UNIVERSITI PUTRA MALAYSIA

EVALUATION OF A RICE CROP GROWTH MODEL FOR SELECTED LOCAL MALAYSIAN RICE VARIETIES AT IADA KETARA, TERENGGANU

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IPTSM 2021 25

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2020

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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October 2020

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Rice is a staple food for more than half of the world's population. Current recommended rates of fertilizers are determined through field, pot culture or greenhouse trial experiments. These approaches are costly, labour extensive and time consuming. As an alternative, simulations of rice crop growth models are valuable tools to perform complex scenario studies including studies of nitrogen (N) fertilization. However, before a model can be used locally, the model's performance must be evaluated. The main objective of this thesis is to evaluate the performance of a rice crop growth model, ORYZA(v3), in simulating six rice crop physiological traits for five Malaysian rice varieties namely MR219, MR220CL2, MR269, MR297 and UPUTRA. The specific objectives are (i) to investigate crop physiological responses of MR219, MR220CL2, MR269, MR297 and UPUTRA treated with three N rates under field conditions and (ii) to calibrate and validate ORYZA(v3) using the rice crop physiological data obtained from the field experiment conducted in IADA KETARA, Terengganu. In this thesis, a field experiment was carried out to investigate the physiological responses of Malaysian rice varieties to three N treatments using a Split-plot Randomized Complete Block Design experimental design. The main factor in this study was N rates arranged in four blocks while the subplot factor was the five selected rice varieties. The three N treatments are T1 (76 kg N ha^{-1}), farmer's practice T2 (109 kg N ha^{-1}), and T3 (142 kg N ha^{-1}). Statistical analysis of two-way ANOVA was conducted to investigate the effects of N and varieties on the rice crop physiological traits. The ORYZA(v3) was calibrated and validated using the field experimental data sets. In this study, the Nash-Sutcliffe efficiency (NSE) was used as an indicator of the model performance as the NSE reflects the overall fit of model simulations against the observations. Except for the dry biomass of panicles, the two-way ANOVA shows that there is lack of N responses on most of plant physiological traits especially in relative chlorophyll content, leaf area index and dry biomass of green leaves. Each of the variety has different biomass partitioning percentage for different plant organs at different growth phases, but

overall, no distinct trend was observed. Calibration of ORYZA(v3) using T1 data consistently resulted in acceptable NSE, where 25 out of 30 rice crop physiological traits of the T1 treatment had NSE of above 0.6. ORYZA(v3) was poorly calibrated T2 and T3 treatments. Except for MR220, validation of the model shows better fit between simulations and observations for the T2 treatment compared to the T3 treatment for the other four varieties. In this thesis, calibrated crop files improved the performance of ORYZA(v3) in simulating the local Malaysian rice varieties for the low N treatment when compared to using a default crop file. Confidence in ORYZA(v3)'s performance and its robustness can be increased with more data in future.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN MODEL PERTUMBUHAN TANAMAN BAGI VARIETI PADI MALAYSIA TERPILIH DI IADA KETARA, TERENGGANU

Oleh

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Nasi ialah makanan ruji bagi separuh daripada keseluruhan penduduk dunia. Sehingga kini, pengesyoran kadar baja untuk tanaman padi kebiasaannya ditentukan melalui kajian percubaan di lapangan, di dalam pasu, atau di dalam rumah hijau. Kesemua kaedah tersebut memerlukan sumber kewangan yang besar, tenaga kerja yang banyak dan memakan masa. Sebagai satu alternatif, simulasi model pertumbuhan tanaman adalah kaedah yang boleh digunakan untuk mengkaji scenario rumit termasuk kajian pembajaan nitrogen (N). Namun, prestasi model tersebut harus diuji sebelum digunakan untuk keadaan tempatan. Objektif utama di dalam tesis ini adalah untuk menguji prestasi model pertumbuhan tanaman, ORYZA(v3), untuk mensimulasi enam ciri fisiologi tumbuhan bagi lima varieti padi Malaysia iaitu MR219, MR220CL2, MR269, MR297 dan UPUTRA. Objektif spesifik adalah untuk (i) menyiasat tindakbalas fisiologi varieti MR219, MR220CL2, MR269, MR297 dan UPUTRA yang dirawat dengan tiga kadar N pada keadaan sebenar di lapangan dan (ii) menentu ukur dan mengesahkan model ORYZA(v3) menggunakan data ciri fisiologi padi yang diperolehi dari kajian lapangan yang dijalankan di IADA KETARA, Terengganu. Di dalam tesis ini, kajian lapangan dilakukan untuk menyiasat tindakbalas ciri fisiologi varieti padi Malaysia yang dirawat dengan tiga kadar N yang berbeza dengan menggunakan kaedah reka bentuk blok lengkap rawak beserta plot berpecah (RCBD). Faktor utama dalam kajian ini adalah kadar N yang disusun di dalam 4 blok secara rawak dan faktor subplot adalah 5 varieti padi terpilih. Tiga kadar N yang digunakan adalah T1 (76 kg N ha^{-1}), amalan petani T2 (109 kg N ha^{-1}), dan T3 (142 kg N ha^{-1}). Analisis statistik ANOVA dua-hala digunakan untuk menyiasat kesan N dan varieti pada sifat fisiologi tanaman padi. Di dalam kajian ini, kecekapan Nash-Sutcliffe (NSE) digunakan untuk mengukur prestasi model kerana nilai NSE dapat mencerminkan kesamaan antara simulasi model dan data pemerhatian secara menyeluruh. Kecuali untuk biojisim kering panikel, ANOVA dua-hala menunjukkan terdapat kekurangan tindak balas N pada kebanyakan ciri fisiologi tanaman terutama pada kandungan klorofil relatif,

indeks keluasan daun dan biojisim kering daun hijau. Setiap variati mempunyai peratusan pembahagian biojisim yang berbeza bagi setiap organ tanaman pada fasa pertumbuhan yang berbeza, tetapi secara keseluruhan tidak ada trend yang ketara. Penentukuran ORYZA(v3) menggunakan data rawatan T1 secara konsisten menghasilkan NSE yang memuaskan, di mana 25 daripada 30 ciri fisiologi tanaman padi T1 mempunyai NSE melebihi 0.6. Hasil penentukuran ORYZA (v3) untuk T2 and T3 adalah tidak memuaskan. Kecuali untuk MR220, pengesahan model menunjukkan keputusan yang lebih baik antara simulasi dan pemerhatian untuk T2 berbanding dengan rawatan T3 untuk empat varieti yang lain. Di dalam tesis ini, penggunaan fail tanaman yang telah ditentu ukur meningkatkan prestasi ORYZA (v3) dalam mensimulasikan varieti padi tempatan Malaysia untuk rawatan T1 jika dibandingkan dengan penggunaan fail tanaman asal. Keyakinan terhadap prestasi ORYZA (v3) dan kemantapan dapat ditingkatkan dengan mengunakan lebih banyak data pada masa akan datang.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to my supervisory committee Dr. Nurulhuda Khairudin, Associate Professor Dr. Farrah Melissa Muharam, Associate Professor Dr. Zed Diyana Zulkafli and Professor Dr. Razi Ismail for their continuous guidance and valuable suggestions throughout my study.

I further thank my examiners Dr. Aimrun Wayayok and Prof. Ir. Dr. Ibni Hajar Haji Rukunudin for the valuable suggestions to improve this thesis. My appreciation also goes to the chairperson of the viva-voce Associate Professor Dr. Hasfalina Che Man and co-chairperson Dr. Mahirah Jahari.

I also would like to express thank you to Dr. Zulkarami Berahim, Mr. Kas Wady Zakaria, Asniyani, Yaya, Imran, Zul and Najja for their support throughout the experimental work at IADA KETARA. My appreciation also goes to Ms. Norhasimah Sulaiman from ITAFoS for arranging the online viva-voce.

I also would like to thank all my family members especially my parents and wife for their continuous support and always believing in me.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ABG	Above ground biomass
ANOVA	Analysis of Variance
APSIM	Agricultural Production Systems Simulator
ASLA	A parameter function to calculate SLA
BD	Bulk Density
BSLA	B parameter of function to calculate SLA
C	Carbon
CERES	Crop Environment Resource Synthesis
DAS	Days after sowing
DL	Dry biomass of dead leaves
DOA	Department of Agriculture
DRLVT	Leaf death coefficient
DSLA	D parameter of function to calculate SLA
DVRI	Development rate in photoperiod sensitive phase
DVRJ	Development rate in juvenile phase
DVRP	Development rate in panicle development
DVRR	Development rate in reproductive phase
DVS	Development stage number
FAO	Food and Agriculture Organization
FERTO	Fertilizer Recommendation Tool's Rate
FL	Flowering
FLV/FLVTB	Fraction shoot dry matter partitioned to the leaves
FNRT	Fraction N translocation from roots

FSHTB	Fraction total dry matter partitioned to the leaves
FSO	Fraction shoot dry matter partitioned to the panicles
FSOTB	Fraction shoot dry matter partitioned to the dry panicles
FST	Fraction shoot dry matter partitioned to the stems
FSTTB	Fraction shoot dry matter partitioned to the stem
FSTR	Fraction of carbohydrates allocated to stems
GL	Green leaves
ha	Hectare
IADA BLS	Integrated Agricultural Development Area Barat Laut Selatan
IADA Kemasin Semerak	Integrated Agricultural Development Area Kemasin Semarak
IADA KERIAN	Integrated Agricultural Development Area Kerian
IADA KETARA	Integrated Agricultural Development Area KETARA
IADA P.Pinang	Integrated Agricultural Development Area Pulau Pinang
IADA Pekan	Integrated Agricultural Development Area Pekan
IADA Rompin	Integrated Agricultural Development Area Rompin
IADA Seberang Perak	Integrated Agricultural Development Area Seberang Perak
IRRI	International Rice Research Institute
KADA	Kemubu Agricultural Development Authority
KST	Saturated hydraulic conductivity

LAI	Leaf Area Index
LAI_OBS	Observed Leaf Area Index
LMS	Least Mean Square
LOI	Loss in Ignition
MADA	Muda Agricultural Development Authority
MgO	Magnesium Oxide
MARDI	Malaysian Agricultural Research and Development Institute
MSE	Mean squared of error
MT	Metric ton
N	Nitrogen
NE	Nebraska
NOP	Number of plants
NSE	Nash-Sutcliffe Efficiency
OM	Organic Matter
PH	Plant Height
PI	Panicle initiation
PM	Physiological maturity
PTF	Pedo-transfer function
RCBD	Randomized Complete Block Design
RGRLMN	Minimum relative growth rate of leaf area
RGRLMX	Maximum relative growth rate of leaf area
RH	Relative humidity
RMSE	Root mean squared of errors
SLA	Specific leaf area
SLAMAX	Maximum value of SLA

SLATB	Supply table of specific leaf area
SNH4X	Soil ammonium content
SNO3X	Soil nitrate content
SO	Dry biomass of panicles
SOC	Soil organic carbon
SON	Soil organic nitrogen
SOM	Soil organic matter
SPAD-N	Relative chlorophyll content in leaf
St	Dry biomass of stem
TC	Total Carbon
TN	Total Nitrogen
USA	United States of America
WAGT	Dry weight of above ground biomass
WCAD	Volumetric water content at air dryness
WCFC	Volumetric water content at field capacity
WCLI	Initial volumetric water content
WCST	Saturated volumetric water content
WCWP	Volumetric content at wilting point
WLVD	Dry weight of dead leaves
WLVG	Dry weight of green leaves
WSO	Dry weight of storage organs
WST	Dry weight of the stems
WAGT_OBS	Observed Dry weight of above ground biomass
WLVD_OBS	Observed Dry weight of dead leaves
WLVG_OBS	Observed Dry weight of green leaves

WSO_OBS	Observed Dry weight of storage organs
WST_OBS	Observed Dry weight of the stems

CHAPTER 1

INTRODUCTION

1.1 Background

About half of the world population including 30 million Malaysians consume rice (GRiSP, 2013; Omar et al., 2019). Rice industry in Malaysia improved after the green revolution (Roslan et al., 2012). The green revolution was initiated in India in the mid of 1960's focusing on introducing high-yielding variety of maize, wheat and rice in order to increase grain production in the country (Beck, 1995). The green revolution in general was able to reduce a country's dependence on imported rice and increase the country's self-sufficiency; in Asia, the rice production improved from 2.03 t ha^{-1} in 1965 to 3.04 t ha^{-1} in 1982, which is 2.5% increment (GRiSP, 2013). In the year 1970, the green revolution movement in India motivated the Government of Malaysia to introduce the concept of integrated agriculture to increase rice grain production (Roslan et al., 2012).

From the year 1990 to 2016, Malaysia's rice grain production was relatively stagnant (2 million MT) compared to other countries in the Southeast Asia such as Indonesia (30 million to 45 million MT) , Vietnam (13 million to 28 million MT) , Thailand (11 million to 22 million MT) and Philippines (6 million to 13 million MT) (Omar et al., 2019). Malaysia's current self-sufficiency level remains the lowest compared to the other country in Southeast Asia region from year 2000 to 2016 (Harun et al., 2017; Omar et al., 2019). Current 70% self-sufficiency level is insufficient to meet the demand for local consumption (Harun et al., 2017; Omar et al., 2019).

Nitrogen (N) is one of the macro nutrients for rice crop growth and the N requirement by the rice crop is dependent on the growth stages (Makino, 2011; Yoshida, 1981). One of the main challenges in rice cultivation is to optimally apply the N for rice crop growth and to increase the rice grain production. In practice, the recommended rates of fertilizers are determined through field, pot culture or greenhouse trial experiments (Fageria et al., 2014; Ibrahim et al., 2017; Khairunniza-Bejo et al., 2017). However, this approach is costly, labour extensive and time consuming.

As an alternative, simulations of rice crop growth models are valuable tools to perform complex scenario studies in order to explore opportunities for understanding of the complex crop-soil-water system, increasing system productivity, assessing environmental trade-offs, and forecasting the effects of a changing climate on the production at a reduced cost, labour and time (Basso et al., 2016; Gaydon et al., 2012; Yuan et al., 2017).

In this thesis, the performance of a rice crop growth model, i.e., ORYZA(v3), in simulating six rice crop physiological traits is evaluated for five Malaysian rice varieties, namely the MR219, MR220CL2, MR269, MR297 and UPUTRA.

1.2 Problem statement

N fertilizer application must be efficiently managed to improve N uptake by rice crop in order to maximise rice production (Guan et al., 2011; Sheng-gang et al., 2012). Therefore, to ensure improved and sustainable rice production, selection of a suitable rice variety and optimal fertilizer usage, subject to Malaysian climate conditions must be accounted for.

Typically, the recommended N fertilizer rates are determined through field, pot culture or greenhouse trial experiments (Fageria et al., 2014; Ibrahim et al., 2017; Khairunniza-Bejo, 2017). However, this approach is costly, laborious and time consuming. As an alternative, scenario studies via simulations of rice crop growth models are valuable tools to investigate optimum N fertilizer rates for different rice varieties at a reduced cost, labour and time.

Only a handful of studies have reported on the evaluation of rice crop growth models for Malaysian rice varieties (Vaghefi et al., 2011; Vaghefi et al., 2016). ORYZA(v3) is a recent improvement of the frequently used ORYZA2000 rice crop growth model (Bouman et al., 2001; Li et al., 2017). ORYZA(v3) had only been evaluated for four combinations of N and water treatments in flooded rice systems in China, Philippines and India (Li et al., 2017). Currently, to the best of our knowledge, existing rice crop growth models, in particular ORYZA(v3), have not been extensively evaluated and used to assess productivity of Malaysian rice systems.

1.3 Objective

The main objective of this thesis is to evaluate the performance of a rice crop growth model, ORYZA(v3), in simulating five rice crop physiological traits for five Malaysian rice varieties namely MR219, MR220CL2, MR269, MR297 and UPUTRA.

The specific objectives are:

1. To study physiological responses of MR219, MR220CL2, MR269, MR297 and UPUTRA treated with three N rates under open field conditions.

2. To calibrate and validate ORYZA(v3) using the rice crop physiological traits obtained from the open field conditions experiment.

1.4 Scope and limitation

The scope and limitations of this study are as follows.

1. An open field experiment was conducted for one season at Kg. Lubuk Kawah, Besut, Terengganu. The area was located within IADA KETARA granary area.

2. The field experiment was conducted from February to June 2018.

3. Rice varieties used in this study were MR219, MR220CL2, MR269, MR297 and UPUTRA.

4. N treatments consisted of three rates which were 76 kg N ha^{-1} (30% less than the farmer's rate, T1), 109 kg N ha^{-1} (farmer's rate, T2) and 142 kg N ha^{-1} (30% more than the farmer's rate, T3).

5. The rice crop growth model studied in this thesis was the ORYZA(v3) which was developed by the researchers from the International Rice Research Institute (IRRI). The model was an improvement of an earlier version of rice crop growth model ORYZA2000.

6. ORYZA(v3) simulated the effects of rice phenological properties, water management, N treatment, soil physical and chemical properties, micrometeorological properties on the crop physiological traits. Effects of other macro- and micro-nutrients and pest and disease were not conceptualised in ORYZA(v3).

1.5 Thesis overview

In this thesis, the performance of a rice crop growth model, namely ORYZA(v3), in simulating the rice crop physiological traits of five local varieties subject to local climate conditions was investigated. Chapter 1 describes the background to this work. Research objective, scope and limitation as well as the importance of the study are provided in this chapter. Chapter 2 provides a literature review of rice cultivation. The chapter further describes the importance and comparisons of six rice crop growth models. Chapter 3 describes the materials and methods. This

chapter is divided into two main sections. The first section of Chapter 3 covers the experimental design, sampling and statistical analysis of the crop physiological traits. Meanwhile, the second section of Chapter 3 describes details on ORYZA(v3) rice crop growth model including data requirement and followed by the procedures for calibration and cross-validation of the model. Similarly, Chapter 4 is also divided into two main sections. The first section of Chapter 4 discusses the results and finding of statistical analysis from experimental design for a comprehensive understanding of the data. The second section of Chapter 4 discusses simulations and evaluations of ORYZA(v3) rice crop growth model. Finally, Chapter 5 provides conclusions of the findings and recommendations to improve the model robustness in the future.

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