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USE OF COMPUTER MODELS IN AGRICULTURE: A REVIEW

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Abstract

Computer models are being highly used in agriculture sector to increase efficiency of decision making, and to find out the best cropping and management options. However, to get good output from those models, need to select best models for particular crops and good data source for calibration and validation process. Otherwise outputs of the model do not address the real situation in the field. In this study select three crop models used in rice cropping system and discussed about present data requirement, their application in rice cultivation and model limitations and future potentials. APSIM, ORYZA2000 and DSSAT models were evaluated in this research. However those available models are highly depended on the technical data such as climate, soil, crop and management data and those models do not significantly consider economic and social-cultural factors in agriculture systems. Therefore, simulation results by models do not match with the observed values. Due to this Limitation there is a mandatory requirement to make necessary adjustment or improvements in those models by considering farmers' socio-economic and cultural indicators. In addition, most of the computer models are concentrating in the same crops. When consider the Sri Lankan context , Sir Lanka cultivate comparatively considerable amount of other field crops mainly vegetables with rice where most of these computer models have not been developed to capture the management of vegetables with rice. Hence these limitations in current computer models create an opportunity for researchers to think about new computer models which can capture local conditions and resulting with better model outputs.

Keywords: Efficiency, computer models, socio-economic and cultural data

Introduction

Rice is the staple food of most of the Asian as well as other developing countries. Two third of the world population is concentrated in Asia and land extend used in agriculture is continuously decreasing due to high population growth, urbanization and industrialization in most of the developing countries including Asia. There is a crucial need to increase the land and water productivity in order to feed the increased population (FAO, 2013). In agriculture systems, decision making has become a difficult task due to uncertainty in climate, various types of inputs, different types of management practices and environmental conditions. Application of computer models in decision making will be a potential solution to find out the best cropping and management systems and computer models need comparatively less time and low cost than field trials, can run for several field trials at a given time duration, has a possibility of incorporating the changes in climatic parameters to predict the yields. On the other hand, the generation of new data and knowledge through traditional agronomic research methods and its communication are not sufficient to meet these increasing challenges. In addition, these field trials are time consuming and expensive.

The current challenges in crop production with the context of continuously increasing demand for higher

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crop yields while reducing inputs such as fertilizer, water and pesticide, have created an increasing demand for agronomic knowledge and enhanced decision support guidelines. In considering the present context, crop models are increasingly being used to improve cropping techniques and cropping systems (Uehera and Tsuji, 1993; Penning de Vries and Teng, 1993; Boote et al., 1996). Crop modeling has resulted through combination of mechanistic models designed by crop physiologists, agronomists, soil scientists, hydrologists and meteorologists. Crop models make it possible to identify, very rapidly, the adaptations required to enable cropping systems to respond to changes in the economic, environmental or regulatory contexts (Rossing et al., 1997). The overall objective of this study was to identify the present data requirement in computer models, limitations and future potentials to increase accuracy of model output and efficiency of decision making process.

Methodology

Three crop models (APSIM, ORYZA 2000 and DSSAT) were selected and one application of each models in paddy cultivation were reviewed based on what are the crops and what are the data can be used to model calibration and validation (In here APSIM model application were based on the raw data collected from field). Finally discussed what the limitations of each crop models and what are the future challenges scientists have to face when developing better crop models related to particular region or country.

Results and Discussion

Different Types of Models used in Crop and Water Management in Agricultural System

Crop growth models have been used since 1970s (Hoogenboom, 2003). Crop growth is a very complex phenomenon and a product of a series of complicated interactions of soil, plant and weather. In addition to climatic factors, there are large number of edaphic, hydrologic, biotic and agronomic factors that influence crop growth and productivity (Nagarjuna, 2009). In the past decade, the dynamics of crop growth models have made substantial progress (Gerdes, 1993) and many crop models are available on the market. Some of models are, ORYZA1 (Kropff et al., 1994), CERES-Rice (Singh et al., 1993), SIMRIW (Simulation Model for Rice-Weather relations) (Matthews et al., 1994) ,rice-weed competition model (Graf et al., 1990) ,ORYZA2000 (Bouman, 2006), DSSAT (Decision Support System for Agrotechnology Transfer) (Jones et al., 2003), APSIM (Agriculture production Simulator) (Keating et al., 2003), AquaCrop (Raes et al., 2009) and STICS model (Simulateur Multidiscplinaire Pour Les Cultures Standard) (Bruno et al., 1998) . Also scientists have developed some specific models to soil and water management such as SPAW (Soil-Plant-Air-Water) model (Saxton and Willey, 2006). Each model has its specific objective(s) and, its own set of assumptions and complexity. Computer models have achieved various degrees of success in application. They all have their weaknesses and failed under certain circumstances, therefore authors of models should clarify the limitations of their models and ranges of applications (Ma and Schaffer, 2001).

Crop Models Applications in Rice Cultivation to Increase Productivity

APSIM Model

APSIM is a software tool that enables sub-models to be linked to simulate agricultural systems (McCown et al., 1996). APSIM has various modules grouped and categorized as plant, environment and management. APSIM was developed (APSRU, 1991) to simulate biophysical process in farming systems, in particular where there is interest in the economic and ecological outcomes of management practices in the face of climatic risks. APSIM has been used in a broad range of applications, including support for on-farm decision making, farming systems design for production or resource management objectives, assessment of the value of seasonal climate forecasting, analysis of supply chain issues in agribusiness activities.

Model application- Modeling the Effect of Water Stress on Paddy Yield Using APSIM (Kumara et al., 2013)

A study was done in Kadaweramulla area of the Kurunegala district in Sri Lanka. Seven farmers who were cultivating Bg 358 rice variety in the 2012/2013 Maha season were selected. APSIM crop model was used to evaluate paddy yield under different water management options (Irrigation only, Rainfall only and Irrigation+Rainfall conditions) to identify water stress condition for paddy cultivation. Also the model was used to simulate rice yield under number of dates irrigation supply and simulated water content in the root zone under different water management options for each farmer and graphically showed.

The following data were used in the modeling exercise

Crop data: leaf area index, number of panicles, dates of the main phenological stages, and genetic coefficients.

Management data: starting date of ponding, end date of ponding, maximum depth of ponding, start date of irrigation

Weather data: rainfall, maximum and minimum temperatures, sunshine hours

Soil data: pH, organic matter, N-N03, N-NH4, bulk density, texture, moisture content

According to the results of different water management options, the simulated yield was higher under the irrigation+rainfall option compared to other two options because of less water stress conditions (Fig. 1). According to the simulated data, after increasing no of irrigation days for paddy field, paddy yields continuously increases in the low soil moisture fields (Fig. 2) and after some point, yield starts to decrease. The fields which had comparatively higher soil moisture conditions showed opposite results (Fig. 3). Those two phenomena mainly happened due to low and high water stress conditions, respectively. (in the diagram, IRRI+RF =Irrigation+Rainfall, NRF =No rainfall, NIRRI=No irrigation, OBSERVED =Observed yield in each field).

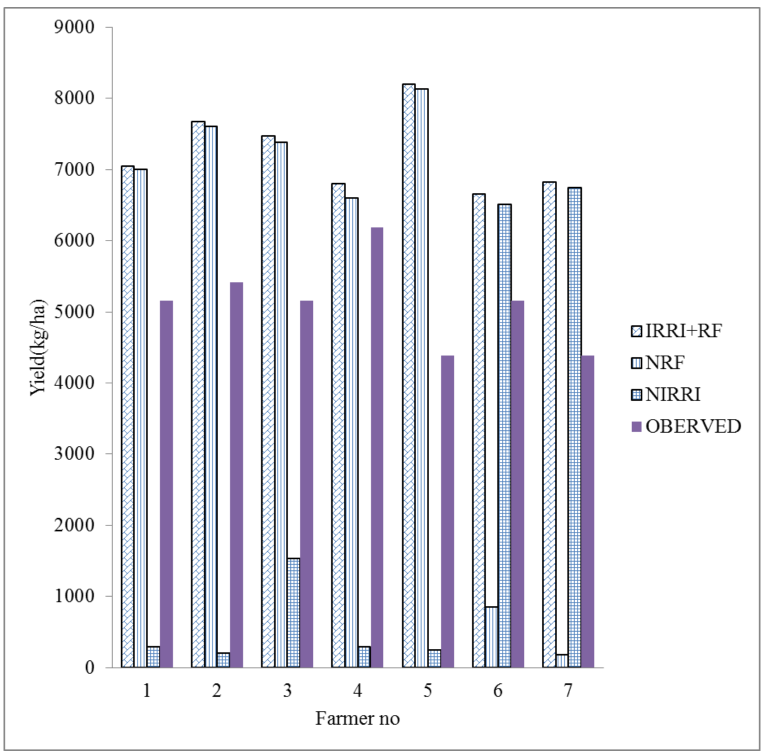


Figure 1: Yield variation with different water management methods for each farmer

Simulated yield is high under irrigation + rainfall water management method. Farmer no 6 and 7 rice fields have high yields under without irrigation. These two fields were located in lower part of the catena with poor drainage conditions. This location has comparatively higher soil moisture conditions compared to other fields studied.

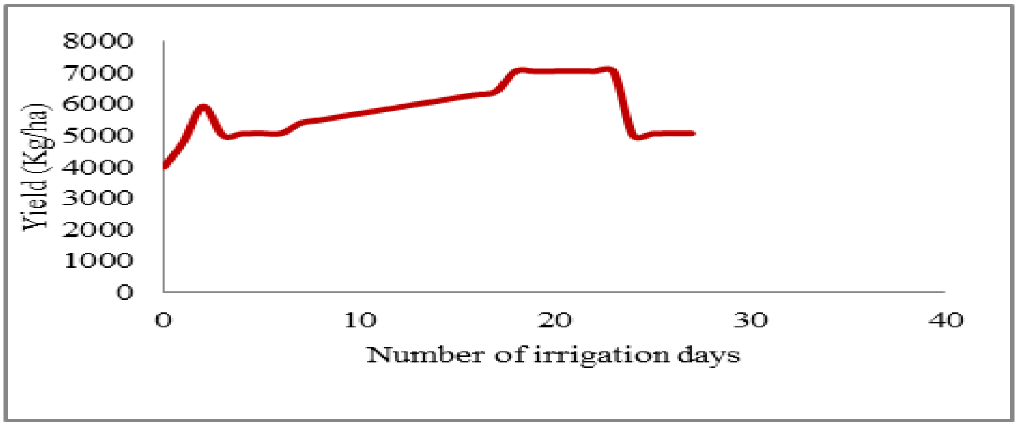


Figure 2: Yield variation with number of irrigation dates provided for farmer no 1

Field belongs to farmer 1 had low moisture condition according to analyzed results. The simulated yield was gradually increased with increasing number of irrigation days for that field and the highest yield was obtained at 23 number of irrigation dates.

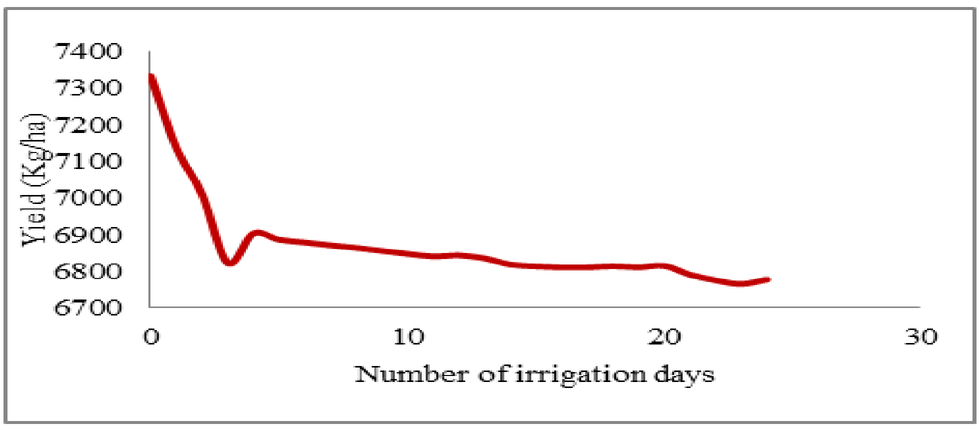
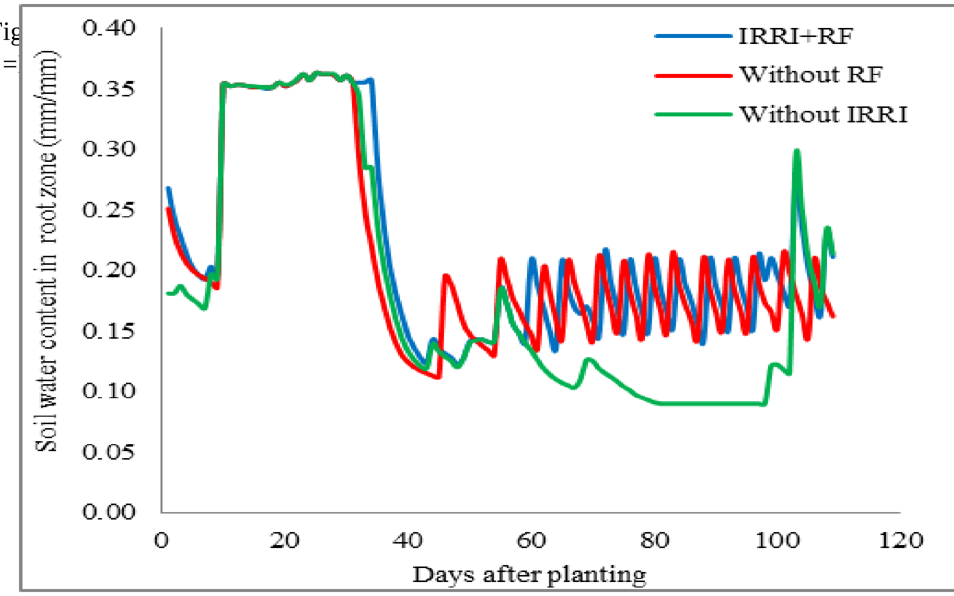


Figure 3: Yield variation with number of irrigation dates provides for farmer no 7

The field of farmer no 6 has high moisture content and therefore, without any irrigation, that field can provide higher rice yield. When increasing the number of irrigation days, yield starts to decreased due to higher moisture stress.

Fig ds (IRRI+RF
= ut irrigation



According to results of Fig. 4, soil water content in the root zone is varied in whole life cycle of the rice plant. During the initial stages of the season, the high soil water content is due to land preparation which uses high amount of water. After 10-14 days, farmers start irrigation and maintain standing water in the field for about 14 days.

ORYZA2000 Model

ORYZA2000 is the successor to a series of rice growth models developed during the 1990s under the project "Simulation and Systems Analysis for Rice Production" (SARP). It is an update and integration of the models ORYZA1 for potential production (Kropff et al., 1994), ORYZA_W for water-limited production (Wopereis et al., 1996), and ORYZA-N for nitrogen-limited production (Drenth et al., 1994). It simulates the growth and development of a rice crop in situations of potential production, water limitations, and nitrogen limitations. A detailed explanation of the model and program code is given in Bouman et al. (2001), and the key modules for potential- and water-limited-production are well explained in the literature (Arora et al., 2006; Boling et al., 2007; Feng et al., 2007).

Model application- Evaluation and application of ORYZA2000 for irrigation scheduling of puddled transplanted rice in North West India (Sudhir et al., 2011).

This study tested the ability of the ORYZA2000 model to simulate the effects of water management on rice growth, yield, water productivity (WP), components of the water balance, and soil water dynamics in north-west India.

Following data were used.

Crop data: leaf area index, dates of the main phenological stages, genetic coefficients etc.

Management data: starting date of ponding, last date of ponding, maximum depth of ponding, starting date of irrigation

Weather data: rainfall, maximum and minimum temperatures, sunshine hours

Soil data: pH, organic matter, bulk density, texture, moisture content

The scenario analysis for 40 rice seasons always indicated some yield penalty when changing from continues flooding (CF) to alternate wetting and drying

(AWD) (Humphreys et al., 2008). ORYZA2000 performs well in predicting the effects of irrigation scheduling on crop growth, yield, water balance components and water productivity of puddled transplanted rice when calibrated for the range of stresses × seasonal conditions. The results of the simulations are consistent with the findings of field studies that AWD has great potential for large irrigation water savings resulting increased irrigation water productivity in comparison with CF. The main cause of the irrigation water saving in AWD is greatly reduced drainage with a relatively small (60 mm) decrease in ET. The effects of the irrigation treatments (AWD) on ET are small, and drainage water is likely to be internally recycled in this region Thus, results suggest that no impact of changing irrigation management from frequent to less frequent AWD on groundwater depletion resulting a regional sustainability of water resources.

DSSAT

DSSAT was developed using CERES-Rice model by International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT) (Tsuji et al., 1998). The model encompasses process-based computer models that predict growth, development and yield as a function of local weather and soil conditions, crop management scenarios and genetic information. The crops that are covered include grain cereals, grain legumes, tuber crops, cotton, sugarcane, and various other species. DSSAT includes a basic set of tools to prepare the input data, as well as application programs for seasonal, crop rotation and spatial analysis. This model not only predicts crop yield, but also resource dynamics, for water, nitrogen and carbon, and environmental impacts, such as nitrogen leaching. In addition, the DSSAT includes an economic component that calculates gross margins based on harvested yield and byproducts, the price of the harvested products, and input costs (Simone, 2012).

Model application- Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model (Basak et al., 2010).

Following data were used.

Weather data: solar radiation, maximum and minimum air temperature, rainfall,

Crop data: leaf area index, dates of the main phenological stages, genetic coefficients etc.

Management data: seeding rate, fertilizer applications, irrigations Water, planting date, planting depth, row spacing, plant population

Soil data: soil pH, surface runoff, evaporation from the soil surface, drainage etc.

The yield of BR3 and BR14 boro varieties for the years 2008, 2030, 2050 and 2070 have been simulated for 12 locations (districts) in Bangladesh. The model predicted significant reduction in yield of both varieties of boro rice due to climate change. The average yield reductions of over 20% and 50% have been predicted for both rice varieties for the years 2050 and 2070, respectively. Increases in daily maximum and minimum temperatures have been found to be primarily responsible for reduction in yield. Increases in incoming solar radiation and atmospheric CO_2 concentration have increases rice yield to some extent, but their effect is not significant compared to the negative effects of temperature. Variations in rainfall pattern over the growing period have also been found to affect rice yield and water requirement. Increasing temperatures and solar radiation have been found to reduce the duration of physiological maturity of the rice varieties. Model results also suggest that in addition to reducing yield. DSSAT modeling system could be a useful tool for assessing possible impacts of climate change and management practices on different varieties rice and other crops.

Comparison of model input data

Table 1: Data requirements for each model

Model		**APSIM**	**DSSAT**	**ORYZA2000**
Data requirement	Weather Data	✓	✓	✓
	Soil data	✓	✓	✓
	Crop data	✓	✓	✓
	Management data	✓	✓	✓
	Economic data	✓	✓	×
	Social data	×	×	×
	Cultural data	×	×	×

As illustrates in table 1 each model required different types of data. Basically all three models totally depend on the technical data such as crop data, climate data, soil data but APSIM and DSSAT the newly developed models now consider on economics data and those models do not significantly consider about socio-economic and cultural backgrounds of farming society.

When considering the Sri Lankan situation, population growth, urbanization, and industrialization create problems and fresh water availability for irrigation in agriculture is becoming a major issue. In village level, more than 12000 minor tanks systems are available for crop cultivation, but those water sources are not being efficiently used. Hence, the use of computer models to increase crop and water productivity under these minor tank systems will help the sustainability of rural agriculture while guaranteeing the water and food security. In Sri Lankan context, we can't use those models directly under the village based agriculture systems since these models have been made in developed countries according to their context. Hence,

it is a mandatory requirement to make necessary adjustment or improvements in those models because those models do not consider farmers' socio-economic situation, attitudes, farmer organization decisions, irrigation water quality, irrigation water allocation and political influence in agriculture. Therefore, simulation results generated without considering socio-economic and cultural factors do not match with the observed values. When model is run only by using technical data results failing failure in the final output of computer models. As an example, during the APSIM model application, simulate results and observed values are found to be highly different because of farmers decision making and model inputs are completely different.

In addition, most of the crops simulating computer models are concentrating in the same crop (mono culture) such as rice, wheat, maize, and some legumes. However, in Sri Lankan situation, Sri Lankan farmers cultivate comparatively large amount of other field crops (OFC) mainly vegetables (Brinjol, Okra, Tomato, Cabbage, Carrot, Pumpkin etc) with rice where most of these computer models have not been developed to capture the management of vegetables with rice. In the Maha season, generally the entire field is cultivated with rice crop while during the Yala season, rice+OFC cultivation is a common practice of farmers in Sri Lanka. These situations create an opportunity for researchers to think about new computer models which can capture Sri Lankan conditions resulting to increased agricultural and water productivity. The development of a computer model to select the best cropping system considering water availability, climate, soil, management, economic, social, and farmer organization decisions will helpful to increase water, land and crop productivity in Sri Lanka.

Conclusion

APSIM model applications gave evidence on how scarce water resources can be managed efficiently for rice cultivation and increasing water productivity. ORYZA2000 model application depicts how computer models can be used in irrigation scheduling and how those computer models analyze under field conditions. In addition, DSSAT model application depicts what are the future challenges to paddy cultivation and how those challenges can be predicted using past data and computer models. All computer models govern by technical data and gave less priority to socio-economics and cultural aspects. Also all models are concentrating in same crops. Therefore simulated results by models do not compatible with the observed data. Hence there is a future potential to developed new crop models considering all data forms and possible combination of crops cultivate in the particular country.

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