A Simulation and Genetic Optimization Framework for Optimizing Nitrogen Fertilization for Rice Crop

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Abstract

Precision agriculture is a technique that can enhance the current agricultural production system dramatically. Optimizing Nitrogen fertilization for rice crop is one of important research issues in Precision agriculture because it can decrease the cost of rice farming, reduce environmental pollution and increase grain yield. The optimal amount of nitrogen (N) and schedules depend on several factors such as soil conditions, cultural practices, varieties of rice, and etc. For traditional approaches of fertilizer optimization, may costly and take a long time.
Therefore, a new simulation and Genetic optimization framework for searching for the optimal fertilizer schedules and the optimal amount of nitrogen (N) for rice crop are proposed. The proposed framework is based on genetic algorithm and *Oryza*2000 Model. Firstly, the *Oryza*2000 Model is calibrated and validated using field experimental data. Secondly, the calibrated *Oryza*2000 model is utilized as simulation model in searching for the optimal fertilizer allocations during the crop growing period and the optimal amount of nitrogen (N). To validate the proposed framework, field experiments are conducted in Chachoengsao Province of Thailand. From the experiments, the total yield of rice crop significantly increases after applying the optimal fertilizer schedules and the optimal amount of nitrogen (N) provided from the proposed simulation-optimization framework. The results of the study suggest that by employing a calibrated crop growth model combined with genetic algorithm can lead to achieve maximum yield.

Keywords: *Nitrogen Fertilization Application Optimization, Rice growth simulation models, Genetic algorithm*

INTRODUCTION

Rice is a staple food for more than 3 billion people in the world (IRRI 2005).Thailand also consumes rice as their staple food. Rice production (2012-2013) is likely to drop to around 37.4 million tons due to droughts and continental climate, which is below3.6% from an estimated 38.8 million tons in the previous year (An official of the Agriculture Ministry, Thailand). For a long period, one important investigative area for scientists has been how to follow the changing weather to adjust timely cultivation measures and acquire a stable and high grain yield with lower investment.

With the rapid development of information technology, great progress has been made both in system cybernetics (Wiener, 1961; Rose, 1974; Hudetz, 1975; Masuch et al., 1990) and in crop simulation (Duncan,1965; de Wit, 1971: McMennamy et al., 1983; Ritchie et al., 1987; Penning de Vries et al., 1989: Williams et al., 1989) during recent decades. Crop simulation has been concerned with more than ten kinds of crops, including wheat, maize, rice barley and sorghum. *Oryza*2000 is an application for summarize the scientific background of the lowland rice models. This application has developed at the International of Rice Research Institute (IRRI) in the Philippines in cooperation with Wagenigen University and Research Center (WUR) the Netherlands by Bouman et.al and released in the year 2001.

Recent developments in crop growth simulation model have given the opportunities for simulating the field conditions. Adequately calibrated and validated agricultural system models provide a systems approach and a fast alternative method for developing and evaluating agronomic practices. This approach is also useful to minimize nutrient additions while meeting the demand imposed by rapid growth.

In this study a novel approach for N fertilizer application management is proposed. The approach employs Oryza2000 model (Bouman et al.2001) for developing optimal N application schedules for rice crop Oryza sativa by integrating it within an optimization framework. The parameters of *Oryza*2000 model are optimized and validated using the data collected from field experiments conducted in three crops. Then, the calibrated *Oryza*2000 is integrated with a genetic algorithm (GA) based optimization framework to derive optimal N fertilizer schedules that maximizes the crop yield. The results are compared with traditional N fertilizer application techniques. *Oryza*2000 is selected for the current research since paddy is the major crop cultivated in the study area.

SIMULATION –OPTIMIZATION FRAMEWORK

A block diagram of the proposed simulation-optimization framework is presented in Fig.1.The optimization framework along with a simulation model is to determine the optimal nitrogen balance. The objective function of the optimization scheme is to maximize the total yield from the nitrogen balance application command.

Initially, genetic algorithm generates initial population. The constraint conditions of populations are governed by decision variables (or parameter). Each pattern of populations is considered as N application schedules for rice crop Oryza sativa. Then, each nitrogen pattern is evaluated by simulating with *Oryza*2000 model. *Oryza*2000 model will provide calculated yields of crop for each nitrogen pattern. These calculated yields of crop are considered as fitness values for each nitrogen pattern. Then, nitrogen patterns (or populations) with top *m* fitness values are selected. These selected nitrogen patterns (or populations) are crossed over and then mutated to generate the next generation of nitrogen patterns. New nitrogen patterns of the next generation are allowed having a lower and upper bound of the values within -10% and +10% from previous generation. These new nitrogen patterns are re-evaluated until stopping criteria met. Finally, the best N application schedules for rice crop Oryza sativa can be found.

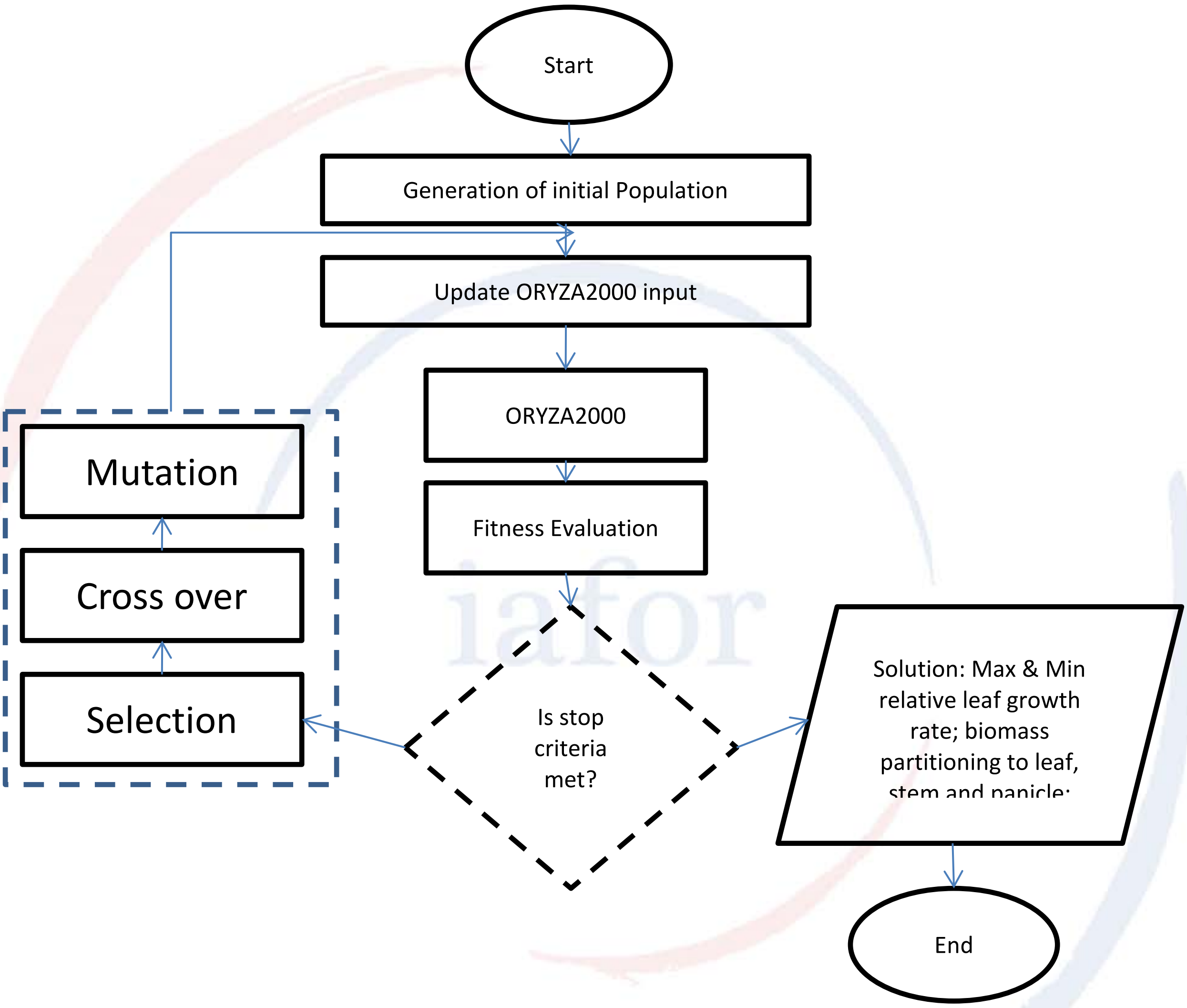

Fig. 1 Optimum of Nitrogen pattern scheduling using crop growth in simulation-optimization framework

Crop growth simulation model-ORYZA2000

ORYZA2000 is an eco-physiological crop growth model that simulates the growth, development and water balance of rice in situations of potential, water limited, and nitrogen limited conditions on a daily basis. Since rice is the major crop cultivated in the study area, we selected this model for our study. While there are a few other crop growth models for rice that are available [e.g., RICEMODE (McMennary and O'Toole 1985], WOFOST (Boogaard et al. 1998)], the *Oryza*2000 has been extensively used and tested for its efficiency in water limited conditions, and the results were encouraging (Belder et al. 2007; Feng et al. 2007; Arora 2006;Belder et al.2004), and therefore is considered in the current study.

A detailed explanation of the model along with the program source code is given in Bouman et al.(2001). The model assumes that the crop is well protected against diseases, pests and weeds, and consequently the model does not consider the yield reduction due to these factors. The model computes the rate of phonological development of rice on a daily time scale based on the daily average temperature and photoperiod. The dry matter at plant organs is computed considering the daily heat units. The detailed scientific description of dry matter production can be obtained from Bouman et al.(2001). The simulated total dry matter is partitioned by the model among various parts of the crop (roots, leaves, stems, and panicles) using partitioning factors, which are to be determined through calibration.

ORYZA2000 is programmed in Compaq Visual Fortran using the FORTRAN Simulation Environment(FSE) as developed by Ban Kraalingen(1995).A detailed explanation of the model and program code is given by Bouman et al.(2001).Below, we summarize the model for potential and nitrogen-limited production(Version2.11,April 2004).The model is freely available, complete with source code, full scientific description, supporting libraries and documents, user guidelines and a self-instructive training course, through internet(www.ORYZA2000.com or www.knowledge-bank.irri.org/oryza2000) or by request to the International Rice Research Institute(IRRI).

EXPERIMENTS

The Study Area

The proposed framework for optimal nitrogen scheduling under nitrogen balancing condition is applied on cultivate command area of Bangkha Chachoengsao, central of Thailand in Bangprakong river basin, which is the main river at the east area of Thailand. This area has effect from disaster every year (floating and drought).The overall area has high acid soil which may cause low productivity.

Parameter estimation of ORYZA2000

The ORYZA2000 model is calibrated using the data from field experiments conducted at Chachoengsao province, central of Thailand, during 2012-2013.The experiments are laid out in a split plot design with three replication of three difference nitrogen rate by growing medium duration rice variety. Nitrogen application considered for the experiment are (1) application of 0 kg/ha^{-1} with RD31, RD41 (2) application of 180 kg/ha^{-1} with RD31, RD41 and (3) application of 255 kg/ha^{-1} with RD31, RD41. The experiments and crop period are presented in Table 1.

Table 1 Details of Nitrogen application experiments on Rice (Oryza sativa)

Location Bangkha Chachoengsao (13 ◦N 101 ◦E)

Crop Transplanting	Experiment					
	0 kg/ha		180 kg/ha		255 kg/ha	
	RD31	RD41	RD31	RD41	RD31	RD41
Water dept(Cm)	10	10	10	10	10	10
Showing date	Jun	Jun	Jun	Jun	Jun	Jun
Transplanting date	Jul	Jul	Jul	Jul	Jul	Jul
Panicle initiation date	Aug	Aug	Aug	Aug	Aug	Aug
Flowering date	Sep	Sep	Sep	Sep	Sep	Sep
Maturity date	Oct	Oct	Oct	Oct	Oct	Oct
Duration(days)	120	115	120	115	120	115
Seedlings per hill	1	1	1	1	1	1
Plant pop. (hills m^{-2})	50	50	50	50	50	50
Seasonal rainfall(mm)	35	35	35	35	35	35

Remark: Jun=June, Jul=July, Aug=August, Sep=September, Oct=October

During the experiments, the dates of sowing, emergence transplanting, active tillering, panicle initiation, flowering and physiological maturity are recorded in each experimental plot. In order to determine the total crop biomass and leaf area index at different stages of crop growth, crop samples are collected at active tillering, panicle initiation, flowering, and maturity. At the time of harvest, yield components are measured in terms of total crop yield, weight of grains and the straw weight. During the period of experiment, the climatic parameters such as values of minimum and maximum temperature, relative humidity, sunshine hours, wind speed and rainfall on each day are recorded. The calibrated model is evaluated for its performance using the data corresponding to the nitrogen treatments of RD31 and RD41 variety from all three replication insert into *Oryza*2000 model.

RESULTS AND DISCUSSIONS

The results of the simulations are presented in Table 2. According to Table 2, the simulated yields are better than the observed yields. Here, the observed yields are considered as the average yields for rice yield in this study area. Therefore, the nitrogen pattern that obtained from the proposed simulation-optimization framework is promising to give an optimum yield for rice crop in this study area. However, the results in Table 2 are only simulated results. In the future, the field experiments for rice crop with the nitrogen pattern, which is obtained from the proposed simulation-optimization framework, will be conducted. Then, the results from the field experiments will be compared with the simulated resulted.

Table 2 observed and simulated crop yield for calibration and validation for different seasonal and nitrogen schedule treatments experiments

Crop Yield for calibration	Experiment (Treatment)	
	180 kg/ha	
	RD31	RD41
Yield(Prior Experiment) Kg ha^{-1}	4,646	4,316
Yield(Simulated),Kg ha^{-1}	5,323	4,688
Error (%)	12.72	7.94

Remark: 1 hectar = 6.25 rai

In addition, the plots of observed and simulated crop yield as well as biomass during the data used for validation of the model are presented in Figs.3 and Fig.4, respectively. Fig.3 is amount of Nitrogen (kg/ha) in a soil after genetic algorithm generate nitrogen schedule compare with total nitrogen of soil by original application. Fig.4 compares between dry weight of storage organs (Kg/ha) result of genetic generate nitrogen schedule pattern with original application Run2 is nitrogen application schedule generated from genetic algorithm more than Run3 is original application.

From the fore going discussions it is clear that the calibrated *Oryza*2000 model is capable of simulating the nitrogen balancing condition of rice crop effectively, and can be used to develop nitrogen application management schedules.

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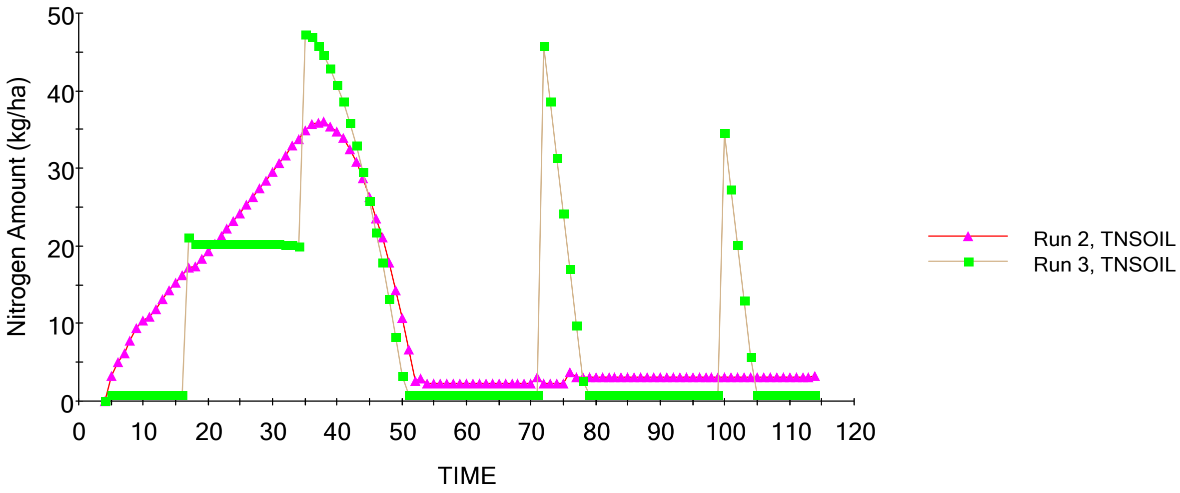

Fig.3.Amount of Nitrogen (kg/ha) between Genetic generate (Run 2, TNSOIL) and original application of observed (Run 3, TNSOIL)

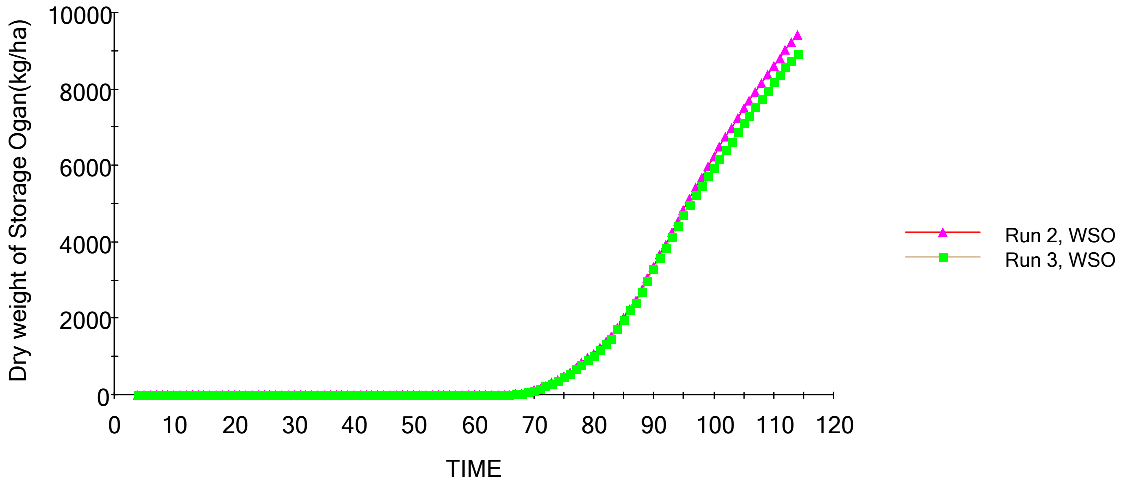

Fig.4. Dry weight of storage organs (Kg/ha) between Genetic generate (Run 2, TNSOIL) and original application of observed (Run 3, TNSOIL)

SUMMARY AND CONCLUSIONS

In the current study, a simulation-optimization framework is proposed to develop optimal nitrogen schedule for rice crop under nitrogen balance conditions. The framework utilizes a rice crop growth simulation model to identify the critical periods of growth that are highly sensitive to the reduction in final crop yield, and genetic algorithm based optimizer develops the pattern optimal nitrogen allocations during the crop growing period. The nitrogen allocation by the genetic optimizer is performed in such a way that the reduction in total crop yield is minimal during the crop. The model *Oryza*2000, which is employed as the crop growth simulation model, is calibrated and validated using field prior experimental data to corporation in the proposed frame work. The Framework it can be accuracy with more experimental also that waiting for testing of result with in real next experiment of paddy rice.

The proposed simulation-optimization framework is applied to develop optimal nitrogen schedules for Chachoengsao central part of Thailand. The effectiveness of the framework is compared with that of traditional nitrogen schedule plans. The result indicated that a no uniform distribution of nitrogen uptake during the growing period of the crop, imposed by the proposed framework, is able to increase crop yield. The major advantage of the proposed model is that it eliminates the limitation of triggering nitrogen remaining levels of soil, which is followed in the traditional methods. The model also eliminates the subjective decisions about the splitting of nitrogen requirement between different growth stages based on their sensitivity to top yield. Overall, the results of the study suggest that by employing a calibrated crop growth model combined with an optimization algorithm can lead to achieve maximum nitrogen use efficiency.

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