SIMULATION OF RICE (KDML 105) YIELD BY CERES RICE MODEL FOR SUITABLE PLOT MANAGEMENT

KUNZANG TSHERING

MASTER OF SCIENCE IN AGRICULTURAL INTERDISCIPLINARY
MAEJO UNIVERSITY
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
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ชื่อเรื่อง การจำลองผลผลิตข้าวหอมมะลิ 105 โดยใช้ CERES RICE MODELเพื่อการจัดการแปลงที่เหมาะสม
ชื่อผู้เขียน Mr.Kunzang Tshering
ชื่อปริญญา วิทยาศาสตรมหาบัณฑิต สาขาวิชาสหวิทยาการเกษตร
อาจารย์ที่ปรึกษาหลัก ผู้ช่วยศาสตราจารย์ ดร.ชลินดา อริยเดช

บทคัดย่อ

การทดลองปลูกข้าวหอมมะลิ 105 ในแปลงทดลอง เพื่อการจัดการการคาดคะเนผลผลิตด้วย CERES Rice Model โดยการทดลองในแปลงทดลองเป็นเวลา 10 เดือน นำข้อมูลมาทำการวิเคราะห์ผลด้วย CERES Rice Model ใน DSSATv 4.7.2 ระดับการใช้ข้อมูลน้อยที่สุด ที่ระดับ 1 ได้สมการ(r^2 =0.8798) (Y=35.639x _+ 902.69) ค่าคาดคะเนผลผลิตมีค่า 3,000 กิโลกรัมต่อเฮคเตอร์ พบว่า ผลที่ได้มีค่าแตกต่างกันกับผลการทดลองในแปลง ที่มีค่า 3,800 กิโลกรัมต่อเฮคเตอร์ ทั้งนี้อาจเกิดจากดินปลูกในแปลงทดลองที่มีผลผลิตที่แตกต่างกันจากคุณภาพเนื้อดินที่แตกต่างกัน โดยผลผลิตรวมแปลงที่1-6 มีค่ามีค่าแตกต่างกันดังนี้ 2,870, 2,876, 3,216, 3,105, 3,789 และ 3,980 กิโลกรัมต่อเฮคเตอร์ โดยมีความเป็นไปได้ในการใช้โปแกรมนี้ในการคาดคะเนผลผลิตทางการเกษตรได้

คำสำคัญ : CERES, จำลอง, DSSAT, แบบจำลอง

Title	SIMULATION OF RICE (KDML 105) YIELD BY CERES RICE MODELFOR SUITABLE PLOT MANAGEMENT
Author	Mr. Kunzang Tshering
Degree	Master of Science in Agricultural Interdisciplinary
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ABSTRACT

This experiment was carried out in order to simulate rice variety KDML 105 yield with the use of CERES Rice Model in DSSATv4.7.2 over a period of 10 months. The objective of the study was to design and record a minimum set of data level 1 as per the requirement of the DSSAT. Based on those recorded data, it was aimed at generating files for running the model and make assessing whether the recorded data and created files could fit the model. It revealed that the finding indicated a successful generation of input files and simulation of the model. When the mean values for simulated and observed data were compared, it was noted that though the simulation and the running the model was successful, an increased number of treatments and replication with more numbers of run would increase efficiency of model prediction. The model predicted 3,000 kgs grain weight per hectare while observed value showed 3,800 kgs of grain weight per hectare at (r^2 =0.8798), where (Y=35.639x _+ 902.69). The final yield observed are from treatment (T1-T6) 2,870, 2,876, 3,216, 3,105, 3,798, 3,980kgs/hectare. It is also assumed that ununiformed number of plants across some plots during the sequence of harvests may have affected in model prediction too.

Keywords : CERES, Simulate, DSSAT, Model

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Kunzang Tshering

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ABBREVIATIONS

AAD	Agro-ecosystem Analysis and Development
DAT	Anthesis Date
CERES	Crop-Environment Resource Synthesis
CWAD	Crop Dry Weight
CWAM	Tops Weight at Maturity
DSSAT	Decision Support System for Agrotechnology Transfer
FI	Future Internet
FSR	Farming System Research
GWAD	Grain Dry Weight
HWAM	Yield at Maturity
IBSNAT	International Benchmark Sites for Agro-Technology Transfer
ICT	Information and Communication Technology
IoTs	Internet of Things
IRD	Integrated Rural Development
KDML	Kao Dok Mali (Thai name for a rice variety)
LWAD	Leaf Dry Weight
MADT	Maturity Date
Om	Organic Matter
SARD	Solar Radiation
SWAD	Stem Dry Weight
SWUD	Seed Weight Undried
USDA-SCS	United States Department of Agriculture- Soil Conservation Service
WSNs	Wireless Sensor Networks

CHAPTER 1

INTRODUCTION

The millennium declaration of setting year 2015 as target date for halving the number of people who live in extreme poverty is seen as a realistic and achievable because of extra ordinary progress shown by some developing countries. However many countries still are far short of reaching the target estimating up to 1 billion people who are likely to remain destitute by the targeted date (Cervantes-Godoy, D. and J. Dewbre 2010). In 1979 Theodore Schultz while accepting his Nobel Prize in Economics, said in his speech: `` *Most of the people in the world are poor, so if we knew economics of being poor we would know much of economics that reality matters. Most of the world's people earn their living from agriculture, so if we knew the economics of agriculture we would know much of the economics of being poor''* (Shultz 1979). Globally, according to (World Bank, 2008a) the percentage rate of poverty has declined steadily for which the achievement in economic growth has been credited, while the people depending on agriculture in developing countries are living in poorer condition than the people engaged in other economy sectors. These conditions are attributed to the fact that agriculture is a complex system governed by many biophysical and environmental factors. Understanding the interaction among various variables of this complex system is very important for increased production and sustainability in agriculture production. The Earth's land resources are indirectly proportionate to the increasing number of people that the land must support which creates major problem for agriculture. While natural resources must be protected for sustainability, production must be increased to meet the rapidly growing demands. A new agriculture research is invented to supply information to farmers, policy makers and other stakeholders for making decisions on accomplishing agriculture sustainability over climate variations.

In this direction the use of crop models in agriculture research is being encouraged (Patricia Oteng-Darko et.al, (2012) because crop production are traditionally carried out based on experience and conventional agronomic research without considering the underlying biological and physical principles involved. Thus the application of correlation and regression analysis did provide qualitative understanding of variables and their interactions involved in cropping system which contributed to the progress in agriculture science according to (Kumar and Chaturevdi, 2009). However the quantitative information obtained from this type of analysis were very site specific, that the information obtained can only be applied to other sites which has similar climate and soil types in addition to management aspects.

As knowledge accumulation progressed, the results obtained from observations changed from qualitative to quantitative and adoption of mathematics as a tool to express biological hypotheses. Further the advances in computer technology made possible the consideration of combining several factors in various interactions, which made it possible to combine soil, plant and climatic conditions quantitatively to predict yield accurately. In crop modeling knowledge of plant growth and development from disciplines like crop physiology, agro-meteorology, soil science and management or agronomy can be integrated quantitatively and in a process oriented way. DSSAT (Decision Support system for Agro technology-Transfer) is one such model used over 25 years by researchers, consultants, extension agents, farmers and decision and policy makers in over 120 countries worldwide. The latest or the current version DSSAT 4.7 has simulation model for over 32 crops and it is supported by data based programs for soil, weather, crop management and experimental data with utilities and application program to make it functional for the users.

Research Problem:

Precision Agriculture is information and technology based farm, where new technologies are used to make better decisions on aspects of crop production focusing on site specific inputs for long term cost benefits, it is also an alternative to enhance productivity and profitability. The benefit of precision farming are that they can reduce the cost involved in inputs such as water, fertilizers, herbicides and pesticides that will eventually reduce harm to environment as well through approach of site specific recognition for management.

Bhutan is a small and landlocked country striving to achieve food self-sufficiency since the early 1960s. While the country's aim has been conservation of environment and achieving self-sufficient and food security, the arable land for agriculture has been on the decline and losing to urbanization. Farming has been becoming costly with increase in cost of production and lack of technical expertise in the rural areas. Crop modeling has never been applied for production aspects leading to experienced and traditional practice based farming. With the climate change and development in technologies, gearing agriculture farming towards technology based farming would greatly save resources and time which would probably increase the production and reduce the cost of production. Therefore the study is aimed at fulfilling the following objectives

Research Objective:

The main objective of the study is to apply simulation application on crop growth and yield by using modeling software DSSAT 4.7. The sub-objective of the study is:

1. To design field experiment and record minimum data for CSM CERES- rice crop model
2. To generate specific file formats of weather, crop, soil and other management inputs suitable for the model
3. To evaluate the model by comparing predicted and observed data

Research Questions

Based on research objectives the under laid questions are formulated

1. What are minimum sets of data required for operating the model?
2. How minimum sets of data are collected for running the CSM-CERES rice model.
3. How to transfer raw data from non-DSSAT to DSSAT format
4. How files (A), (T), (X), Weather and soil data are generated for running the model

Expected Results:

1. To be able to recommend and guide and design experimental data requirement for Extensions and farmers for crop modeling
2. The knowledge gained from the study will be replicated in Bhutan for different crops
3. The outcome of the study can be used as reference for policy makers and farmers for application of crop modeling and its importance

Scope of the study:

The study was carried out over a period of 10 months, with emphasis on theoretical aspects and concentrating on Rice crop for the experiment. The experiment will be conducted in Agriculture Resource System Research Station, Chiang Mai University, Thailand. The study was focused on Rice variety Kao Dok Mali 105 (KDML 105) for experimental data requirement. The study allows focus on yield prediction and management guide apart from making decisions in agriculture production. Other variables included are soil, water, daily weather, fertilizer and environmental conditions. The study also allowed special attention on minimum set of data for calibration and operation of the model. The study could not cover medium and maximum set of data required for model calibration and operation

CHAPTER 2

Literature Review

The related literature referred and reviewed during the course of proposing this study are presented here under; All literature are related to agriculture interdisciplinary and crop modeling concepts

Agriculture ecology and farming system research:

Ecology played important role in establishing settled farming from the era of hunting and gathering. It is evident from history of agriculture that ignoring and breaking the linkage between ecology and agriculture could lead to social and ecological problems. For instance the success of green revolution was engineered focusing on breeding programs using high payoff genetic characteristics and distributing for production together with fertilizers, pesticides etc. This has led to issues like pest and disease outbreak, decline in soil quality, pollutions. As a result the conventional approach evolved to tackle these problems individually as they arise. According to Conway and McCauley 1983; KEPAS 1984, these are systemic problems that are linked to each other through agro ecological and socioeconomic processes causing many ways in the incompatibilities between these processes and the technology introduced. The next phase of agriculture therefore demanded radically a different and holistic approach with sense of complexities of agro ecological and socioeconomic processes. Eventually the target was a fine grained agriculture based on mosaic of varieties, inputs and techniques each fitting a particular social, economic and ecological niche. So far there has been two approaches the (FSR) Farming System Research and (IRD) Integrated Rural Development, However in this paper Conway presents the third approach called (AAD) Agro-ecosystem Analysis and Development that is different from the other two approaches in two important respects. Firstly it can deal with all level in agro-ecosystem's hierarchy and secondly it provides analysis technique together with packages of technology that focus on other performance indicators apart from productivity. It is further informed that this approach was not intended as alternative for the other approaches but offered as an approach that can be used within the frame work of others and for research and development programs. The author presents key concepts, method of analysis with examples of its applications drawn from workshops held in Indonesia and Thailand followed by challenges of designing of agro-ecosystem and development. It is mentioned that transformation of an ecosystem into an agro-ecosystem involves many changes. The complexities of agro-ecosystem can be captured by four system properties that together can describe the essential behavior of agro-ecosystem. The four properties are productivity, stability, sustainability and equitability. These properties can be used as performance indicators which can be employed to trace the agro-ecosystem's historical evolution and to evaluate its potential, however there are tradeoffs involved between productivity and stability on one side and sustainability and equitability on the other and sometimes between all the properties. The paper highlights on, knowing the key processes to produce improvement performance of agro-ecosystem and management which requires multidisciplinary process and procedure. The pattern analysis is felt as an important phase of the process by identifying four patterns that deter system properties. The four patterns are time, space, flow and decisions with their own reflections and roles in each process of agro-ecosystem. The paper also presents agro-ecosystem technology assessments, agro-ecosystem technology development, and sets of technology packages such as integrated pest management, multiple cropping, agroforestry, crop-livestock ploy culture, soil ecology, selection of agro-ecosystems etc. The author, in his concluding comments states that the research and development and extension in the third world will approach the pattern predominated in the west.

Crop modeling: A tool for agriculture research – A review:

Conventional and experienced based agronomic research using statistical analysis are used for crop production studies without referring to the biological and physical principles involved, nevertheless application of correlation and regression analysis did give progressive understanding of the variables and their interaction in cropping system. But it was realized that quantitative information gathered from this analysis could not be applied to other sites where the variables differed hampering the decision making. Advances in technologies made it possible to combine many factors like soil, plant and climate systems for accurately predicting crop yields. As a consequence, access to powerful computers made it possible to apply knowledge of plant growth and development from many disciplines like physiology, soil science, agro-metrology and agronomy to integrate quantitatively and in manner of process oriented for crop growth modeling. The technology further allows users to combine technical knowledge of crop models with economic aspects and environmental impact evaluation. DSSAT according to Tsuji, *et. al.* 1994 is an excellent example of technology or management tool that makes farmers to combine biological needs of crops to the physical character of land to obtain particular goal. Modeling is a new discipline with basic ground information but application of models in research is not easily accessible and not being aware about the structure and other limitations are perceived as constraints for application of models. Therefore, Patricia Oteng-Darko. *et. al* (2012), in this review presents description on modeling, brief history of models, application across different disciplines and its limitation before concluding. Crop modeling, according to the review is using equations or sets of equations representing the system's behavior or in other words models are computer program that imitates the growth and development of crops and predicts the growth of its components like leaves, roots, stems and grains. Further the model not only predicts the final state or the yield but also has the information on processes involved and their interactions. Historically, crop growth simulation model and its development has been process of progression in scientific research with first attempt made in sixties on photosynthetic rates of crop canopies, yet, there has been a dramatic change in crop growth models despite many challenges with each model. The introduction of micro-metrology in the models improved the simulation that became to be the basic crop growth simulator. The products of DSSAT helped the users to match biological needs of crop and physical aspects of land that provided better land use planning as the package contained data base management system for soil, weather, genetic coefficient, and inputs management with strategy evaluation program for choice of variety, dates of planting, population density, irrigation, stress status etc. Hence DSSAT provided the ability to reduce time and cost of experiments for evaluation of new cultivars and new management systems. The models are categorized into different groups depending on the purpose for its design. Some of the types of models are Empirical models, Mechanistic models, Deterministic models, Dynamic models, Simulation models, stochastic models and optimizing models. The crop model as per the review can be used in understanding research, enhancing improved experiment documentation and organization of data, cross discipline integration, site specific experimentation, and analysis of yield, climate change projection and yield forecasts. The model limitations presented are similar to many other technologies such as not being aware of the technology, the accuracy of the models, computers power etc. In conclusion the author pointed out that gaps in knowledge for users need to be addressed for saving time and money and contribute to developing sustainable agriculture that can cater to world's food needs. This topic enhances and brings me to conclude crop models improves documentation of experiment data and data organization. Crop modeling further integrate disciplines and climate change projections and forecasting of yield can be attained.

Modeling the smart farm:

Though the specific objective in smart farming varies, the main objective is the efficiency. Use of Information and Communication Technologies (ICT) remained underutilized in agriculture. To be able to make economically viable and environmentally friendly decisions, effective collection, processing, management and actualization of different sources of information is fundamental which enables strategic planning. Recent developments in ICT especially the sensing technologies provide significantly in managing information at farm with details that had not been there before which also offers fascinating possibilities of developing farm specific models for individual farmers to use their plans. In the end environmental impact depends on how agriculture up scales in response to increasing demand, therefore the system of modeling is viewed as enabling tool such as field maps of soil properties, crop or pasture growth rate, emission of greenhouse gas using GPS and others. For instance in dairy sector models for predicting feed intake both for lactating cows and mixed rations. Since 1990s research in farm simulation and modeling has evolved to cover more than one farm enterprise, however despite the use of, there have been limitations for efficient management. And some of the reasons for these limitations were complexity, lack of time and concern for forecast in relations among variables. The farmers expected readymade solutions and models did not lend themselves to this, rather they compel the farmers to consider alternate strategies for production. While there are issues on model perceptions, understandings and interactions, it was felt necessary that three components of agriculture namely biological processes, farm management and advisory services be facilitated and yet the uptake of simulation model remained disappointing despite the compelled concept. Feed intake models are valuable when used in coexistence with other models that predict animal responses in terms of body weight change, milk yield and efficient nutrient use.

Simple models such as NRC that considers only characters and milk yield can be effective than sophisticated models, never the less incorporation of additional factors is limited as reported. The paper also informs that comparing all models are difficult as all models are not suitable for predicting milk production, but simpler models are very tolerant to variations and hence it is concluded that mathematical nutrition model needs to be developed to correctly measure the greenhouse gas emitted by ruminants. Both environmentally and nutritionally it's necessary to reduce methane (CH_4) as (CH4) has strong greenhouse effect environmentally and nutritionally it represents loss of feed energy. 41% of ammonia and 2% methane emissions are produced by 91 million cattle within the EU. Factors such as level of intake, quality of feed, composition of diet and environment influences the CH4 production in ruminants. It is also demonstrated that by managing farm implements CH4 emissions can be reduced without lowering the production. The fuzzy logic driven based models proved effective in detecting abnormal situations and giving information of such situations. It's found out that a non- linear auto-regressive model was more accurate than regression model in dairy domain but still the need for an analytical model with more accurate, robust and reusable was felt a must. Still with considerable research on management and nutrition of dairy cows, there remains much on-farm variability in its application.

For precision agriculture sensing technologies are basics and for cattle, identification of common diseases can be done through non-invasive and cheap technologies however, for multiple agri-food domains and dairy farms RFID is the most common used sensing technology. Wireless Sensor Networks (WSNs) application has been predominantly used in agriculture and food industry on domains like crop management, phenotype measurement, rustling and greenhouse management. Wireless Sensor and Actuator Networks (WSANs) are famously attended in irrigation control, mobile sensing domains realized through drones is still at an early age.

Enabling smart farm with Internet of Things (IoTs) mechanism is seen as prerequisite for integrated system and services which will be able to handle ever-increasing and diverse real time data stream, handle incomplete and contradictory data, capture and correlate data etc. There is no doubt that IoTs will be an absolutely necessary technology for smart farm but their concurrence with Future Internet (FI) offers a basis for a new generation Farm Management Information System that will make smart farms become active nodes for business to business solutions and in agriculture value chain. Some of the problems with smart farm technologies are the issue of usability and identification of best practice for adoption in other domains. Therefore both farm and farmer centric approaches are needed to take forward sustainably the concept of smart farm technologies.

The author concludes with the message that there are multiple benefits from the smart farm are enormous but how to realize these benefits within the dimensions remain unclear. As a result recommends farm specific models which is attainable and offers innovation. Therefore I felt this literature informs or educates how information and technology plays vital role in improving efficiency of making economically viable and environmentally friendly decisions.

Over view of IBSNAT or International Benchmark Sites Network for Agro-technology Transfer:

The purpose of the IBSNAT project was to enable agricultural decision makers to explore and empower farmers and policy makers with capacity to choose a better future for themselves and society according to (G. Uehara and G. Y. Tsuji, 1998.) The other objective of the IBSNAT or the International Benchmark Sites Network for Agro-technology Transfer was to apply systems analysis and simulation to problems faced by resource poor farmers with focus on areas of new and untried agriculture technologies. Way back in 1992, in order to assemble the decision support system, an international meeting of agriculture and systems scientists was convened in India for designing a decision support system for agro-technology transfer where participants are asked to concentrate on systems analysis and crop simulation models as the primary ways to harmonize crop requirements with land characteristics though the scope of the meeting outcome was limited to ten food crops then was supposed to be critical from food security point of view which includes four cereals (maize, rice, sorghum and wheat), three grain legumes (dry beans, groundnut and soybean), and three root crops (aroid, cassava and potato)

(Kumble, 1984). Prior to the convention of this conference, only four (wheat, maize, groundnut and soybean) of the ten crop models were available in fully developed or partial forms. During the first IBSNAT crop modeling workshop in 1983 in Venezuela, the need to standardize the input and output structure of the available models were revealed in order to access common data base. Following the workshop an application called DSSAT (Decision Support System for Agro-technology Transfer is formulated and programed into a computer software. Five years after the meeting in India the first prototype DSSAT was assembled providing the users with easy access to soil, crop and weather information. (G. Uehara and G. Y. Tsuji, 1998). A typical scenario simulated by DSSAT involves a comparison of new variety with the one already grown by farmers if planted on same day on a same soil type with same management inputs can be simulated in few minutes on a desktop computer which otherwise would have consumed the entire professional life of an agronomist. The meeting in India also agreed on the minimum set of data for crop, soil, weather and management for running the models. In brief this literature takes you to no. of crops that are possible to simulate and what are the sets of data required for running model.

Data for model operation, Calibration and evaluation:

According to Hunt, 1994, all models that simulate crop require information on one or more aspects of the aerial and soil environment must be supplemented with initial conditions and on systems aspects. It was recognized with time and experience that the models operating at daily time step were the most applicable application for problems with crop production and environment sustainability. Thus every efforts were focused on defining set of data which can be used widely used for models at given complexity that could be regarded as minimum set of data for the operation of models to be used for transfer of agro-technology. In this pursuit, the IBSNAT scientists viewed balancing the degree to that of incorporation details of different components of soil-crop- atmosphere and the data for operation of models to be equally balanced with different components of the system as their uppermost consideration. Therefore the minimum set of data endorsed and required for model operation and calibration are as follows.

Operation

i. Site

- Latitude and longitude, elevation; average annual temperature
- Slope and aspects, spacing and depth

ii. Weather

- Daily solar radiation, maximum and minimum temperature, precipitation

iii. Soils

- Classification using local system or USDA-SCS taxonomic system
- Basic characteristics (organic carbon, pH, drainage coefficient)

iv. Soil analysis

- Surface layer measurement of organic carbon, organic nitrogen, pH, P and K

v. Initial conditions

- Previous crop, water, ammonium and nitrate

vi. Management

- Cultivar name and type
- Planting date, depth and method, row spacing and direction, plant population
- Irrigation and water management, dates, methods and amount or depth
- Fertilizer (inorganic) and inoculant application
- Chemical (eg: pesticide) application (material, amount)
- Environment (aerial) adjustments
- Harvest schedule

Calibration

Vii. Crop Performance

- Date of emergence
- Date of flowering or pollination(where appropriate)
- Date of onset of bulking in vegetative storage organ (where appropriate)
- Date of physiological maturity
- Leaf area index and canopy dry weight at three stages during the life cycle
- Canopy height and breath at maturity
- Canopy (above ground) dry weight or harvest index (plus shelling percentage for legumes)
- Yield of appropriate economic unit (e.g. kernels) in dry weight terms
- Harvest product individual dry weight (e.g. weight per grain, weight per tuber)
- Harvest product per number at maturity (e.g. seed per spike, seed per pod)
- Damage level of pest (disease weeds etc.) infestation (recorded when infestation first noted, and at maximum
- Number of leaves produced on the main stem

- N percentage of economic unit
- N percentage of non-economic parts

However IBSNAT has recognized that all required weather data for a particular site and a particular time are often not available, therefore in such cases it has been suggested that the integrity of minimum data set be maintained by calculating surrogate values or using data from nearby sites and required radiation values could be estimated from computations of solar radiation above the atmosphere, a function of day of year and latitude, and measurement of the hours of bright sunshine (Davis and McKay, 1988, 1999). All aspects of management on crop such as environmental modifications (e.g. extension of photoperiod) that are imposed on some crops for physiology studies need to be reported. Prominent crop management includes planting date, planting depth, row spacing, plant population, fertilizer, irrigation and inoculation. The most found useful data for calibration of many models are (1) the time of occurrence of the major plant development stages; (2) the dry weights of the major plant organs at various times throughout the growing season; (3) the final yield and its components; (4) the number of branches, leaves, fruits, and other organs; and (5) the main stem and branch heights. For evaluation of the model the essential parts of minimum data sets are: (1) a complete information record necessary to run the model such as information on aerial and soil environment, the starting conditions, information on cultivars and crop management; and (2) field information on the aspects that the model is desired to predict, however the data set should not have been used before for calibration and has to represent the complete array of environments where the model will be applied. After completion of this topic you get to understand and know how data can be collected and be categorized or setting parameters for operation and calibration of the model

Estimate of Rice Consumption in Asian Countries and the World Towards 2050

The staple food for more than world' s half a population is rice which accounts for more than 20 percent of calorie intake globally. Six Asian countries (China, India, Indonesia, Bangladesh, Vietnam and Japan) produces and consumes over 90 percent of rice in the world (FAO, 2004). As per FAO though the rice consumption has declined with urbanization and living style but more than one- fourth of Asian countries are poor and there is unmet demand for rice. The annual population growth rate of Asia is 1.8 percent, which means there is an increase in rice demand in the region. About 45 million rice consumers are added annually in Asian region where 61 percent of the world's population lives. The problems of soil salinity, high cost of development, water shortage, and environmental concerns are bigger challenges in rice production. Therefore, systems modeling of rice farming could be an option for increased production and decision making. Bhutan is still not self-sufficient in rice due to reasons such as land fragmentation, labor shortage, limited area etc. As a result crop modeling for decision making and implementation would be of paramount importance

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Conceptual Frame work

The conceptual frame work of the study is based on minimum set of data requirement collection by designing a suitable experiment for plot management, creating and generating input files from those sets of data and exporting to DSSAT format for simulating CERES rice model. The mean results from the simulation against the observed will be compared and efficiency of the model evaluated.

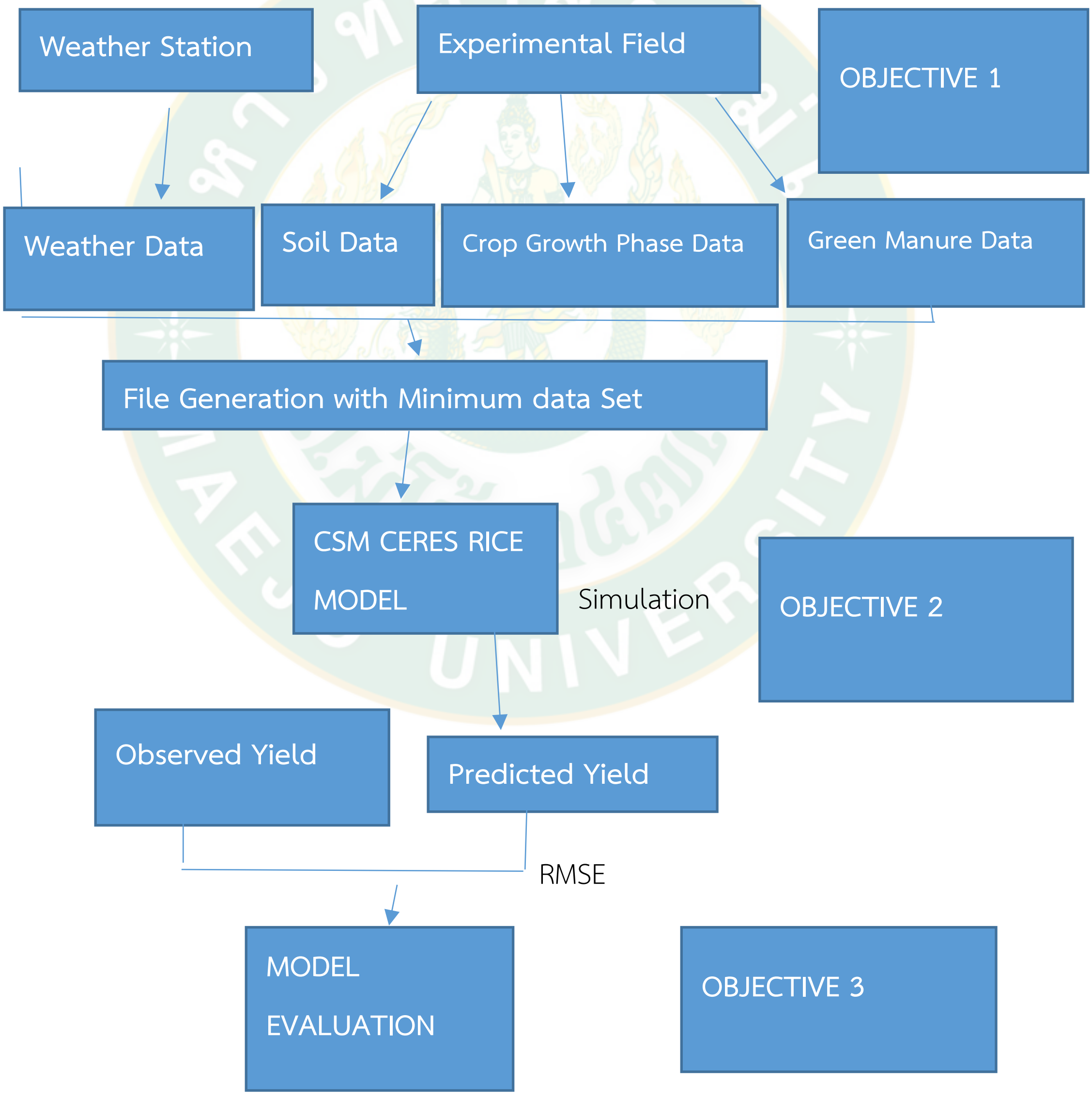

Figure 1 The conceptual frame work

Study site and location

A simple experiment to record the data with regards to plant (Rice KDML105) is conducted at Agricultural Resource System Research Station, Faculty of Agriculture, Chiang Mai University during the 2018 rice cropping season in Chiang Mai. The field is located at an elevation of 300masl with $18^{\circ}46'$ N, $98^{\circ}55'$ E. Prior to collecting the growth and development of rice plant in the field, following minimum set of data required are collected to fulfill the operation requirement of CERES rice Model in DSSAT 4.7.2

3.2 Field Experiment

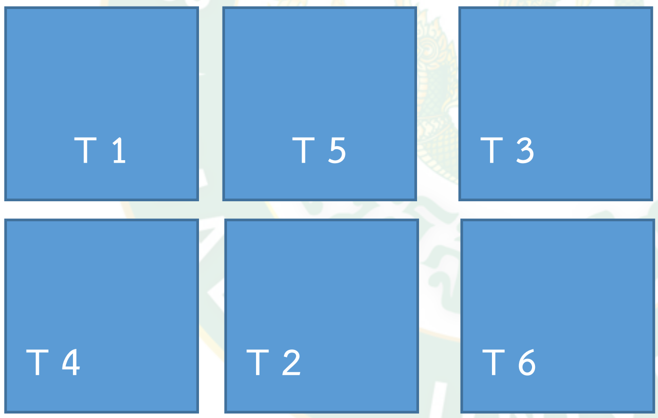

Figure 2: Field Experiment Design

3.2.1 Treatments

Six plots are laid for the experiment on rice KDML 105 (figure 2) with different soil texture and soil nutrient as derived from the pre soil analysis results.T1 or treatment one is sandy clay soil with no additional or supplementary nitrogen applied from green manure incorporation, T2 or treatment two is loam soil with no application of additional nitrogen from green manure. T3 or treatment three is sandy clay soil with low or less amount of nitrogen from green manure, T4 or treatment four is loam soil with low amount of nitrogen applied. T5 or treatment five is sandy clay soil with high amount of nitrogen applied by green manure incorporation, T6 or treatment six is treated with high amount of nitrogen from green manure application on loam soil.

3.2.2 Replication

The final harvest procedure in DSSAT for rice is applied as replication as described in crop data under data collection

3.4. Data collection

Data collection is categorized into two parts as physical data and crop management data. Physical data consists of data from weather and soil while the management data consists of data from green manure and crop data

3.4.1 Weather Data:

The daily sets of weather data (table…) are referred from daily statistic reports of Mae Hai metrological; station based just about 10meters from the field location at Agricultural Resource System Research Station, Faculty of Agriculture, Chiang Mai University, Chiang Mai for a period of one year from 1st Jan 2018 to 31st Dec 2018. Solar radiation (SARD), maximum temperature (TMax), minimum temperature (TMin) and rainfall (Rain) are recorded and exported to WeatherMan software in DSSAT format in DSSAT v4.7.2

Table 1 Weather Data

Date	Sunlight(MJ/Ms?day	Tem(Max) (Degree Celsius)	Tem(Min) (Degree Celsius)	Rainfall(MM)

3.4.2 Soil Data

The soil samples are collected from the selected site (field) prior to conducting the experiment. The soil samples are then taken to laboratory with Maejo University, department of soil science, faculty of Agriculture production and are analyzed for soil PH, OM, P, K, and soil texture.

Table 2 Soil

Plot code/Treatments	OM	P	K	PH	Texture
CH12					

3.4.3 Green Manure

Green manure plants in rice fields proved effective in supplying nitrogen as these plants have the capacity to fix atmospheric nitrogen into soil. The positive role of green manure plants in crop production are known since ages. The other benefits of green manure are it improves soil's physical, chemical and biological properties, controls weed and as a consequence crop yields too. And most importantly green manure potentially reduces nitrate (No_3^-) leaching risk and lower the nitrogen requirement for the succeeding crops. Green manure (*Sesbinia aculeata*) seeds are sown after soil sampling and before the transplant of rice at different seed rates as densely seeded and sparsely seeded in four different fields treating two fields with large quantity of seeds and two fields with lesser amount of seeds. While the remaining two fields are left without sowing with green manure seeds. After 25 days green manure seeds are harvested from four fields and samples are taken to the field for analysis. The sample plants are first dried, crushed into powder, taken to lab and analyzed for total nitrogen (N%)

Table 3 Green manure data:

Plot Code	Total N (%)
CH12	

3.4.4 Crop Data (Plant Sampling and procedures)

As per the specified procedures in DSSAT for cereals, following steps are applied for plant sampling and data recording. This process is repeated four times to serve as replications.

1. Cut the plants from identified area to ground level and recorded numbers of plants harvested

2. Plant population calculated and recorded (Plants/ms)

Plant population $= \frac{No\ of\ plsnts\ harvested}{Harvest\ area}$

3. Ten representative subsample plants are selected and no. of panicles calculated (panicle/ms)

Panicle no$= \frac{plant\ populationxno.of\ panicles\ in\ subsample}{10}$

4. Seeds are separated from all panicles including the subsample

5. Seed weight (undried) recorded

6. 1000 seeds counted, recorded undried weight and calculated seed number (seed no./ms)

$$Seed\ no. = SWUDX\frac{\frac{1000\ seedsD}{1000\ SUD}}{harvest\ area}$$

7. Stover weight are recorded and 10 subsample plants are selected and its weight also recorded

8. Then subsample is separated into leaf sheaths, leaf blades, stem and rachis which is oven dried at 70 C and dried weights are recorded. After which dried weights are calculated (g/ms)

9. $LB\ wt. = Stv\ wt\ UD x \frac{\frac{LB\ Ss\ wt.D}{StvSs.wt\ UD}}{Harvest Area}$

10. $LS\ wt. = Stv\ wt. UD\ x\ \frac{\frac{LSSs\ wt.D}{StvSs\ wt.UD}}{Harvest\ Area}$

11. Subsample seed of 1/8 of total seed weight (undried) is selected. Recorded seed weight and oven dried at 70 C for 7days and dried seed weight are recorded

12. Then dried seed weight are calculated

$$Seed\ wt. dry = seed\ wt(UD)X \frac{\frac{Ss\ wt. D}{Ss\ wt. UD}}{Harvest\ area}$$

13. $St. wt\ D = Stv\ Ud\ x \frac{\frac{StSs\ wt. D}{StvSsUD}}{Harvest\ Area}$

14. $Rc. Wt = Stv\ wt. UD\ x \frac{\frac{RcSs\ wt.D}{StvSsUD}}{harvest\ Area}$

15. Then finally above ground biomass (dry) is calculated and recorded:

$$Above\ ground\ Biomass(g/ms = LB\ wt. + LS\ wt. + St. wt + Rc\ wt. + Seed\ Wt$$

Figure 3: Plant Sampling and Procedures

Source: DSSAT dictionary

During the process of crop growth phase following data are collected as per the parameters set under each table

Table 4 Crop growth phase Data

Parameters	CH12	CH13	CH14	CH22	CH23	CH24
Date of Transplantation						
Date of panicle initiation						
Date of physiological Maturity						
Date of Harvest						

Table 5 Type: Dried

Treatments	LWAD(Leaf weight)	SWAD(Seed weight)	GWAD(Grain Weight)	CWAD(Above ground weight)
1				

Dried weights will be calculated from fresh weight and converted to DSSAT format as shown in table (6), for which the process is repeated four times

3.5 Data Analysis

All recorded data are entered in DSSAT shell and files A, T, X are created for analysis using CSM CERES rice model and results exported to statics and excel for discussion

CHAPTER 4

RESULT AND DISCUSSION

As guided by the objectives the results of each files are generated from DSSAT by running the model and are exported to excel for discussion according to the objectives;

4.1 Weather Results

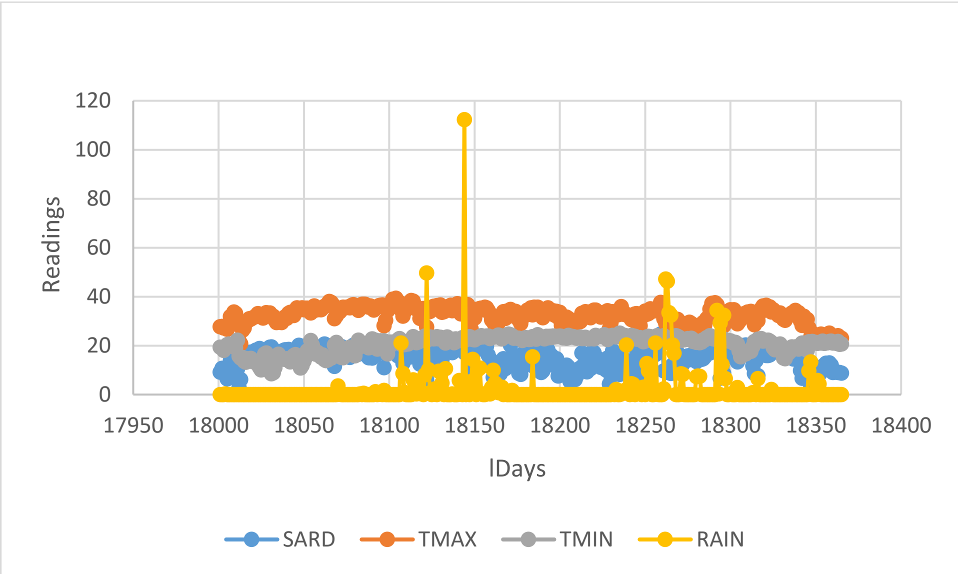

Figure 4: Annual weather report

Table 6 Annual average weather data

Count of Days	Average of SARD	Average of Tmax	Average of Tmin	Average of Rain
365	15.15	32.34	20.68	2.317

The above graph shows the weather pattern of Mai Hai, Chiang Mai, Thailand with respect to solar radiation, maximum and minimum temperature and rainfall from 1st Jan 2018 to 31st Dec 2018. It's evident that highest rainfall was received around 150th day

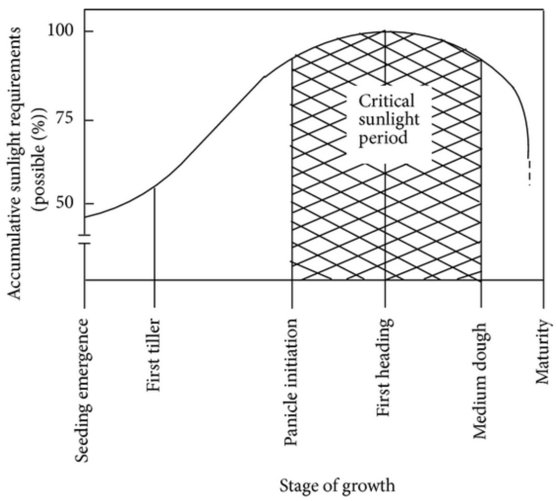

Figure 5: Critical light periods in rice plant

which corresponds to 30th May 2018. It can be perceived that the year 2018 did not receive heavy and continuous rainfall. The average annual rainfall was 2.317mm with 32.34 degree Celsius and 20.68 degree Celsius as average maximum and minimum annual temperature respectively but average rainfall received during the rice growing season from mid -August to November is slightly higher at 4.91mm. The average temperature requirement is 20 to 27° C and annual minimum rainfall requirement is 115cm with almost hundred percent light (fig 5) during the critical phase of rice plant according to W. O nyang'au *et.al* (2014), though rice is a short day plant. The data is further exported to weatherman in DSSAT format as aimed in objective one

4.2 Soil

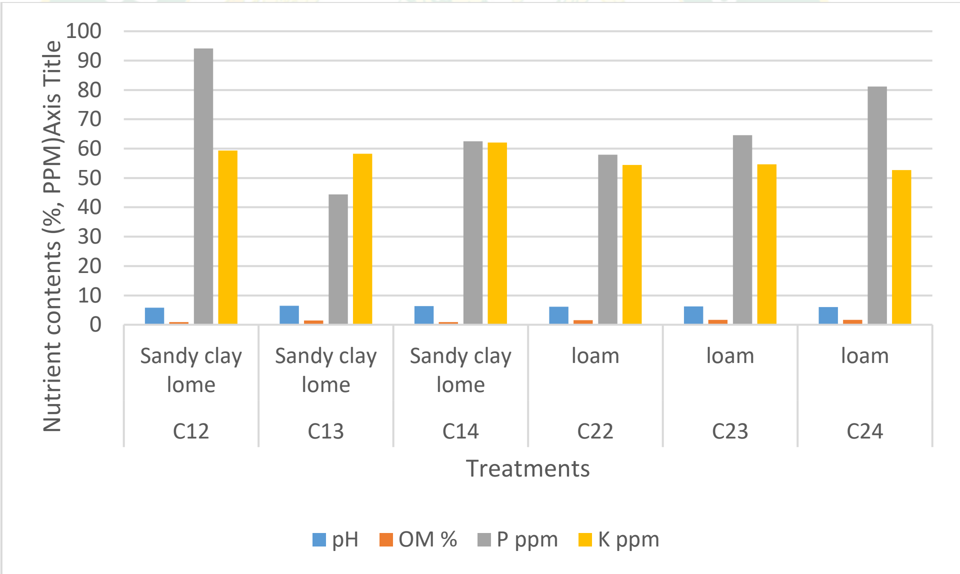

Figure5: Soil results

The treatment are to be read in acceding order from C12 to C24 as treatment T1 to T6. On analysis of soil samples in lab the soil texture of the site consisted of two types viz; sandy clay and loam. The results also found out that the organic matter content of the soil is comparatively low. The average phosphorous content is 67ppm followed by potassium at 57ppm while the organic matter content is 1.4% only. Therefore it can be perceived that the soil is not an ideal soil for rice cultivation considering its porosity. As per literature the best suited soil for rice cultivation is silt clay to silt clay loam. From the results it also indicates nutrients are slightly higher in sandy clay soil when compared to loam soil. The data is also entered in DSSAT format and soil file created as intended in objective one.

Table 7 Soil Analysis report

Field ID	Treatment	Soil Texture	pH	OM	P	K
				%	ppm	ppm
C14	1	Sandy clay	6.37	0.9	62	62
C23	2	loam	6.22	1.7	65	55
C13	3	Sandy clay	6.41	1.5	44	58
C22	4	loam	6.18	1.6	58	55
C12	5	Sandy clay	5.8	0.9	94	59
C24	6	loam	6.06	1.6	81	53

4.3 Green Manure

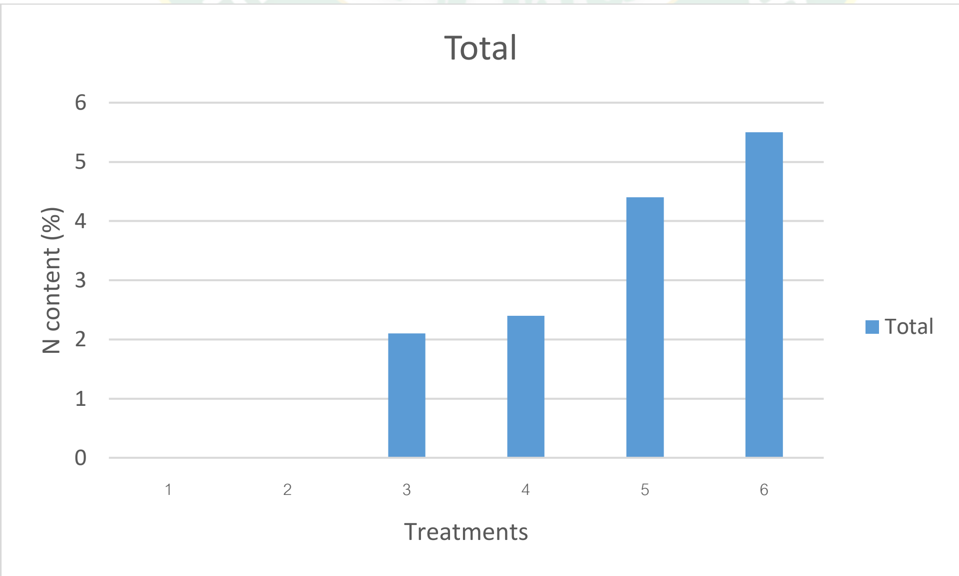

Figure 6: N content (%) from green manure

The graph presents the Nitrogen (%) content of each plot. The result indicated that higher the weight proportionated to higher Nitrogen content. And this is the basis for defining treatments as high, low and no N from green manure. The data are also created in Xbuild of DSSAT file under crop management file accordingly as aimed in objective one of this study. The samples files are attached as annexures

Table 8 Total N content from Green Manure analysis

Field ID	Sum of Total N %
CH12	NA
CH13	2.1
CH14	2.4
CH22	5
CH23	4.4
CH24	NA
Grand Total	**28**

4.4 Growth phase data

The table below shows the no of days taken to different physiological stages after transplantation. Dates for different stages are recorded when more than 50% of the plants reached different stages except for the final harvest date which is recorded when all plants were matured for harvesting. And finally as mentioned in objective one and two the recordings are reflected or entered in DSSAT Xbuild file under crop management.

Table 9 Growth phase days/dates

Parameters	T1	T2	T3	T4	T4	T5
Date of transplantation	15/08/2018	15/08/2018	15/08/2018	15/08/2018	15/08/2018	15/08/2018
Date of panicle initiation	04/10/2018	04/11/2018	04/12/2018	04/13/2018	04/14/2018	04/15/2018
Date of physiological Maturity	30/11/2018	30/11/2018	30/11/2018	30/11/2018	30/11/2018	30/11/2018
Date of harvest	02/12/2018	02/13/2018	02/14/2018	02/15/2018	02/16/2018	02/17/2018

4.5 Plant sampling data

The first harvest was carried out when more than 50% of plant gained or achieved all harvestable and measureable parts such as leaf blade, leaf sheath, grain and stem. While the final harvest or the forth harvest was carried out when plant reached maturity or harvesting stage. The results of the harvests from first to final are shown below. The results are the dried weights of plant parts from each treatments and converted to DSSAT format as per objective one and two. LWAD refers to weight of leaf blade and leaf sheath, SWAD refers to weight of stem, GWAD refers to weight of grain and CWAD refers to weight of above ground biomass. These are recorded in DSSAT files as Files A, T and X with which objective one and two are achieved. The sample of files are attached as annexures with specific file names.

Table 10 Recordings from first harvest

Treatments	LWAD	SWAD	GWAD	CWAD
1	218.93	209.4	40	468.33
2	181.02	214.7	37.2	432.92
3	212	219	47	478
4	289	209	58	556
5	341.46	302	65	708.46
6	327	387.6	69	783.6
Grand Total	**1569.41**	**1541.7**	**316.2**	**3427.31**

Table 11 Recordings from second harvest

Treatments	LWAD	SWAD	GWAD	CWAD
1	310	250	62	622
2	289	238	69	596
3	321	297	74	692
4	356	286	79	721
5	416	403	89.5	908.5
6	421	434	93	948
Grand Total	**2113**	**1908**	**466.5**	**4487.5**

Table 12 Recordings from Third harvest

Treatments	LWAD	SWAD	GWAD	CWAD
1	789	802.1	478	2069.1
2	712	796	463	1971
3	879	914	689	2482
4	964	800.8	700	2464.8
5	1678	1232.6	790	3700.6
6	950	953	776	2679
Grand Total	**5972**	**5498.5**	**3896**	**15366.5**

Table 13: Recordings from Final harvest

Treatments	LWAD	SWAD	GWAD	CWAD
1	887	1267	2870	5024
2	793.25	1212	2876	4881.25
3	890	1386.02	3216	5492.02
4	1220.75	1323	3105	5648.75
5	1688	1509.34	3798	6995.34
6	1007	1664.06	3989	6660.06
Grand Total	**6486.01**	**8361.43**	**19854**	**34701.44**

4.6: Yield from first to final harvest (simulated vs Observed)

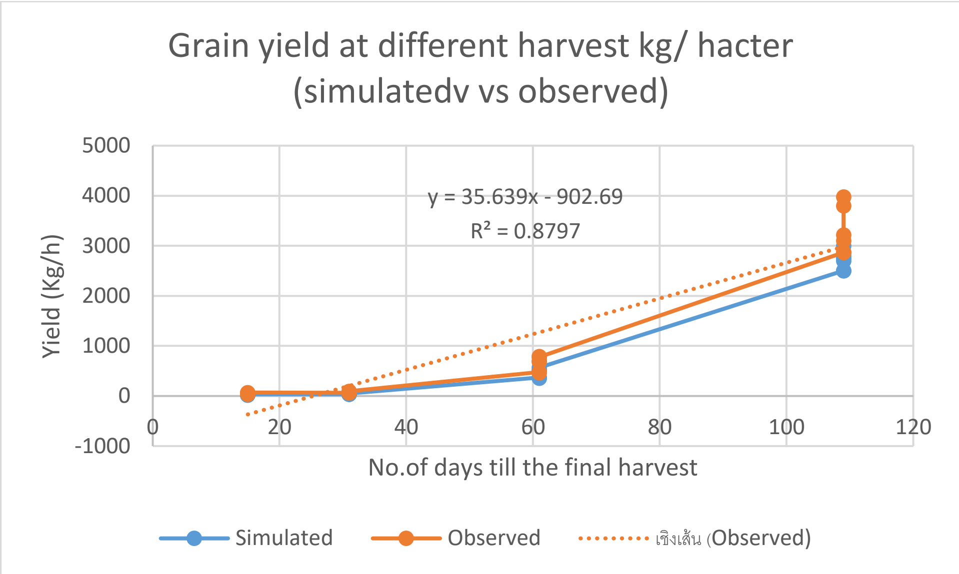

Figure 6: Yield Accumulation during Growth Phase

Table 13 Grain yield (total) at each harvest shown as simulated and observed

Days	No of treatments	Total weight (Simulated	Total weight Observed
15	6	1998	2881
31	6	3436	3867
61	6	5383	6384
109	6	6905	7841
Grand Total	24	17722	20973

The grain yield at each harvest are represented by figure 6 and table 10. The results indicate that model can be run and operated with data presented in each figures and tables under this chapter. However the difference in mean values (y=35.639_+ 902.69) and (r square=0.8797) indicates there is correlation among input data and the simulated values, although model is evaluated as aimed in objective three, yet more number of runs with more treatments and replications could have more accuracy while evaluating the model. While DSSAT documents identification of sites uniform plant cover, it was observed during the harvest that some plots did not have uniform plant covers. Since identification of sites are governed by measurement of lengths after avoiding border plant effects, relocation of harvesting was impossible during the harvest.

4.7 Files is DSSAT shell

Some of the examples of files in DSSAT shell are presented hereunder:

Weather file (DSSAT)

The weather file in DSSAT shell consists of solar radiation (SARD), maximum temperature (TMAX), minimum temperature (TMIN) and rainfall. These are the minimum sets of data level 1 for running the DSSAT model

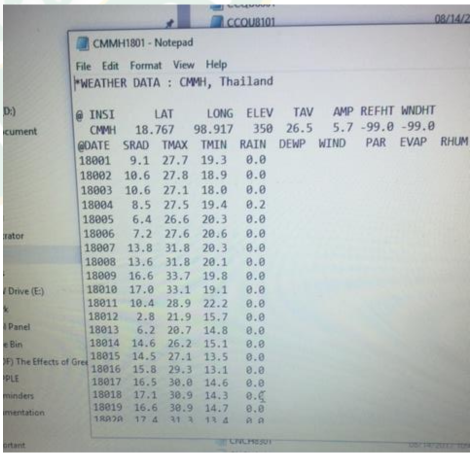

Figure 7: weather file in DSSAT shell

Creating and generating files (X) DSSAT format

The objective of this is to be able to create and generate data from non DSSAT format to DSSAT format in CERES rice model. The file X contains information on site and its environment, name of weather station, soil name, person's information and institute name with year, treatments, management and simulation options. The most important information required here are weather station and soil data apart from all management from irrigation, fertilizer application, planting date till harvest date

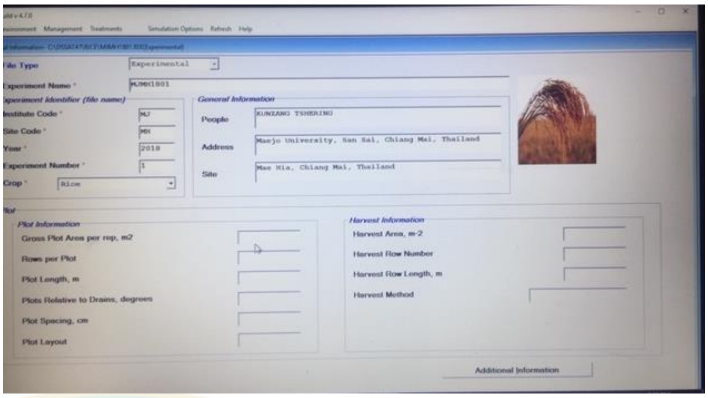

Figure 8: Data indenting in CERES rice model in DSSAT

File (A) created in DSSAT

Inputs file (A) in DSSAT consist of anthesis day in represented as (ADAT), maturity day as (MDAT) in (YRDOY) format, Tops weight at maturity as (CWAM), yield at maturity as (HWAM) and harvest index as (HIAM) for each treatment.

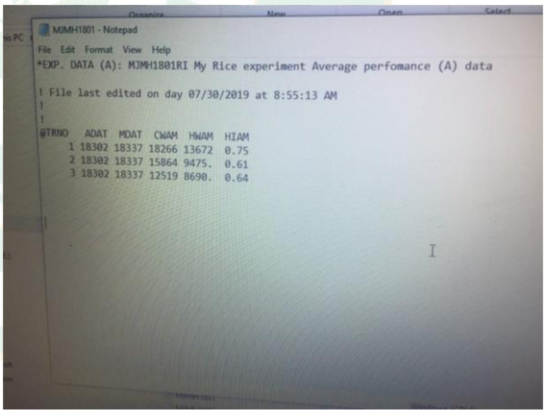

Figure 9: File (A) in DSSAT shell

File (T) created in DSSAT

Input file (T) in DSSAT has information on dates as (YRDOY), leaf weight kg/h as (LWAD), stem weight kg/h as (SWAD), (GWAD) represents grain weight kg/h and biomass is defined as (CWAD)

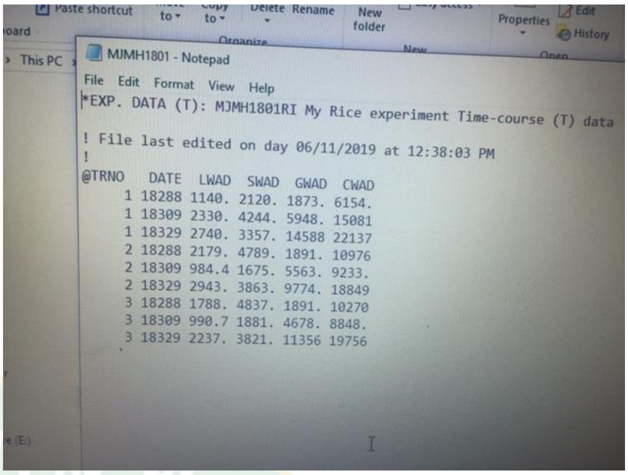

Figure 10: File (T) in DSSAT shell

CHAPTER 5
CONCLUSION

The study was conducted with an aim to gather and record minimum set of data level 1 requirement for operating and running DSSATv4.7.2 by conducting a small experiment at local level. The crop modeling concept and its application in farming system was felt important and necessary tool for making decisions when we think of agriculture and its complex system. Crop modeling is also a sub-set of precision agriculture where factors like soil, weather, management and plants physiological parameters are imitated by computer technology when fitted with input files. Bhutan is a small and land locked country with 2.3% land available for agriculture (RNR statistics 2015) and with food security and environment conservation as its top goal, crop modeling for decision making could play a very important role. With crop modeling concept the experiment was conducted mainly to design experiment requirements as per DSSAT operation and running guidelines, generate required input files and run the model for its accuracy and sensitivity. During the course of this study data on soil, weather, green manure and field data were collected and converted to DSSAT format from non-DSSAT format. It was experienced that even for minimum set of data level 1 it involves lots of time and attention. Works involved collecting whole year's weather data, soil lab analysis, and plant sampling for harvest to measure biomass which needs to be repeated for 4 times from 6plots without assistance was a tough task. However at the end of the study basics on crop modelling aspects are learnt through practical doings. As mentioned earlier the study was not aimed at investigating a hard core research and come to conclusive findings but it was rather aimed at applying basic inputs and information required for running DSSAT model. Through this study the ways and methods on collecting minimum set of data required are achieved, converting raw data to DSSAT form and generating inputs file was successful and finally running the CERES rice model could be operated and comparison between predicted and observed data could be established, though the difference between mean values of predicted and observed are bit on higher side for grain yield at (3000 as simulated and 3980 kgs/h as observed). Where (y=35.639x _+ 902.69) at (r square =0.8797). However it was learnt that an increased or larger numbers of treatments and replications with increased number of runs could give more precise and accurate information for decision making on management aspects. It was also noted that while harvesting for biomass avoiding border effects and selecting or identifying uniform crop stand with larger area could increase the efficiency of the model. A well designed experiment with more information in file X is important for more efficiency. More parameters for plant growth phase is another important aspect for increased accuracy in simulation and prediction.

APPENDIX

Appendix A: Input File (A)

*EXP. DATA (A): RI My Rice experiment Average perfomance (A) data

! File last edited on day 09/02/2019 at 3:07:50 PM

!

@TRNO	ADAT	MDAT	CWAM	HWAM	HIAM
1	88	108	1124	370.	0.
2	88	108	791.	126.	0.
3	88	108	1292.	316.	0.
4	88	108	1233	490.	0.
5	88	108	1745	498.	0.
6	88	108	1656	598.	0.

Appendix A-1: Input file (T)

*EXP. DATA (T): Rice RI My Rice experiment Time-course (T) data

! File last edited on day 09/05/2019 at 4:45:01 PM

!

@TRNO	DATE	LWAD	SWAD	GWAD	CWAD
1	18242	102.	112	20	234
1	18258	110	150	42	302
1	18288	289	302	178	679
1	18336	387	367	370	1124
2	18242	181	114	37	322
2	18258	189	138	69	396
2	18288	312	196	72	580
2	18336	353	312	126	791
3	18242	112	119	47	278
3	18258	321	197	74	592

3	18288	379	314	289	982
3	18336	490	486	316	1292
4	18242	289	209	58	556
4	18258	356	286	79	721
4	18288	364	300	400	1064
4	18336	420	323	490	1233
5	18242	341	302	65	708
5	18258	416	403	89	908
5	18288	578	532	390	1500
5	18336	688	559	498	1745
6	18242	327	387	69	783
6	18258	421	434	93	948
6	18288	550	553	476	1579
6	18336	507	560	589	1656

Appendix A-2: Input file (X)

*EXP.DETAILS: MJMH1801RI MJMH1801

*GENERAL

@PEOPLE

KUNZANG TSHERING

@ADDRESS

Maejo University, San Sai, Chiang Mai, Thailand

@SITE

Mae Hia, Chiang Mai, Thailand

@ PAREA PRNO PLEN PLDR PLSP PLAY HAREA HRNO HLEN HARM.........

-99 -99 -99 -99 -99 -99 -99 -99 -99 -99

*TREATMENTS -------------FACTOR LEVELS------------

@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM

1 1 1 0 No N from GM(sandy Clay) 1 1 0 0 1 1 0 0 0 0 0 0 1

2 1 1 0 No N from GGM (Loam) 1 1 0 0 1 1 0 0 0 0 0 0 1

3 1 1 0 Low N from GM (Sandy Clay 1 1 0 0 1 1 1 0 0 0 0 0 1

4 1 1 0 Low N from GM (Loam) 1 1 0 0 1 1 1 0 0 0 0 0 1

5 1 1 0 High N from GM (Sandy Cla 1 1 0 0 1 1 2 0 0 0 0 0 1

6 1 1 0 High N from Gm (Loam) 1 1 0 0 1 1 2 0 0 0 0 0 1

*CULTIVARS

@C CR INGENO CNAME

1 RI TR0001 KDML105

*FIELDS

@L ID_FIELD WSTA.... FLSA FLOB FLDT FLDD FLDS FLST SLTX SLDP ID_SOIL

FLNAME

1 MJMH1801 CMMH1801 -99 -99 DR003 -99 -99 -99 SL -99 TH01750001

Rice Production

@L ....XCRD ....YCRD .....ELEV ....AREA .SLEN .FLWR .SLAS FLHST FHDUR

1 -99 -99 350 800 40 -99 -99 FH101 -99

*SOIL ANALYSIS

@A SADAT SMHB SMPX SMKE SANAME

1 18227 -99 -99 -99 -99

@A SABL SADM SAOC SANI SAPHW SAPHB SAPX SAKE SASC

1 15 -99 -99 -99 -99 -99 -99 -99 -99

*INITIAL CONDITIONS

@C PCR ICDAT ICRT ICND ICRN ICRE ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME

1 RI 18196 -99 -99 1 1 -99 -99 -99 -99 -99 -99 -99

@C ICBL SH2O SNH4 SNO3

1 -99 -99 -99 -99

*PLANTING DETAILS

@P PDATE EDATE PPOP PPOE PLME PLDS PLRS PLRD PLDP PLWT PAGE PENV PLPH SPRL PLNAME

1 18227 -99 45 -99 T R 20 0 5 -99 25 28.3 -99 20 -99

*IRRIGATION AND WATER MANAGEMENT

@I EFIR IDEP ITHR IEPT IOFF IAME IAMT IRNAME

1 -99 -99 -99 -99 -99 -99 10 -99

@I IDATE IROP IRVAL

1 18196 IR006 50

*FERTILIZERS (INORGANIC)

@F FDATE FMCD FACD FDEP FAMN FAMP FAMK FAMC FAMO FOCD FERNAME

```
 1 18227 FE024 AP003    10    20   -99   -99   -99   -99   -99 -99
 2 18227 FE002 AP016    10    40   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 18227 RE002   200  1.65   -99   -99   -99    15 AP003 -99

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 18227   -99   -99   -99   -99   -99  -99

*TILLAGE AND ROTATIONS
@T TDATE TIMPL  TDEP TNAME
 1 18227 TI007    15 -99

*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 18196 A   0 A   0 A   0 A   0 A 0.0 A   0 A   0 A   0

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 18336 GS014     H     A   -99   -99 Rice

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 18196  2150 MJMH1801                    RICER
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     N     N     N     N     N     Y     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
MESEV MESOL
 1 ME              M     M     E     F     R     L     R     1     G     S     2
```

```
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     A     N     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT
DIOUT VBOSE CHOUT OPOUT FMOPT
 1 OU              N     Y     Y     1     Y     N     N     N     N     N     Y     N     Y     A

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          18001 18001    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 01001   100     0
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Appendix B; Weather Input file

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*WEATHER DATA : CMMH, Thailand

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  CMMH   18.767   98.917   350  26.5   5.7 -99.0 -99.0
@DATE  SRAD  TMAX  TMIN  RAIN  DEWP  WIND   PAR  EVAP  RHUM
18001   9.1  27.7  19.3   0.0
18002  10.6  27.8  18.9   0.0
18003  10.6  27.1  18.0   0.0
18004   8.5  27.5  19.4   0.2
18005   6.4  26.6  20.3   0.0
18006   7.2  27.6  20.6   0.0
18007  13.8  31.8  20.3   0.0
18008  13.6  31.8  20.1   0.0
18009  16.6  33.7  19.8   0.0
18010  17.0  33.1  19.1   0.0
18011  10.4  28.9  22.2   0.0
18012   2.8  21.9  15.7   0.0
18013   6.2  20.7  14.8   0.0
18014  14.6  26.2  15.1   0.0
18015  14.5  27.1  13.5   0.0
18016  15.8  29.3  13.1   0.0
18017  16.5  30.0  14.6   0.0
18018  17.1  30.9  14.3   0.0
18019  16.6  30.9  14.7   0.0
18020  17.4  31.3  13.4   0.0
18021  17.5  31.5  13.4   0.0
18022  18.1  32.0  12.9   0.0
18023  18.1  33.0  12.2   0.0
18024  18.8  32.2  11.0   0.0
```

18025	18.4	32.2	10.1	0.0
18026	14.8	31.2	13.4	0.0
18027	16.3	32.5	16.6	0.0
18028	17.9	33.4	17.0	0.0
18029	18.4	33.1	14.7	0.0
18030	19.3	33.3	12.2	0.0
18031	19.4	31.9	8.4	0.0
18032	18.3	31.9	8.8	0.0
18033	17.7	30.4	10.9	0.0
18034	13.4	29.4	14.7	0.0
18035	16.9	29.6	16.4	0.0
18036	16.8	30.1	14.5	0.0
18037	15.8	29.3	14.5	0.0
18038	18.0	30.5	14.4	0.0
18039	18.3	31.6	14.3	0.0
18040	14.7	31.0	14.5	0.0
18041	18.3	33.2	14.2	0.0
18042	18.1	33.6	13.3	0.0
18043	17.2	32.6	13.6	0.0
18044	15.9	32.2	15.9	0.0
18045	17.0	33.9	16.3	0.0
18046	18.3	35.3	15.8	0.0
18047	20.0	34.4	13.6	0.0
18048	19.8	34.8	10.8	0.0
18049	17.8	35.4	11.8	0.0
18050	17.6	34.6	13.6	0.0
18051	17.4	35.3	15.2	0.0
18052	16.2	35.2	17.8	0.0
18053	18.5	35.1	17.2	0.0
18054	17.0	33.3	22.0	0.0
18055	18.7	34.7	20.1	0.0

18056	19.7	36.1	17.8	0.0
18057	16.7	34.4	16.4	0.0
18058	18.3	35.0	17.2	0.0
18059	17.3	34.7	16.5	0.0
18060	15.5	34.5	15.3	0.0
18061	17.2	35.2	16.2	0.0
18062	20.6	36.0	14.2	0.0
18063	20.2	36.2	13.8	0.0
18064	18.5	37.0	14.0	0.0
18065	16.4	38.0	14.8	0.0
18066	19.7	37.6	14.9	0.0
18067	16.3	36.6	15.3	0.0
18068	11.4	30.9	20.2	0.0
18069	15.4	32.0	21.3	0.0
18070	17.8	34.0	20.4	3.5
18071	16.3	33.6	17.3	0.2
18072	19.5	34.6	15.1	0.0
18073	18.1	35.6	15.0	0.0
18074	18.6	35.5	16.8	0.0
18075	17.8	35.5	16.0	0.0
18076	17.0	35.7	18.5	0.0
18077	15.1	35.4	19.2	0.0
18078	18.9	36.4	18.0	0.0
18079	20.1	36.7	18.1	0.0
18080	18.0	35.8	15.8	0.0
18081	19.8	35.7	18.4	0.0
18082	16.4	34.4	22.2	0.0
18083	18.9	35.1	19.5	0.2
18084	17.6	36.8	20.3	0.0
18085	17.1	36.8	20.7	0.5
18086	19.4	36.8	20.6	0.0

18087	17.9	35.9	20.0	0.0
18088	14.9	35.6	19.1	0.0
18089	14.9	36.1	21.5	0.0
18090	14.8	35.5	22.8	0.0
18091	16.6	34.4	21.0	0.0
18092	15.9	35.4	22.1	1.1
18093	20.6	35.7	18.5	0.0
18094	17.7	36.3	20.9	0.2
18095	20.5	36.4	21.9	0.2
18096	21.8	36.6	19.2	0.0
18097	10.9	28.0	21.9	1.6
18098	19.3	30.3	20.4	0.0
18099	21.4	34.2	16.5	0.0
18100	20.1	36.6	19.4	0.0
18101	18.5	37.0	21.4	0.0
18102	19.9	38.9	20.8	0.0
18103	19.8	38.9	21.2	0.0
18104	18.0	39.3	21.6	0.0
18105	15.8	37.9	22.3	0.0
18106	18.4	37.6	22.8	0.0
18107	19.3	34.5	20.4	20.9
18108	12.8	32.0	21.2	8.5
18109	17.9	33.8	20.3	0.9
18110	17.8	35.3	21.4	0.0
18111	20.2	36.8	20.5	0.0
18112	15.2	36.2	22.0	0.0
18113	18.6	38.4	22.1	0.0
18114	16.1	38.2	23.6	6.0
18115	18.7	36.4	22.0	2.1
18116	19.3	34.9	21.1	0.2
18117	18.2	34.4	21.4	2.8

18118	12.3	31.1	22.5	0.9
18119	22.0	34.6	22.9	0.2
18120	20.9	35.1	22.2	0.0
18121	17.6	35.0	23.9	8.1
18122	5.9	27.5	22.0	49.7
18123	21.1	33.6	22.5	10.1
18124	14.5	33.9	23.4	0.7
18125	20.9	35.3	23.2	0.0
18126	20.6	36.0	22.7	0.2
18127	19.9	35.5	22.9	2.3
18128	16.5	36.3	23.7	0.0
18129	16.8	36.1	22.6	9.4
18130	17.3	36.5	23.4	2.5
18131	14.0	33.6	22.4	4.6
18132	16.7	33.8	22.9	0.0
18133	22.3	34.3	21.0	10.6
18134	21.3	35.7	23.5	0.0
18135	20.8	36.0	22.2	0.0
18136	21.0	36.4	22.1	0.0
18137	17.1	34.2	22.6	0.2
18138	18.2	34.6	21.1	0.0
18139	20.1	36.6	22.7	0.0
18140	21.2	37.1	21.7	0.0
18141	19.4	36.6	22.0	5.8
18142	18.3	32.9	22.5	1.4
18143	18.8	34.9	23.2	0.0
18144	17.1	33.8	22.2	112.2
18145	17.5	35.3	22.4	0.0
18146	22.3	36.7	22.9	0.2
18147	20.2	34.9	23.7	0.0
18148	6.1	26.8	23.0	5.3

18149	10.9	31.3	22.4	14.3
18150	11.5	31.2	22.3	5.1
18151	18.1	34.7	23.1	0.0
18152	21.2	34.0	23.1	10.1
18153	21.1	35.1	23.3	10.8
18154	23.1	35.3	24.0	0.2
18155	18.9	34.7	23.5	0.0
18156	20.8	35.6	23.7	0.0
18157	19.7	35.3	23.9	0.2
18158	16.2	34.3	23.9	0.9
18159	14.5	33.0	22.9	0.2
18160	11.9	30.4	23.4	2.8
18161	7.0	29.6	23.5	9.9
18162	7.5	28.0	23.5	4.6
18163	8.2	28.3	23.6	3.2
18164	10.3	29.2	24.2	0.7
18165	8.4	30.2	23.9	1.8
18166	12.9	32.2	22.6	3.0
18167	14.5	33.8	23.3	0.0
18168	10.5	31.0	24.0	0.9
18169	14.3	34.1	24.2	0.0
18170	12.2	34.0	24.6	0.0
18171	20.1	34.7	24.3	0.0
18172	13.4	32.2	23.9	1.6
18173	12.4	33.9	23.0	0.0
18174	15.8	34.0	23.1	0.0
18175	13.8	32.6	23.0	0.0
18176	8.6	30.5	22.9	0.0
18177	8.2	29.0	22.5	0.0
18178	11.1	31.3	22.0	0.0
18179	17.1	32.7	22.9	0.0

18180	14.5	32.4	23.2	0.0
18181	18.9	34.5	22.6	0.0
18182	16.7	34.3	22.5	0.0
18183	18.4	35.4	22.6	0.0
18184	11.7	32.5	23.6	15.4
18185	13.9	35.6	23.4	0.0
18186	19.4	34.8	22.5	0.0
18187	17.7	35.6	24.4	0.0
18188	14.3	33.9	23.7	0.0
18189	9.0	32.2	23.4	0.0
18190	9.6	31.3	23.1	0.0
18191	16.8	33.7	22.7	0.0
18192	15.9	33.5	23.8	0.0
18193	18.1	35.4	23.0	0.0
18194	13.9	34.6	23.7	0.0
18195	15.9	33.0	23.2	0.0
18196	12.0	34.2	23.9	0.0
18197	13.3	32.4	23.4	0.0
18198	14.5	34.0	23.8	0.0
18199	7.5	31.5	23.6	0.0
18200	12.0	33.5	23.9	0.0
18201	8.4	28.1	23.8	0.0
18202	7.9	29.7	23.1	0.0
18203	8.2	29.9	23.3	0.0
18204	11.9	31.6	23.0	0.0
18205	11.2	31.0	24.1	0.0
18206	5.3	25.6	23.3	0.0
18207	8.7	29.5	23.8	0.0
18208	6.0	30.1	23.6	0.0
18209	6.1	29.0	23.2	0.0
18210	7.6	29.7	22.9	0.0

18211	10.3	30.6	23.4	0.0
18212	10.8	29.8	23.5	0.0
18213	16.9	33.2	22.8	0.0
18214	12.1	32.2	22.8	0.0
18215	16.1	33.9	23.3	0.0
18216	9.3	31.8	22.9	0.0
18217	13.4	33.7	22.6	0.0
18218	10.6	31.3	22.9	0.0
18219	17.1	32.6	22.9	0.0
18220	17.0	34.4	22.7	0.0
18221	12.1	34.5	24.2	0.0
18222	14.9	32.6	23.8	0.0
18223	13.7	33.1	23.7	0.0
18224	11.0	31.5	23.7	0.0
18225	11.3	32.0	23.9	0.0
18226	12.0	33.5	24.4	0.0
18227	10.0	31.5	23.6	0.0
18228	14.8	34.2	22.4	0.0
18229	4.3	26.9	23.9	0.0
18230	7.5	29.4	23.5	0.0
18231	17.9	33.8	24.1	0.2
18232	15.5	33.5	23.9	0.0
18233	12.0	32.9	23.4	2.1
18234	9.8	32.5	24.0	0.0
18235	8.2	33.0	25.0	0.0
18236	16.4	35.9	23.7	0.2
18237	9.2	32.8	23.8	0.9
18238	10.3	32.9	24.2	1.6
18239	10.8	32.7	23.4	20.2
18240	9.0	32.1	23.5	0.5
18241	7.8	32.1	23.4	0.0

18242	8.8	30.5	24.1	4.4
18243	9.7	32.5	23.9	4.1
18244	14.7	32.9	23.7	0.0
18245	18.0	33.1	22.5	0.2
18246	6.6	27.2	23.2	1.4
18247	10.0	28.0	23.3	1.4
18248	15.7	32.8	22.6	0.0
18249	18.4	32.1	21.5	3.0
18250	19.4	34.1	21.7	0.0
18251	14.9	32.7	23.5	12.7
18252	16.9	33.0	23.8	9.7
18253	18.2	34.9	23.7	4.6
18254	22.0	34.6	23.1	0.0
18255	18.2	34.0	22.9	0.0
18256	16.3	34.3	23.3	20.9
18257	19.0	34.8	24.0	0.7
18258	22.6	35.3	22.8	0.0
18259	24.6	37.5	23.6	0.0
18260	21.7	36.3	23.6	0.0
18261	9.6	30.9	24.0	2.3
18262	9.7	29.0	22.9	47.1
18263	9.0	29.4	22.0	46.2
18264	9.2	28.0	23.0	33.4
18265	8.5	28.1	22.8	32.4
18266	12.0	27.9	22.0	20.2
18267	9.0	28.0	23.6	16.8
18268	18.4	30.4	24.0	0.0
18269	17.0	30.7	23.8	0.0
18270	15.7	29.8	23.4	0.0
18271	12.3	28.4	22.1	8.4
18272	12.4	28.5	22.3	8.2

18273	13.9	28.9	22.3	0.0
18274	14.0	28.6	22.6	0.0
18275	15.8	29.0	22.8	0.0
18276	14.2	29.5	22.5	0.0
18277	16.0	29.0	23.0	0.0
18278	14.4	27.8	21.6	0.0
18279	15.0	28.0	22.0	0.0
18280	13.4	27.9	21.2	7.2
18281	16.3	28.0	21.4	7.5
18282	15.0	27.0	21.1	7.4
18283	14.3	28.3	21.4	0.0
18284	14.6	29.3	22.3	0.0
18285	15.4	28.4	22.3	0.0
18286	16.8	30.9	23.2	0.0
18287	17.8	31.6	23.3	0.0
18288	17.0	34.8	24.0	0.0
18289	18.9	37.1	23.4	0.0
18290	20.0	36.9	22.7	0.0
18291	19.5	37.4	22.6	0.0
18292	18.7	36.7	23.5	34.3
18293	17.2	35.0	23.6	0.2
18294	6.6	31.5	22.7	29.2
18295	11.6	30.7	22.5	12.2
18296	8.5	28.1	22.7	32.4
18297	16.8	32.1	22.1	6.4
18298	17.8	32.6	22.2	0.0
18299	19.2	34.1	21.8	0.0
18300	19.6	34.5	21.9	0.2
18301	19.8	34.0	21.5	0.0
18302	19.2	34.6	20.8	0.0
18303	14.5	33.0	21.2	0.0

18304	13.3	28.9	20.6	2.8
18305	17.6	29.8	17.7	0.0
18306	20.1	31.4	15.4	0.0
18307	19.9	31.7	16.2	0.0
18308	20.0	33.0	16.7	0.0
18309	20.2	32.8	16.6	0.0
18310	19.9	33.6	17.3	0.0
18311	19.0	33.3	17.9	0.0
18312	19.0	34.0	17.6	0.0
18313	11.7	30.2	19.6	0.7
18314	8.6	28.5	21.6	0.7
18315	13.7	31.8	21.5	0.0
18316	7.7	30.1	22.6	6.4
18317	17.4	33.1	22.0	0.0
18318	18.2	35.0	22.8	0.0
18319	16.6	36.2	21.8	0.0
18320	16.6	36.0	22.1	0.0
18321	15.9	36.4	22.0	0.0
18322	15.9	35.9	22.2	0.0
18323	16.1	35.8	21.8	0.0
18324	17.1	33.7	21.2	2.1
18325	18.3	34.6	19.0	0.0
18326	18.1	33.6	18.2	0.0
18327	17.6	33.4	19.1	0.0
18328	17.5	32.3	18.9	0.0
18329	18.4	33.3	20.6	0.0
18330	18.2	31.7	18.4	0.0
18331	18.5	30.6	14.8	0.0
18332	18.2	30.3	14.6	0.0
18333	16.6	31.4	16.9	0.0
18334	17.4	32.4	16.8	0.0

18335	17.0	32.4	17.6	0.0
18336	16.6	33.3	19.4	0.0
18337	14.4	32.8	18.7	0.0
18338	16.4	34.3	19.4	0.0
18339	17.0	33.3	18.7	0.0
18340	17.1	33.4	18.5	0.0
18341	9.7	30.0	19.0	0.0
18342	6.5	28.2	21.1	0.0
18343	15.5	32.0	21.0	0.0
18344	10.2	28.6	19.5	0.0
18345	12.6	30.6	18.0	0.0
18346	6.8	27.3	21.5	9.7
18347	3.4	23.5	20.8	13.3
18348	10.4	25.0	21.6	0.0
18349	9.8	23.4	21.0	0.0
18350	11.2	23.4	21.3	0.0
18351	8.3	22.0	20.9	5.7
18352	8.0	23.1	21.2	4.2
18353	10.0	24.6	21.0	0.0
18354	9.6	23.7	21.8	0.0
18355	12.0	23.5	20.8	0.0
18356	12.7	24.0	21.0	0.0
18357	11.2	24.3	21.1	0.0
18358	12.9	25.0	21.7	0.0
18359	12.0	24.3	21.8	0.0
18360	9.0	23.9	21.0	0.0
18361	9.1	23.7	21.3	0.0
18362	9.2	23.7	20.9	0.0
18363	9.0	24.0	21.6	0.0
18364	8.9	23.0	20.5	0.0
18365	8.7	23.0	20.6	0.0

REFERENCES

REFERENCE

Gordon Y. Tsuji, G. H. (1998). *Understanding Options for Agriculture Production.* London: Kluwer Academic Publisher.

J.T. Ritchie, U. S. (1998). Cereal growth, development and yield. *ICASA*, 1-31.

L.A.Hunt, K. B. (1998). Data for model operation, calibration and evaluation. *ICASA*.

Murthy, V. R. (2010). Crop Growth Modeling and its Application in Agricultural metrology. In V. R. Murthy, *Crop Growth Modeling and its Application in Agricultural metrology* (pp. 235-261). Hyderbad.

Norsuwan, T. (2014, october). Simulation of drip irrigation and nitrogen effects on Napier Grass as Energy crop. Chiangmai, Thailand.

Patricia Oteng-Darko S.Yebaoh, S. A. (2012). Crop Modeling: A Tool for Agriculture Research; A review. *Journal Of Agriculture Research and development*, 1-6.

Tsuji, G. U. (1998). Overview of IBSNAT. In g. H. Gordon Y. Tsuji, *Understanding Options for Agriculture production* (pp. 1-54). London: Kluwer Academic Publishers.

Allen, Richard G., Pereira, Luis S., Raes, Dirk and Smith, Martin. 1998. *Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements*. Rome: Food and Agriculture Organization of the United Nations.

Cheokul, Renu. 2012. The Renewable and Alternative Energy Development Plan for 25 Percent in 10Years during 2012-2021 Retrieved 19 Mar, 2014, from http://www.dede.go.th/dede/images/stories/pdf/dede_aedp_2012_21.pdf

Hoogenboom, Gerrit, Jones, James W., Porter, Cheryl H., Wilkens, Paul W., Boote, Kenneth J., Hunt, L. Anthony and Tsuji, Gordon Y. eds. 2010. *Decision*

Support System for Agrotechnology Transfer Version 4.5. Honolulu: University of Hawaii.

Jones, M. and Singels, A. 2008. *DSSAT v4.5 Canegro Sugarcane Plant Module*. Mount Edgecombe, South Africa: International Consortium for Sugarcane Modelling.

Russell, J.S. and Webb, H.R. 1976. “Climatic Range of Grasses and Legumes and Tropical Grasses.” *Australian Journal of Experimental Agriculture and Animal Husbandry.* 42: 156-163.

Singels, A., Jones, M. and Berg, M. van den. 2008. *DSSAT v4.5 Canegro Sugarcane Plant Module*. Mount Edecombe: South African Sugarcane Research Institute.

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