SIRBINT, A NEW SIMULATION MODEL TO FORECAST RICE BLAST DISEASE

SIRBINT, UN NUOVO MODELLO DI SIMULAZIONE PER LA PREVISIONE DEL BRUSONE DEL RISO

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Abstract
Pyricularia grisea (Cooke) Sacc. is the causal organism of blast, the most serious disease of rice because of its devastating nature, widespread distribution and existence of several physiologic races. It occurs in epiphytotic conditions in all major rice-growing regions of the world, as well as in Italy. Nowadays, no strategies in current use are based on the dynamics of airborne conidia, the most important means of dissemination of the pathogen, and chemicals and management practices are the only means of blast control. However, blast forecasting may open the possibility of more rational use of fungicides and blast simulation models might prove to be useful in predicting the potential for the disease.
During four growing seasons (2002, 2003, 2004 and 2005) and in two different rice fields located in Northern Italy (Sali Vercellese, Vercelli Province and Castello d'Agogna, Pavia Province), concentrations of *P. grisea* airborne conidia were measured using automatic spore traps. Temperature, humidity and rainfall were also monitored and direct visual estimation of necrosis on leaves, culms and neck nodes was scored. Based on Oryza-1, a new dynamic deterministic model (SiRBInt) simulating the rice-blast interaction and including both weather dependent-crop and pathogen growth patterns was developed. The model is mainly intended to serve technicians working in the extension service and will simulate the potential risk of blast infection. The four years work demonstrated that the model can simulate the blast appearance in field and that it can be used in advising on fungicide application. Validation of the model is needed to verify effect of meteorological data both on rice growth and blast development during a larger number of years.

Keywords: *Pyricularia grisea,* airborne conidia, spore trap

Riassunto
Pyricularia grisea *(Cooke) Sacc. è l'agente causale del brusone, la più pericolosa malattia del riso diffusa in tutte le principali aree risicole del mondo, Italia inclusa. Il patogeno si caratterizza, oltre che per un'elevata capacità infettiva, anche per la sua estrema specializzazione in numerose e differenti razze fisiologiche. In Italia, attualmente, non esistono strategie di protezione della risaia basate sulle dinamiche di aerodispersione dei conidi infettivi, la più importante via di disseminazione del fungo; la lotta chimica ed alcune pratiche agronomiche rappresentano le sole strategie di controllo della malattia. Modelli previsionali in grado di simulare il rischio e la gravità della malattia potrebbero quindi rivelarsi estremamente utili, soprattutto ai fini della pianificazione dell'utilizzo di fungicidi.*
Nel corso di quattro stagioni vegetative (2002, 2003, 2004 e 2005) e in due differenti risaie localizzate nel Nord Italia (Sali Vercellese, Vercelli e Castello d'Agogna, Pavia), è stata monitorata, mediante l'utilizzo di captaspore automatici volumetrici, la concentrazione aerea dei conidi di P. grisea*. Sono inoltre state effettuate azioni di raccolta giornaliera di dati di temperatura, umidità e precipitazione e costante valutazione fitosanitaria* in vivo*. Sulla base di Oryza-1, è stato proposto un nuovo modello (SiRBInt) dinamico e deterministico, in grado di simulare le dinamiche di crescita del riso, lo sviluppo del brusone e l'interazione tra la pianta e il patogeno. I risultati ottenuti nel corso del periodo di studio hanno dimostrato come il modello, pensato come strumento di supporto per operatori tecnici, possa simulare il rischio potenziale di infezione da brusone e possa quindi essere un efficace aiuto per la pianificazione della lotta chimica. Si rendono necessarie ulteriori validazioni, al fine di verificare l'effetto dei dati meteorologici sulla capacità infettiva del patogeno e sulla sua interazione con la crescita del riso.*

Parole chiave: Pyricularia grisea, *conidi aerodiffusi, captaspore*

Introduction
Pyricularia grisea (Cooke) Sacc. (sin. *Pyricularia oryzae* Cavara, Rossman *et al.*, 1990), anamorph of *Magnaporthe grisea* (T.T. Hebert) Yaegashi & Udagawa, is the causal organism of rice blast disease. Blast is considered to be the most important disease of rice worldwide: it is widely distributed (85 countries, Italy included); it can be very destructive when environmental conditions are favorable; its occurrence and severity vary by year, location, variety and even within a field depending on environmental conditions and crop management practices (Hashioka, 1965; Ou, 1985). Moreover, *P. grisea* is highly variable and new races can appear and attack resistant varieties (Valent, 1997). In Europe, for instance, five lineages of the pathogen have been de-

scribed (Roumen *et al.*, 1997) and two additional haplotypes were detected in the Italian *P. grisea* population (Piotti *et al.*, 2005).
Yield loss estimates from different areas of the world have ranged from 1 to 50%. The disease causes loss of rice able to feed 60 million people per year (FAO, 2004). Leaf blast, which is sometimes the cause of the death of young plants up to the tillering stage, is characterized by the appearance of diamond shaped lesions on the leaves. A significant impact on yield is registered when the pathogen attacks the junction of the leaf blade and sheath, causing the typical brown "collar rot" symptom. Finally, infections just below the panicle ("panicle blast") can be very injurious to the crop and cause incomplete grain filling and poor milling quality (Webster and Gunnel, 1992).
In Italy, the first European rice growing country (224.015 cultivated ha and 1.438.336 produced tons in 2005; ENR, 2005), *P. grisea* may cause losses between 5 and 30% in production, depending upon environmental conditions. The use of chemical sprays to prevent infections is a normal practice. Literature provides lots of information both to explain the correct identification of the pathogen or the dynamic of the disease and to determine empirical damage functions for the effect of leaf blast, panicle blast, or combination of both on rice yield (Dhua, 1986; Agarwal *et al.*, 1989; Teng *et al.*, 1991; Bastiaans, 1993). Unfortunately, results already obtained by other Authors (Yamaguchi, 1970; Chang, 1986) are often not applicable in our country and, nowadays, no strategies in current use are based on the dynamics of airborne conidia, the most important means of dissemination of the pathogen.
Airborne spores of fungal plant pathogens have commonly been detected and enumerated by microscopic examination of surfaces on which they have been impacted (for review Gregory, 1961). With regard to *P. grisea*, in previous works the authors investigated the life cycle, suggesting the knowledge of airborne conidia concentration, related to general climatic conditions, as a useful indicator for infection risk (Picco and Rodolfi, 2002; Picco *et al.*, 2004). Nevertheless, forecasting of blast infection only by means of airborne conidia and meteorological data has proven extremely difficult and the understanding of the yield physiology is a prerequisite for the construction of a reliable damage model.
Thanks to the large adoption of personal computer, modelling is getting more and more importance in many disciplines. Crop simulation models are well known in agriculture (Penning de Vries and Van Laar, 1982; Penning de Vries *et al.*, 1991) and some attempts in simulating crop-pathogen interaction for better managing pesticide applications have been carried out (Gunter, 1986; Kanbier, 1987; Rossi *et al.*, 2003).
In this work we propose a new dynamic model called SiRBInt (Simulation of Rice-Blast Interaction). A four years work was conducted to develop the model with the aim to simulate the blast appearance in field and to plan fungicide application (if needed), especially when a chemical with preventive action is used.

Materials and methods

Rice fields investigation

During four growing seasons (from 2002 to 2005), two different rice fields located in Northern Italy (Sali Vercellese, Vercelli Province; Castello d'Agogna, Pavia Province) were investigated. A quantitative aerosporological analysis was carried out to determine the fluctuation of *P. grisea* conidia presence in the air. By means of automatic volumetric spore traps (VPPS 2000 Lanzoni, Bologna, Italy), based on Hirst (1952) principle and installed near each rice field, airborne conidia were continuously sampled. The tapes used for catching spores were replaced every week, cut into segments corresponding to single days and adequately manipulated as described in a previous work by Picco and Rodolfi (2002). The obtained slides were scanned under an optical microscope (x 400) and the results were expressed as the number of conidia/m^3 per day. The sampling method, slide preparation and data interpretation were performed according to the standard method of the aerobiological monitoring (Mandrioli *et al.*, 1991). Meteorological data (temperature, humidity, rainfall and leaf wetness) were monitored through weather stations (ERSAF, Regione Lombardia - Servizio Agrometeorologico, Regione Piemonte). A direct visual estimation of stress on leaves was constantly made using the Standard Evaluation System for rice (INGER-IRRI, 1996).

SiRBInt

The SiRBInt model was based on Oryza-1 model (Kropff *et al.*, 1994). SiRBInt is an ecophysiological dynamic deterministic model which takes into account many physiological traits of rice and how they are affected by the blast pathogen. Both rice and blast have a weather dependent growth (and development). While simulated rice starts growing at the time the user indicates sowing, blast starts its growth when weather conditions are favourable, considering blast spores ubiquitary on non-target plants (*i.e.* weeds) at any time.
SiRBInt consists of two interacting sub-models: the Rice and the Blast sub-models. The rice sub-model derives from Oryza-1, while the blast sub-model was newly built. Oryza-1, originally written in Fortran, was modified to adapt it to the Italian rice characteristics and growing conditions and to Visual Basic for Excel® environment, already used as modelling environment in other studies (Hardisty *et al.*, 1993; Bocchi *et al.*, 1997). Both the subroutines regarding transplanting and the sensitivity to the photoperiod were removed as in Italy transplanting is no more conducted since about 50 years and no variety is photoperiod sensitive. The blast sub-model was derived from physiological studies (Yamaguchi, 1970; Gunter, 1986; Kanbier, 1987; Bastiaans, 1993) which demonstrated the effect of the pathogen on four physiological processes of the crop: (1) effect on max CO_2 assimilation, (2) effect on light use efficiency, (3) effect on maintenance respiration and (4) effect on LAI (Leaf Area Index). All the effects are clearly due to the necrosis on host plant and to blast respiration, both for maintenance and for growth (Figure 1).

The Blast sub-model

Leaf wetness is of great importance in determining blast development (El Rafaei, 1977) but conventional weather database did not record it. Five parameters were taken into account to simulate blast development: maximum temperature (MXTMP), day-night temperature range (DTEMP), maximum relative humidity (MAXRH), day-night relative humidity range (DLTRH), rainfall (RAINF). Data were useful to determine effect of large variation in temperature and relative humidity during a day since the time interval used in the model is one day and does not permit to consider hourly weather change. The effect of the five parameters was computed as damage percentage risk (MXTMPRISK, DTEMPRISK, MAXRHRISK, DLTRHRISK, RAIFRISK). Multiplying them the global blast risk percentage (BLASTRISK parameter) is obtained. The blast risk is translated into a risk level (RISKLVL parameter) with value varying from 0 (=very low risk), to 3 (=very high risk). The rice variety resistance (VARRES parameter) has the same varying value: from 0 (=susceptible) to 3 (=resistant). If RISKLVL is higher than VARRES then the infection start. Before the symptoms become visible a latency period (LATNCY parameter) should be spent. Its duration depends on temperature (Gunter, 1986). At the end of the latency period blast starts to sporulate. Blast duration depends on temperature and is taken into account through the BLASTDVS parameter (0=sporulation start, 1=sporulation end). Blast severity (DISSEV parameter) is depending on blast development stage (BLASTDVS parameter) and on temperature.

DISSEV directly affect four parameters (MF1, MF2, MF3, MF4) that act as multiplication factors inside the algorithm related to the four crop physiological processes. The parameters MF1, MF2, MF3, MF4 can be switched on and off to check the effect of each of them on final growth and yield. The Blast sub-model is detailed in Biloni (2005).

In SiRBInt version 1.13 a paired simulation is possible. Some parameters are used for both the simulations (weather data file, date of sowing, date of simulation

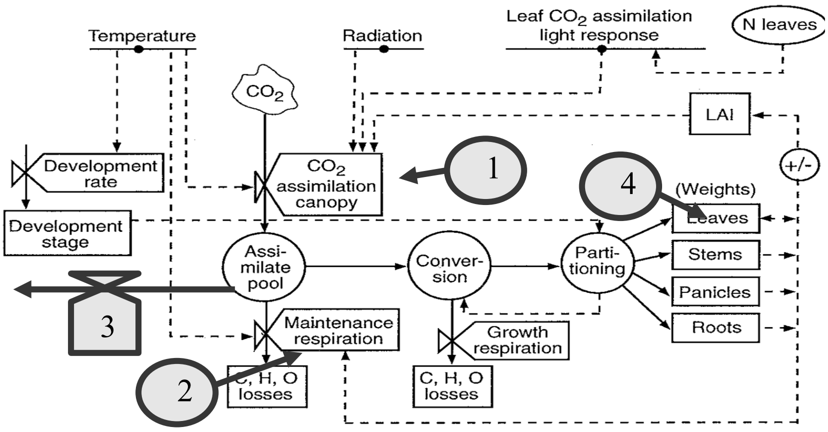

Fig. 1 - Relational diagram of SiRBInt v.1.13 (numbers 1 to 4 indicate the physiological processes affected by blast)

Fig. 1- *Diagramma relazionale di SiRBInt v.1.13 (i numeri da 1 a 4 indicano i processi fisiologici alterati dal brusone)*

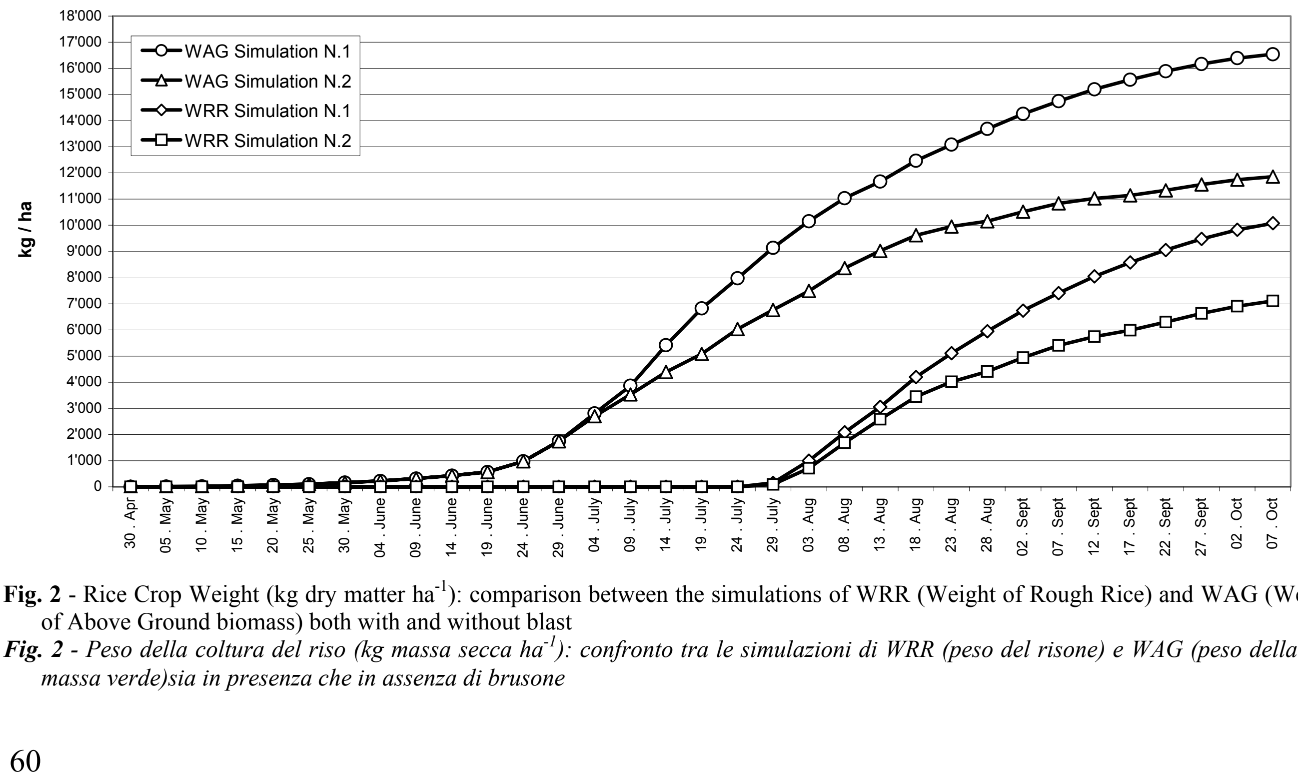

Fig. 2 - Rice Crop Weight (kg dry matter ha^{-1}): comparison between the simulations of WRR (Weight of Rough Rice) and WAG (Weight of Above Ground biomass) both with and without blast

Fig. 2 *- Peso della coltura del riso (kg massa secca ha^{-1}): confronto tra le simulazioni di WRR (peso del risone) e WAG (peso della biomassa verde)sia in presenza che in assenza di brusone*

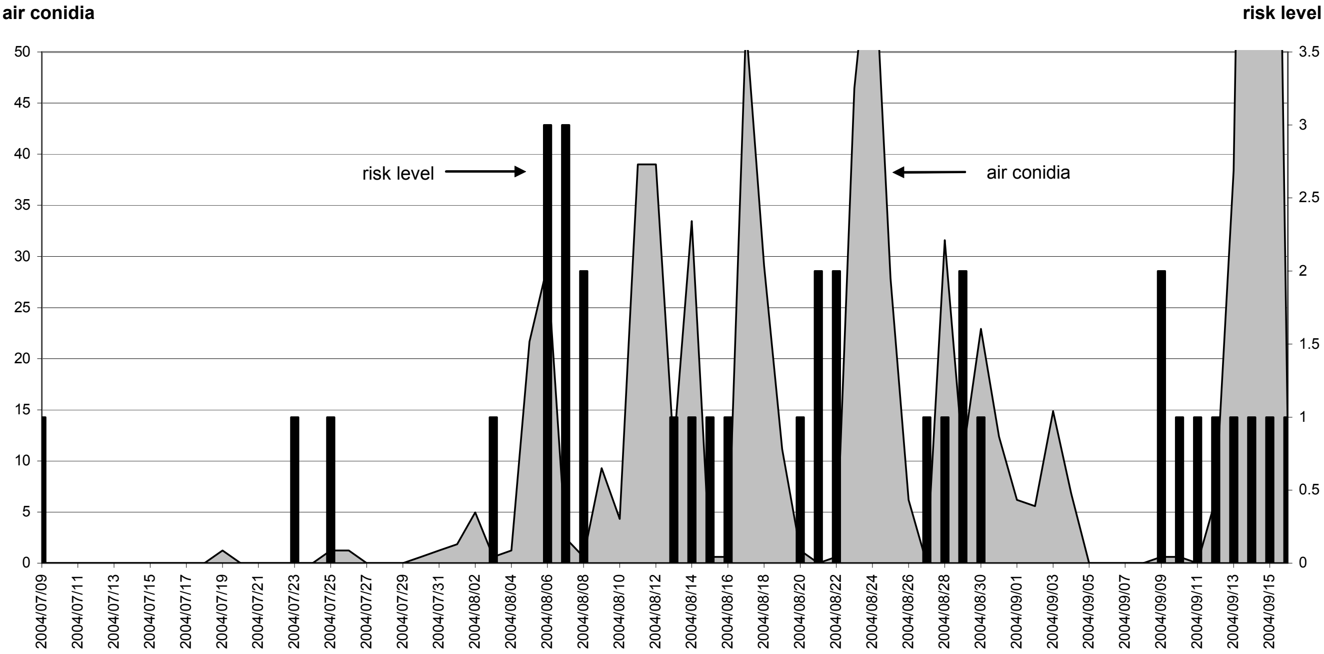

Fig. 3 - Comparison between measured air conidia and blast risk level (Castello d'Agogna, 2004)
Fig. 3 - *Correlazione tra numero di conidi aerodispersi e livello di rischio del brusone (Castello d'Agogna, 2004)*

end, output step, simulated LAI switch, simulated leaf nitrogen switch) while other can be different for each (variety resistance, MF1 to MF4 switches). The common use of the paired simulation is changing just VARRES parameter (value 0 compared to value 3). Value 3 is like applying fungicide or use a totally resistant variety. The yield difference between the two simulations can help deciding whether or not apply fungicide. An example is shown in Figure 2.

Illustrative case-study

Experimental results

The main objective of the rice fields investigation was to quantitatively evaluate the airborne presence of *P. grisea*, in relation to the environmental conditions, and to verify a positive correlation between conidia diffusion and manifestation of blast symptoms. For this purpose, the experimental researches were carried on for four years and at two levels of study, both microscopic and epidemic. Afterwards, experimental results were used to test and validate the proposed simulation model.

During all the monitored seasons, aerosporological data appeared to be useful and reliable in predicting the appearance of both leaf and collar blast disease. The first peak of *P. grisea* conidia (usually detected between the end of July and the first week of August) preceded by a few days (not more than one week) the appearance of the necrotic spots of leaf blast. The peaks of *P. grisea* conidia detected between flowering and maturity (from the mid of August to the first week of September), together with predisposing meteorological factors, indicated a real collar blast risk. Moreover, the well-known processes of conidia germination and penetration agree with these results. Infact (for review Ou, 1985), conidia infect rice under conditions of high humidity and, once inside the plant, invading hyphae swell and fill the cell within twenty-four hours. Penetration of neighbouring epidermal or parenchymal cells occurs within forty-eight hours. The fungus then grows rapidly and, approximately five to six days after inoculation, the first visible symptoms of infection may be observed. Obviously, the exact time required for mycelial growth, sporulation and conidial germination varies with temperature, relative humidity and rainfall.

First simulation results

In Figure 3 measured air conidia and blast risk level are represented with area and bars, respectively. Data collected in Castello d'Agogna, during 2004 were used. The risk level well describes the presence of weather condition adapted for infection start. Few days after a risk level of 1 or more, an increase in air conidia was observed as a confirmation of good simulation. The risk level graph can be used to decide on fungicide application considering time of the year and varietal resistance to blast. In the graph it seems clear that a fungicide application at the beginning of August could be helpful with most of rice variety, at least during the investigated period.

Remarks

The SiRBInt model groups a large amount of information. Data used to develop the model come all from experimental results but their approximation is not uniform. An uncertainty analysis usually reaches the conclusion that more are the simulated processes more is the chance to make a bad simulation since any process will carry on its own uncertainty. SiRBInt can be improved with further investigation to reduce uncertainty risk. With this goal, we will continue with calibration-validation process since when a sufficient number of seasons will be investigated and good output will be obtained.

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