Confalonieri and Bocchi (2005).

The analysis of Covariance (ANCOVA) was performed to examine the influence on RUE calculation of other factors. ANCOVA method belongs to the Generalized Linear Models (GLM), it introduces in linear regression quantitative (APAR) and qualitative (group-of-varieties and meteorological year) explanatory variables to model the dependent variable (Biomass). ANCOVA analysis was performed to identify whether or not the explanatory variables bring significant information to the model (APAR vs Biomass). This analysis allowed testing if meteorological conditions influence RUE values and if the cultivar group are characterised by significant different RUE values.

Results and discussion

Specific Leaf Area dynamic

Figure 1 shows the SLA temporal variability for Volano (2003 dataset) and Gladio (2004 dataset) in relation to development stages. The values of SLA for the two varieties present a typical decreasing behaviour.

The derived values fall in the range of values reported by other Authors. Asch *et al.* (1999) for the first 30 days after sowing measured values that range from 27 to about 60 m^2 kg^{-1} respectively for Indica and Japonica type cultivars differing in early vigour. 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 cultivars grown under different N levels and climatic conditions. The experimental results presented here confirmed that mean Indica SLA values are in general slightly higher than Japonica ones along the growing season. Gladio is in fact a newer variety with respect to Volano, characterised by a more efficient leaf growth.

Table 6 reports the derived values in relation to the specific BBCH and DVSC development code. A mean value, average of the observations carried out during the first part of the crop cycle (Stöckle personal communication), is also proposed to be suitable for models that need a single SLA value for the entire season (e.g. CropSyst).

Coefficient of light extinction

Figure 2 and 3 show PAR extinction coefficient values respectively derived for Japonica type (cv. Volano) and Indica type (cv. Gladio) varieties.

As reported in the Literature (Kiniry *et al.*, 2001; Casanova *et al.*, 1998; Dingkun *et al.*, 1999), k values vary during the season. The two cultivars were sown the same day (24 may 2004) but presented different phenological stages during the same sampling days because of the different lengths of their cycles. Gladio is an early variety while Volano is a medium-late one: the two cultivars need respectively 130 and 155 days from sowing to maturity (Ente Nationale Risi; www.enterisir.it /ris_schede.jsp).

The sampling period for Volano covers four phenologi-

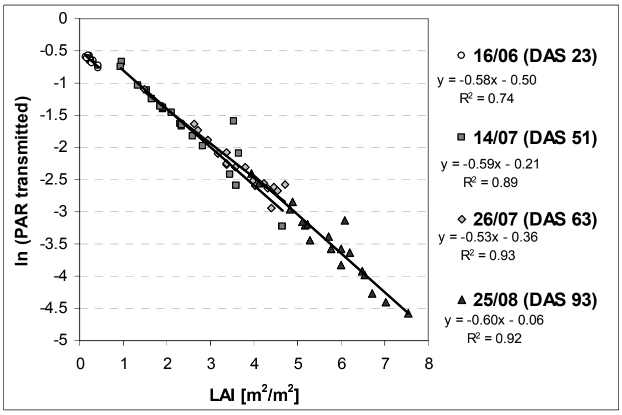

Fig. 2- PAR extinction coefficient derived by regression analysis (continuous line) of ln(PAR_{trans}) and Leaf Area Index for VOLANO (Japonica type). Different k values were calculated at 23 (tillering), 51 (stem elongation), 63 (booting) and 93 (heading) days after sowing.

***Fig. 2**- Coefficiente di estinzione della PAR derivato da analisi di regressione (linea continua) tra ln(PAR_{trans}) e Leaf Area Index per varietà VOLANO (Japonica type). I differenti valori di k sono stati calcolati rispettivamente 23 (tillering), 51 (stem elongation), 63 (booting) e 93 (heading) giorni dopo la semina.*

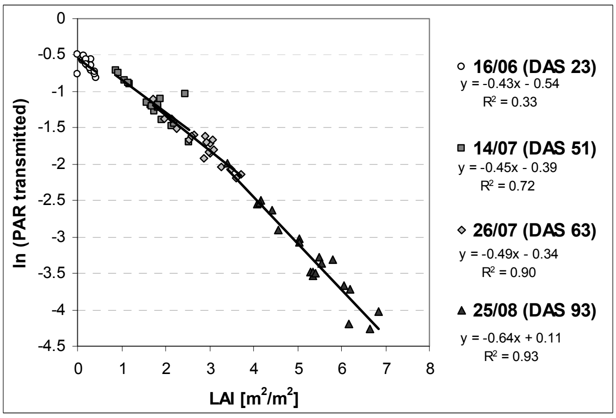

Fig. 3- PAR extinction coefficient derived by regression analysis (continuous line) of ln(PAR_{tran}) and Leaf Area Index GLADIO (Indica type). Different k values were calculated at 23 (tillering), 51 (stem elongation), 63 (booting) and 93 (flowering) days after sowing.

***Fig. 3**- Coefficiente di estinzione della PAR derivato da analisi di regressione (linea continua) tra ln(PARtrans) e Leaf Area Index per varietà GLADIO (Indica type). I differenti valori di k sono stati calcolati rispettivamente 23 (tillering), 51 (stem elongation), 63 (booting) e 93 (heading) giorni dopo la semina.*

cal stages: tillering (BBCH code = 21; DVSC = 0.20) on June 16th; stem elongation (BBCH code = 30; DVSC = 0.40) on July 14; booting (BBCH code = 43; DVSC = 0.68) on July 26, and heading (BBCH = 0.53; DVSC = 0.90) on August 25th. k values at tillering (0.58) and at stem elongation (0.53) are lower than those for booting (0.59) and heading (0.60) as showed by Casanova *et al.* (1998).

The same sampling period and dates correspond, for Gladio, to different phenological stages: tillering (BBCH code = 21; DVSC = 0.20), stem elongation (BBCH code = 32; DVSC = 0.44); booting (BBCH code = 48; DVSC = 0.79), and anthesis (BBCH code = 61; DVSC = 1). k values for Gladio show a wider range being respectively 0.43, 0.45, 0.49 and 0.64.

The different light extinction capacity of the two cultivars is probably due to differences in canopy morphology. Mean Tilt Angle (MTA) parameter provided by LAI2000 describes the general foliage orientation with respect to the zenith direction (LI-COR, Inc., Nebraska, USA). Gladio and Volano present MTA values respectively of 70° and 60° revealing that Gladio has more erect leaves.

Volano, Japonica type, is an old low yielding variety that presents higher k values with respect to Gladio during the entire growing season. Gladio, Indica type semidwarf, is a recent variety selected for its high productivity. As already mentioned, lower values of k allow a better light penetration into the canopy that in correspondence of high LAI value provide a better radiation use efficiency (Kiniry *et al.*, 2001). This characteristic of Gladio derives by its more upright leaves. Last measurement for Gladio presents the highest k value (0.64) because the cultivar is already in flowering stage when panicle are emerged and canopy have changed its habitus being more planofile.

Results suggest that for models which use variable k values as function of different phenological stages, such as WOFOST (Van Keulen and Wolf, 1986), it is better to use different values for the two varieties.

A k mean parameter was also derived for the two cultivars, to be used in models characterized by a single k value for the entire season (e.g. CropSyst [Stöckle *et al.*, 2003] and WARM [Confalonieri *et al.*, 2005]), by interpolating all the collected data (Casanova *et al.*, 1998). Gladio and Volano seasonal k values do not statistically differ (P=0.35) resulted respectively equal to 0.52 and 0.53. A rice crop mean value of 0.53, derived by regression of all the data, is proposed for territorial modelling purpose when it is not practicable to provide a local specific k parameter for the different cultivars. Similar value, k=0.54, was derived by Casanova (1998) for Spanish varieties and by Dingkuhn (1999), who estimated k values ranging from 0.5 and 0.6 for varieties cultivated in Africa.

Tab. 3 – Total biomass, grain yield and HI for the two cultivars, fertilized plot (80 + 80 kg ha^{-1}). Mean values and standard deviation (in brackets) of the four replications are presented and compared to ENR statistics for 2004.

Tab. 3 – *Biomassa finale, produzione di granella and HI dei due cultivar, livello fertilizzazione (80 + 80 kg ha^{-1}). I valori medi e le deviazioni standard (in parentesi) delle quattro repliche sono presentati e comparati alle statistiche di produzione del 2004 dell' ENR.*

CV	**Field experiment**			**ENR-STAT**
	Total biomass	Grain yield	HI	Grain yield
	t ha^{-1}	t ha^{-1}	-	t ha^{-1}
Gladio	15.58 (0.80)	7.23 (0.60)	0.53 (0.01)	5.44 (1.09)
Volano	13.82 (0.39)	5.27 (0.41)	0.39 (0.03)	4.87 (1.43)

Grain yield and HI

Table 3 presents the results of the analysis of total biomass, grain yield and harvest index for the two varieties obtained from the PL1 plots during 2004.

Volano presented a slightly lower AGB with respect to Gladio. However, the difference between the two varieties is significantly appreciable (P< 0.05) on grain weight. Gladio, as expected, presents a higher yield, producing 7.23 t ha^{-1} compare to the 5. 27 t ha^{-1} produced by Volano.

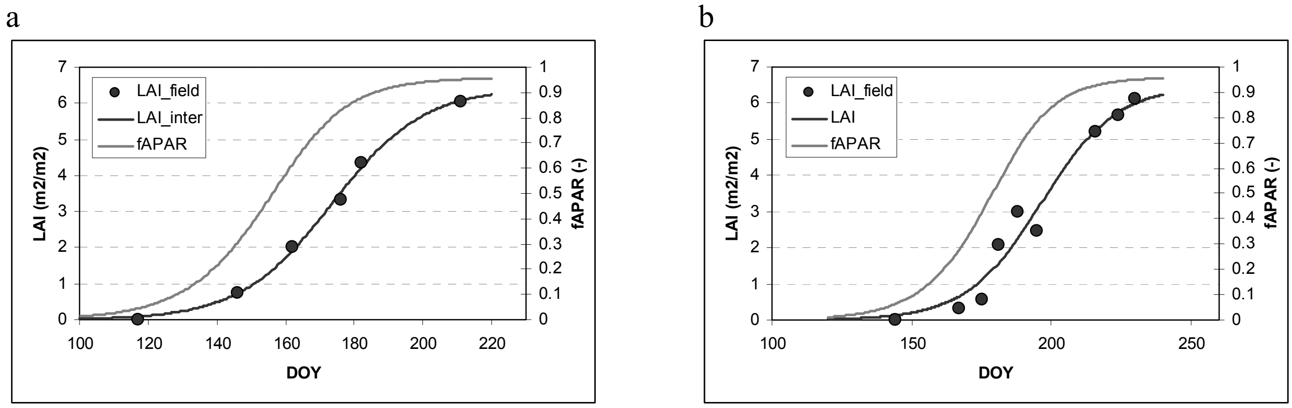

Fig. 4- Field mean LAI values, interpolated value and corresponding fAPAR time series for 2003 (Besate rice fields) (a) and 2004 (Opera rice fields) (b).

Fig. 4*- Misure di campo di LAI: valori giornalieri interpolati e corrispondenti stime di fAPAR per il 2003 (Besate) (a) e 2004 (Opera) (b).*

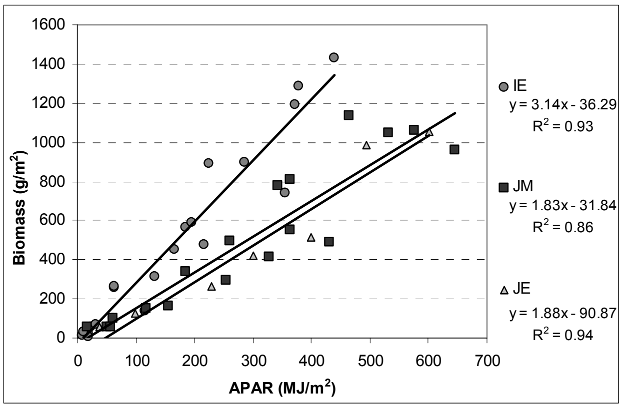

Fig. 5- Regression analysis between field biomass values and relative cumulated APAR. Data were grouped according to rice-group class IE, JE and JM (details in the text).

Fig. 5*- Analisi di regressione tra misure di campo di biomassa e relativa APAR cumulata. I dati sono raggruppati per varietà IE, JE and JM (detagli nel testo).*

Tab. 4- Monthly mean temperature during the growing season of 1990, 2002, 2003 and 2004.

Tab. 4*- Valori medi mensili di temperatura per le stagioni di crescita del 1990, 2002, 2003 and 2004.*

	1990	*2002*	*2003*	*2004*
April	17.45	15.18	16.85	-
May	18.71	17.84	19.38	18.61
June	20.71	23.68	25.42	21.59
July	22.72	23.20	24.56	23.01
Aug.	22.13	22.50	26.25	23.65
Sept.	16.71	21.18	22.43	21.28
May-Jul	20.71	21.57	23.12	21.07
Jul-Sep	20.52	22.29	24.41	22.65

Tab. 5- ANCOVA analysis results for the two data sets: the original APAR data (No Temp. Limited) and the temperature limited effective APAR (Temp. limited).

Tab. 5*- Risultati dell'analisi dell' ANCOVA per i due data set: dati originali di APAR (No Temp. Limited) e valori di APAR effettiva ricalcolati tenendo conto della limitazione di temperature (Temp. limited).*

	Temp. Limited	***No Temp. Limited***
Variable	Pr > F	Pr > F
APAR	< 0.0001	< 0.0001
Year	0.600	0.16*
CV_class	0.893	0.916

The high-yielding characteristic of recent Indica type varieties is highlighted by the value of HI. Gladio presents an HI of about 0.53 sensibly higher (P< 0.001) than Volano, a traditional variety, which presents a value of only 0.39. HI estimated values are in agreement with other Italian field experiments; results demonstrate that for models that use HI approach for grain yield estimation, it is very important to take into account the differences between varieties.

RUE

Examples of field LAI values, interpolated LAI time series and fAPAR profiles for Volano and Gladio are presented in figure 4.

Figure 5 shows the scatter plot of cumulated APAR estimations and related biomass samples for all the available datasets, data were pooled according to the different morfo-physiological and merceological group. From data analysis, it seems that Japonica and Indica type varieties belong to different domain in terms of radiation use efficiency. New Indica type varieties are more efficient with a value of 3.14 g MJ^{-1} with respect to the lower values of 1.83 g MJ^{-1} (Japonica traditional varieties) and 1.88 g MJ^{-1} (recent Japonica varieties).

Differences between Japonica and Indica type can be justified by difference in morpho-physiological characteristics. Estimation of light extinction coefficient (k) for the two rice typologies underline that new Indica type present lower k values that produce better illumination of lower canopy leaves thus maximising total canopy RUE (Kiniry *et al.*, 2001). However, our estimates for Japonica are lower compared to values found in literature.

If all the data are separated according to the year of the

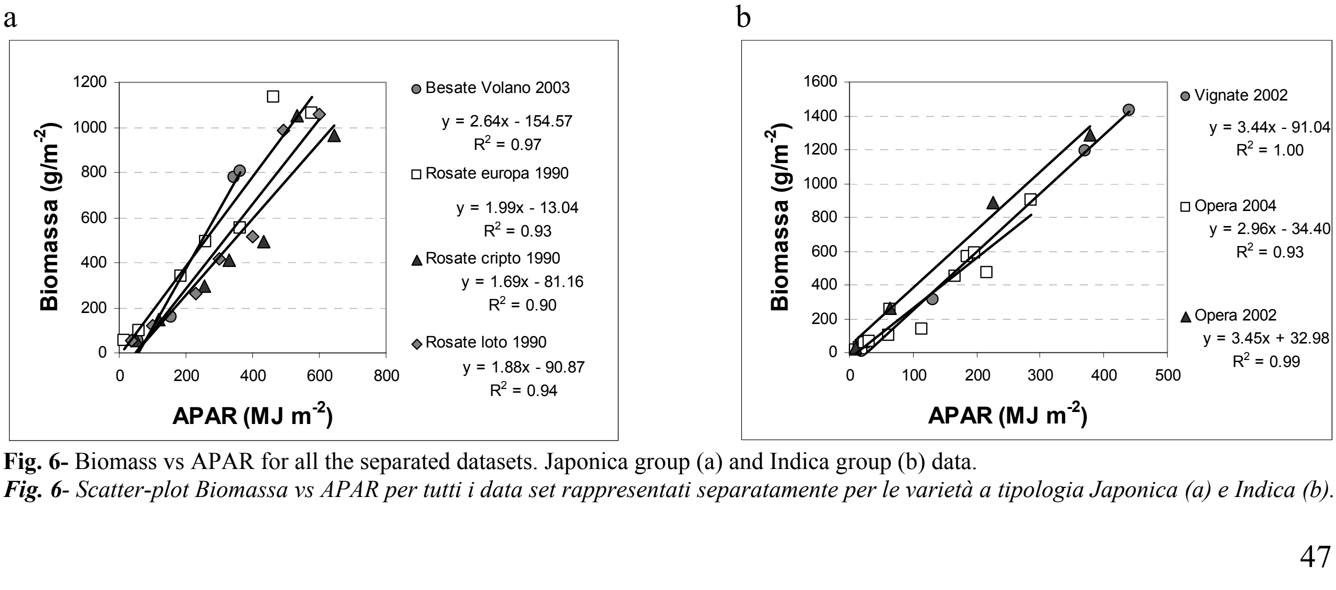

Fig. 6- Biomass vs APAR for all the separated datasets. Japonica group (a) and Indica group (b) data.

Fig. 6*- Scatter-plot Biomassa vs APAR per tutti i data set rappresentati separatamente per le varietà a tipologia Japonica (a) e Indica (b).*

Tab. 6- Summary of crop parameters estimated from field experiments for Indica Early (IE) and Japonica Medium late (JM) rice varieties.

Tab. 6 *- Riassunto dei parametri della coltura riso stimati da dati sperimentali per varietà a tipologia Indica Early (IE) e Japonica Medium late (JM).*

	Unit	Phen. Stage			IE	JM
		Descript.	*DVS*	*BBCH*		
SLA	m^2 kg-1	tillering	0.20	21	27.20	28.51
			0.25	27	28.68	-
			0.38	29	20.92	-
		stem elong.	0.42	30	22.16	17.17
			0.44	32	20.62	-
		booting	0.79	48	17.70	19.49
		heading	0.97	56	18.89	-
		mean first stages	0.25-0.38	21-23	27.50	28.50
k	-	tillering	0.20	21	0.43	0.58
		stem elong.	0.44	32	0.45	0.53
		booting	0.79	48	0.49	0.59
		heading	0.90	53	-	0.60
		anthesis	1.0	58	0.64	-
		mean seasonal	-	-	0.52	0.53
RUE	g MJ-1	seasonal	-	-	3.13	1.83
		Potential Max*	-	-	3.25	2.69
		mean rice	-	-	2.90	
LAI	-	max	0.9-1.0	56	~ 6	~ 7
HI	-	maturity	2.0	99	0.53	0.39
MTA**	degree	mean seasonal	-	-	70°	60°

** Mean Tilt Angle (MTA) foliage orientation respect to the zenith direction

* Potential Max RUE calculated taking into account temperature limitatio

experiment, it is possible to see higher difference among RUE estimation in the Japonica rice group (figure.6a) compared to Indica group (figure 6b).

Differences in RUE estimation among the available datasets can be related to temperature. Table 4 shows the average daily mean temperature for each month of the growing seasons of the experimental data analysed here. These data show that 1990 was the coldest year; in particular, mean temperature for the May-July period is 2°C lower than the other years. 2003 was the hottest year of the century and present the highest temperatures; however 1990 is also ~ 2 °C colder than 2002 and 2004 for the period Jul-Sept.

RUE Max estimation

Specific values proposed for modelling different rice group, obtained separating the different data set and considering thermal limitation, are: 3.25 g MJ^{-1} for IE (R^2=0.90), 2.77 g MJ^{-1} (R^2=0.95) for JE and 2.69 g MJ^{-1} (R^2=0.91) for JM.

Analysis of covariance (Table 5) showed that when temperature limitation is not taken into account the categorical variable Year is significant (*, $P<0.05$) in influencing the results, as a consequence the RUE values obtain by regression analysis are year dependent. However, for both data sets no significant differences are evidenced among cultivar classes. A potential RUE mean value corresponding to a value of 2.89 g MJ^{-1}, compensated for temperature limitation, can be proposed for modelling rice when no information on cultivar typology is available.

RUE rice values published are usually lower than those here derived; Kiniry *et al.* (1989) presented a mean value of 2.2 g MJ^{-1}. More recent results published by Kiniry *et al.* (2001) report mean value slightly higher of 2.26 g MJ^{-1} for 1999 and 2.56 g MJ^{-1} for the warmer season of 2000. However, a recent paper of Campbell *et al.* (2001) presents very high rice RUE data up to 5.66 g MJ^{-1} that almost double the value found by Kiniry *et al.* (2001). High values are also found in old publication, mentioned in Kiniry et al (1989) (Table 1).

In their review Sinclar and Muchow (1998), comparing theoretical limit and potentiality of RUE for corn, soybean and rice, affirm that even if rice does not have the C4 pathway it produces a large fraction of carbohydrate, so its potential RUE must be greater than other C3. They suggest a potential maximum value of about 1.5 g MJ^{-1} of global solar radiation. This figure is equal to more than 2.9 g MJ^{-1} PAR confirming the results of this research.

Table 6 reports a summary of the results, grouped for different rice-group analysed, obtained in the present research; variability of the parameters due to different phenological stages is described and mean seasonal values are provided.

Conclusion

This study underlines the necessity of different parameterisations for modelling rice growth and yield. Rice groups proposed by Confalonieri and Bocchi (2005) present sensible differences in the crop models parameters describing plant morphology. In particular Indica early group shows more erect leaves that provides lower k values and a higher RUE values.

Collected data also showed that meteorological conditions can affect RUE estimation; however, the method used to take into account thermal limitation effect on biomass accumulation allowed comparing different data set retrieving potential maximum RUE values for different groups of rice varieties.

Strongest differences have been observed on grain yield values among rice group producing almost the same AGB. HI values are in fact sensibly different among the two selected cultivars. This aspect underlines the need of describing in crop model the processes that determine different grain mass production in order to provide reliable estimation of crop yield.

Based on these first results, other field measurements can be carried out to study the general validity of the derived parameters. Moreover, experiments addressed to study ontogeny and the effects of plant nitrogen on rice RUE for Mediterranean varieties are needed. In this contest the authors are currently participating to an exploratory research, TOP-FERT http://agrifish.jrc.it/marsstat/topfert/ coordinated by JRC, to study the relationship between rice RUE and top-dressing nitrogen fertilization.

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