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Evaluation of WARM for different establishment techniques in Jiangsu (China)

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ABSTRACT

WARM is a model for rice simulation accounting for key biotic and a-biotic factors affecting quantitative and qualitative (e.g., amylose content, chalkiness) aspects of production. Although the model is used in different international contexts for yield forecasts (e.g., the EC monitoring and forecasting system) and climate change studies, it was never explicitly evaluated for transplanting, the most widespread rice establishment method especially in tropical and sub-tropical Asia. In this study, WARM was tested for its ability to reproduce nursery growth and transplanting shock, using data on direct sown and transplanted (both manual and mechanical) rice collected in 24 dedicated field experiments performed at eight sites in Jiangsu in 2011, 2012 and 2013. The agreement between measured and simulated aboveground biomass data was satisfactory for both direct sowing and transplanting: average R^2 of the linear regression between observed and simulated values was 0.97 for mechanical transplanting and direct sowing, and 0.99 for manual transplanting. RRMSE values ranged from 5.26% to 30.89%, with Nash and Sutcliffe modelling efficiency always higher than 0.78; no notable differences in the performance achieved for calibration and validation datasets were observed. The new transplanting algorithm – derived by extending the Oryza2000 one – allowed WARM to reproduce rice growth and development for direct sown and transplanted datasets (i) with comparable accuracy and (ii) using the same values for the parameters describing morphological and physiological plant traits. This demonstrates the reliability of the proposed transplanting simulation approach and the suitability of the WARM model for simulating rice biomass production even for production contexts where rice is mainly transplanted.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for more than three billion people worldwide, providing 35–75% of their dietary calories (Krishnan et al., 2011). Global rice production amounts to more than 720 million tonnes (FAO, 2011). The cultivated area is concentrated in Asia, with China accounting, alone, for the 28% of the total production (FAO, 2011).

The two main methods for establishing rice plants are direct sowing and transplanting, with the latter implying growing rice seedlings in a nursery bed near the main field before manually or mechanically transplanting them about 15–40 days after sowing (IRRI, 2009). Although transplanting requires significantly more labour than direct sowing, it is still the main technique used to establish rice in developing countries, especially in tropical and sub-tropical Asia. Transplanting, indeed, favours rice over emerging weeds and allows a higher degree of intensification because rice takes up the main field for less time (IRRI, 2009). In the last two decades, transplanting was partially replaced by direct sowing in important producing countries like Malaysia and Thailand (Pandey et al., 2002). However, the price of herbicides still makes manual transplanting the preferred solution in most low-income areas (Chen et al., 2009; IRRI, 2009).

In some temperate Asian countries like Japan, Korea, Taiwan and part of China, the reduced availability of manpower in the countryside and the increasing cost of labour are leading to gradual abandonment of manual transplanting in favour of mechanical techniques (Pandey et al., 2002). Mechanical transplanting is much more efficient than manual in terms of manpower use (1–2 ha person^{-1} day^{-1} compared to 0.07 ha person^{-1} day^{-1}),

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although it requires more financial and technological resources (IRRI, 2009) and is hardly feasible in hilly-terraced regions, like, e.g., those present in northern Philippines.

Among the widespread models for rice simulation, only CERES-Rice (Jones et al., 2003), ORYZA2000 (Bouman et al., 2001; Bouman and van Laar, 2006), APSIM-Oryza (Gaydon et al., 2012a,b), NIAES-Rice (Hasegawa and Horie, 1997) and RIBHAB (Salam et al., 2001) reproduce the key processes involved with nursery growth and transplanting shock. The latter is crucial because of its effect in arresting the main physiological processes involved with crop growth and development after the event, thus extending the length of the crop cycle (Salam, 1992). The duration of the shock depends on seedling age, pulling methods, handling during transplanting, cultivar characteristics and weather conditions before and after transplanting (SARP, 1987).

It is possible to find in the literature various studies where the transplanting algorithms of the above-mentioned rice models were tested under different environmental and management conditions. Sudhir-Yadav et al. (2011) tested the ability of ORYZA2000 to simulate the effects of different water management techniques on transplanted rice in north-western India. Mahmood et al. (2004) applied CERES-Rice to 16 locations representative of the major rice growing regions in Bangladesh to study the effect of water stress on transplanted rice. However, an effective evaluation of the algorithms involved with transplanting should be performed by using datasets with the same (or similar) cultivars established using both the techniques (e.g., Hossain et al., 2002; San-oh et al., 2004), whereas – according to the authors' knowledge – the available studies refer only to either direct sowing or transplanting datasets. The risk, in this case, is to include the effect of biophysical processes dealing with transplanting in the values of parameters that should instead describe only morphological and physiological plant features, or – vice versa – to include cultivar features involved with, e.g., phenology, in the parameters of the transplanting shock algorithms. The assumption behind these considerations is obviously that a model should work with exactly the same set of crop parameters for both the establishment methods, when cultivars with similar features are used. This would demonstrate the reliability of the transplanting algorithm and the coherence of the way it is coupled to the crop model.

WARM (Confalonieri et al., 2009) is a model specific for the simulation of rice-based cropping systems, operationally used by the European Commission for rice monitoring and yield forecasts since 2006, and adopted in different international projects (e.g., EU-FP7 E-AGRI, MODEXTREME, ERMES, World Bank AZS) and networks (i.e., AgMIP). The possibility of reproducing the interaction between fungal pathogens and the host plant, and the impact of abiotic factors (e.g., temperature shocks, lodging) on qualitative and quantitative aspects of productions make this model particularly suitable for evaluating the impact of climate and management scenarios. The main restriction of the first version of the model was the absence of an algorithm for the simulation of processes involved with transplanting.

The objectives of this study were:

- to develop a new algorithm within WARM to reproduce the dynamics involved with both manual and mechanical transplanting;
- to evaluate WARM using datasets where the same (or similar) varieties were grown under both direct sowing and transplanting conditions, in order to verify the capability of the model to reproduce – using the same parameter set – the effect of different establishing methods on rice growth and development.

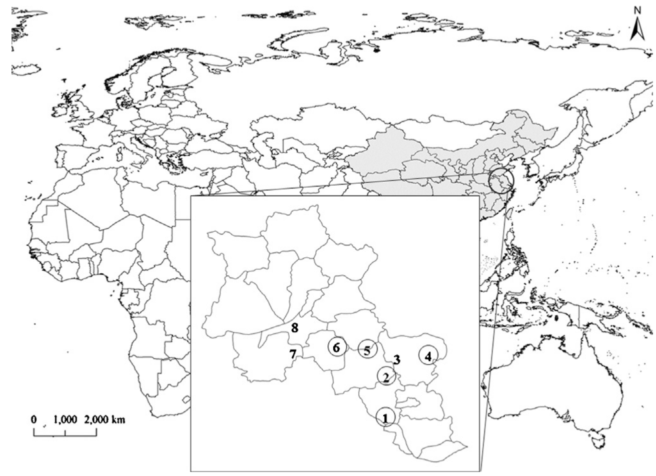

Fig. 1. Experimental sites (see Table 1 for details). Calibration datasets are enclosed by circles.

2. Materials and methods

2.1. Experimental data

Data were collected in the Jiangsu province of the People's Republic of China in 2011, 2012 and 2013, at eight sites located in the central-western part of the province (Fig. 1). The climate in the experimental area is humid subtropical; mean annual temperature is about 15 °C, and daily values often exceed 30 °C in summer. Cumulated rainfall ranges between 800 and 1200 mm. During the period when experiments were carried out, 2011 was characterized by abrupt temperature fluctuations in the sowing periods and temperature slightly lower than the average during the flowering phase; in the same year, the highest cumulated rainfall during the crop cycle was gauged, whereas the highest temperatures during summer were recorded in 2013.

The soils in the sites located in the southern part of the province (experiments 1–5) were clay, whereas those in the central part of the province (experiments 6–8) were clay loam (USDA classification). All the soils presented a medium organic matter content, although higher values were measured in the southern sites (about 25 g kg^{-1} against 20 g kg^{-1} of the central sites), and pH was always subacid, ranging from 6.5 to 6.8. For all the sites, soils had sufficient available phosphorous and medium potassium content.

For all the experimental sites, rice was grown under flooded conditions, thus soil moisture never limited crop growth and development. In the same way, fertilizers (distributed pre-sowing and in one top-dressing event), herbicides and pesticides assured potential conditions for plants in all sites and years. Information on the main characteristics of the experimental sites, on the varieties grown and on management techniques is summarized in Table 1. According to the site and year, rice was directly sown between the first and the second week of June, or transplanted between the third and the fourth week of June. In case of manual transplanting, the mean seedling age at transplanting was 40 days and the seed density in the nursery was around 3000 seeds m^{-2}, coherent with values normally found in literature (e.g., Sharma and Ghosh, 1999; Pasuquin et al., 2008). In case of mechanical transplanting, 58 cm × 28 cm plastic plates were used for the nursery, with 150 g of seeds for each tray (Fischer et al., 2004; FAO, 2012) and seedlings transplanted after about 30 days.

Plant state variables were determined eight/nine times during the crop cycle on 10–20 randomly selected plants per plot according to the variable (Gomez, 1972; Confalonieri et al., 2006). Phenological stages of emergence, booting, heading, flowering and