ENHANCING A REMOTE SENSING BASED CROP GROWTH MODEL TO INCLUDE GENETIC PARAMETERS THAT CAPTURE DYNAMIC SITE SPECIFIC MANAGEMENT ASPECTS

A Case Study of Rice Production in the Mekong River Delta, Vietnam

Stella Kabiri

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A Case Study of Rice Production in the Mekong River Delta, Vietnam

by

Stella Kabiri

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation - Natural Resources Management.

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Dedication

To
My
Mother and Father

Abstract

The objective of this study is to introduce into a remote sensing based crop growth simulation model, genetic parameters that reflect impacts of site specific management aspects to improve yield prediction. It seeks to identify cultivar characteristics of rice genotypes highly influenced by the environment and can be detected by remote sensing, based on model analysis. A cross-locational survey was carried out in ten districts of the Mekong River Delta, a major rice growing region of Vietnam. The ORYZA2000 crop growth model for rice was calibrated with site specific management aspects and observed Leaf Area Index (LAI) and Specific Leaf Nitrogen (SLN) fraction in leaves obtained from red (R) and near-infrared (NIR) regions, represented in MODIS' two 250-m spectral bands. model was simulated in two categories; initial and calibrated. Two most dominant varieties were selected, IR50404 and Jasmine 85. The enhanced crop growth simulation model explained almost 70% of the variation of the predicted yield for all the sites, 80% for Jasmine 85 and 88% of the variance of the predicted yield. The initial model poorly estimated the effect of G x E interactions on yield of both varieties in all the test environments (neutral, saline, acid and acid saline soils). The calibrated model improved the prediction in all the test environments except Jasmine 85 was over estimated in the neutral soils. Sensitivity analysis of the enhanced crop model was run by a simulation strategy based on environmental factors affecting the dynamics of photosynthesis affected by LAI and SLN. The potential yield increase was 14% for the site specific model, 0.6% for IR50404 and 2% for Jasmine 85. Sensitivity analysis also showed that the highest potential yield increase was in the acid saline soils for both SLN and LAI meaning that, these varieties were deficient in these traits for this environment. The output of the simulation shows that it is possible to include dynamic site specific management aspects and genetic parameters from remote sensing based techniques in a crop growth simulation model and satisfactorily predict yield in rice genotypes. It also shows that LAI and leaf N content detected from remote sensing based techniques are traits that can be used in elevation of yield potential in breeding programmes and reduce the duration of costly multilocational trials during cultivar improvement.

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I am grateful to the Netherlands Fellowship Programme for awarding me the Msc. scholarship to undertake my studies at ITC. My heart felt appreciation goes to Mr. Peter Lusembo of the National Agriculture Research Organisation (NARO-Uganda) for nominating me, for this scholarship and for his selfless dedication towards capacity building.

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Table of contents

List of figures

List of tables

1. Introduction

1.1. Back ground

Rice (*Oryza sativa* L.) belonging to the family Graminae is an important staple food for half of the world's population and has an annual production of 5 t /ha under irrigated conditions (IRRI, 1995). As a food crop rice provides more energy per hectare than any other cereal crop and globally ranks second only to wheat in terms of area harvested. A hectare of rice can sustain 5.7 persons for a year compared to 5.3 for maize and 4.1 for wheat (De Datta, 1981). In Vietnam, rice provides 80 percent of the carbohydrate and 40 percent of the protein intake in the diet. It is sown on 4.2 million ha of the 7 million ha agricultural land. Rice production has increased over the last two decades and Vietnam is now one of the world's largest exporters of rice (FAO, 2004). 70 % of the country's rice is grown in the Mekong delta and is known as the 'granary' or 'rice bowl' of Vietnam. The Mekong delta is also considered as one of Southeast Asia's most important rice gene pools (Buu and Lang, 2007).

Due to a postulated population increase in Vietnam of 100 million by 2010, there will be an increase in food demand and yet there is limited land that can be reclaimed for rice production. Vietnam has therefore intensified on procedures to sustainably preserve rice land and narrow yield gaps in all rice ecosystems. The objective is to increase rice yields and corresponding rice production from 30 million to 37-38 million tones. This objective has however, been hampered by the changes in the weather in the past two decades (FAO, 2004).

1.2. Problem statement and Justification

Bannayan *et al.,* (2007) reviewed process based crop simulation models using parameters defined as genetic coefficients to represent genotypic characteristics. These models were prone to bias during simulation which could potentially integrate to a high simulation error at the end of the growing season when final yield at maturity is predicted. They reviewed that this bias was due to the difficulty in predicting impact of weather variability on crop production while simultaneously yields are influenced by under a large range of crop management options. They recommended that introducing Quantitative Trait Loci (QTL) information in these models would enhance the accuracy in prediction. Till present no research has been done to link a remote sensing based crop growth model with genetic/QTL information to include dynamic site specific management aspects in gene based modelling for rice.

Crop management options create the major differences between performance of crop cultivars during on-station experiments and on-farm trials. This is due to, not only biotic and abiotic stresses but also dynamic site specific management operations such as variations in agronomic practices like planting date, plant density choice of cultivar and N management. For instance most of the rice farmers practice direct seeding but the planting dates, nitrogen management and choice of genotypes vary temporally in the same spatial location. Therefore in a given cropping season, any temporal changes in the environment will have a unique effect on the phenology of varying genotypes and therefore final yield at the end of a growing season.

The use of vegetation indices such the Leaf Area Index (LAI) and the Normalized Difference Vegetation Index (NDVI) have been used to estimate crop production for food security purposes (Metternicht, 2003; Rugege, Bouman, Skidmore and Driessen, 2002; Venus, 2000). These have been useful for crop production estimation and have contributed greatly in the improvement of crop simulation techniques. Previous studies indicate that leaf or plant biomass growth and nitrogen accumulation are the two major factors determining crop LAI dynamics (Yoshinda *et al.,* 2007). Light interception by the crop from sunlight is determined by the leaf area index (LAI) and the efficiency with which this light is used in photosynthesis depends on the leaf nitrogen content (Bouman *et al.,* 2001). It has also been shown that genotypic variation in leaf photosynthetic rate is associated with stomatal conductance at a given development stage and the change in leaf photosynthesis is related to leaf nitrogen content per unit leaf area (Ohusumi *et al.,* 2007; Yoshinda *et al.,* 2007).

Measured LAI and leaf N content per unit leaf area have been used to simulate dynamics of above ground biomass growth to identify physiological traits associated with genotypic from remote sensing based techniques has not been used to estimate such physiological plant dynamics to identify genotypic differences (Yoshinda *et al.,* 2007). This research therefore proposes the use of remote sensing based techniques to introduce cultivar characteristics that are influenced by the environment and by dynamic site specific aspects to improve gene based modeling for rice. This study also assumes that the use of leaf area index (LAI) and leaf nitrogen content of a crop, as obtained from remote sensing based techniques can be integrated with genetic aspects into a crop growth simulation model to improve the prediction of the final yield at the end of the growing season.

1.3. Research Objective

The aim of this study is to introduce into a remote sensing based crop growth simulation model, genetic parameters that reflect impacts of site specific management aspects.

1.4. Research Questions

1. Can genetic parameters that reflect impacts of site specific management aspects be integrated into a remote sensing based crop growth simulation model and accurately predict yield?
2. How can a remote sensing based crop growth simulation model be calibrated with genetic parameters that reflect impacts of site specific management aspects?
3. Can remote sensing based techniques be used to detect physiological traits of rice genotypes?

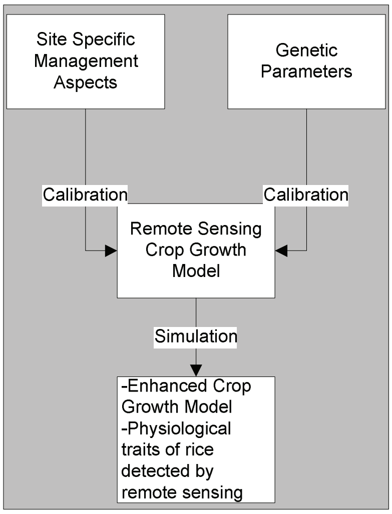


Figure 1: Concept of Research Questions

2. Literature Review

2.1. Evolution of Rice Breeding

There are generally three groups of rice varieties recognized. They are Indica, Javanica, and Japonica and they have distinct differences in nuclear and organeller genome (Kim and Inouye, 1987). Rice breeding developments have been based on the improvement of harvest index and biomass to increase yield potential. The first major breakthrough in the history of rice improvement started in the 1960s, when the recessive gene sd-1 for dwarf plants was incorporated from the Chinese variety known as Dee-geo-wogen (Khush, 2001). This resulted in the development of a number of high yielding varieties with an increased harvest index (Khush, 2001; Zhang *et al.,* 2004). This was followed by the introduction of rice hybrids in China in the 1970s and gradually introduced in other Asian countries with improved yield potential (Peng *et al.,* 1999).

2.1.1 The Rice Genome

The year 2007 marked the declaration of the complete rice genome sequence by the genome sequencing project (IRGSP, 2007). The rice genome has 420 million nucleotides, 5 times and 40 times smaller than the maize and wheat genome respectively (Bannayan *et al.,* 2005) and is distributed into twelve pairs of chromosomes which can be individually recognized (Fukui and Iijima, 1991).

2.1.2 Genotype x Environment (G x E) Interaction

Genotype-by-environment interaction (GxE) is the phenomenon that the relative performance of genotypes varies with environmental conditions. It is attributed to the dependence of expression of underlying genes, or QTL on environments (QTLxE), (Yin *et al.,* 2004). Quantitative Trait Loci (QTL) is a region of DNA that is associated with a particular phenotypic trait.

2.2. Rice Cultivation in the Mekong Delta

2.2.1. Rice Cropping Systems and Rice Seasons

There are three major rice cropping systems and three main rice seasons in the Mekong delta. The sequential cropping systems include; the single crop (SC), the double crop (DC) and the triple crop (TC). These cropping systems are determined by hydrology, rainfall pattern and the availability of irrigation water. The single cropping is rain-fed and is mainly practiced at the coastal area and is subjected to salinity at the beginning of the rainy season. In this system traditional varieties are grown that have a longer growing period. The double cropping system starts at the end of the rainy season and depends on irrigation water. In this system some areas are susceptible to flooding during the rainy season. The triple crop system utilizes all three rice seasons and is practiced in riverine areas with favorable hydrological conditions with controlled availability of irrigation water (Soo Chin Liew *et al.,* 1997).

2.2.2. Temporal Development of Rice

Rice cultivation in the Mekong delta takes place in threes three different cropping period and these include, planting by direct seeding, growing and harvest periods. The growing period includes vegetative, reproductive, and grain filling/maturation stages and takes 110–120 days for tropical varieties.

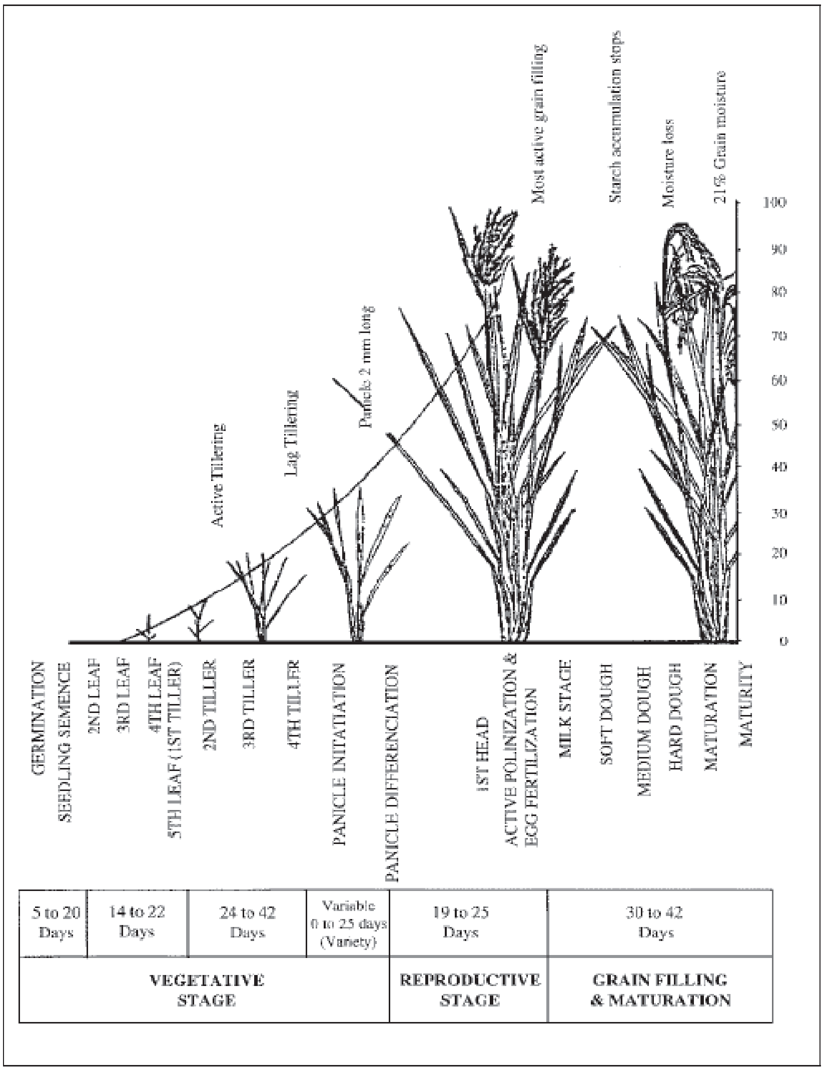


Figure 2: Growth stages of rice (Source: Le Toan *et al.,* 1997).

The duration of the vegetative phase (tillering, elongation, and booting) depends on the variety and is influenced by climatic conditions and cultural practices. This phase is characterized by an increase in plant height, number of tillers, and development of leaves. Tillering starts about 15 days from sowing and continues until flowering. Tillering and stem extension are the growing periods during which rice develops as these produce panicles. New tiller emissions, are slow at first but become faster after 50 to 60 days after transplanting. Plants form clusters that totally cover the area between them. Tiller numbers depend on the variety, soil fertility, temperature, day length, and the planting density.

The reproductive phase includes heading, panicle initiation, and flowering. It lasts for 25–35 days for all varieties. During this phase, there is a decline in the number of tillers, the development of the panicular leaf and panicle formation. After heading, the vegetative growth (height and green biomass) stops. The ripening phase covers grain filling, milk, and dough stages. It lasts about 25–35 days and is characterized by a decrease in leaf and stem moisture content and a decline in the number of leaves (Le Toan *et al.,* 1997).

2.2.3. Pests and Diseases

The most important pest of rice in the Mekong River Delta is the brown plant hopper which is the vector of yellow stunt virus disease of rice.. It has a history of devastating effects in the delta (1978, 1991 and 1992) but decreased in later years due to unfavorable weather conditions such as typhoons and floods (1999-2003), which washed the presence of this pest. In 2006, there was another outbreak of the pest, infecting up to 210,000 ha (Luong, 2007). Its feeding habits include sucking of the soft plant tissues and extracting plant sap from phloem cells. The damage gives the rice field the appearance of a burnt field known as 'hopper burn'(Pham and Buu 1999).

The major cause of the spread of brown plant hopper is attributed to changes in weather in the delta such as fogging and late rains and a narrow gene pool for resistant varieties that have not been diversified in the past ten years. Its spread is also blamed on the farmers' preference for aromatic but highly susceptible rice varieties, such as Jasmine 85, STI, VD20, OMCS2000 and MTL250. Further more, farmers practice high seeding rates, high nitrogen fertilizer applications which in turn attract the pest (Luong, 2007).

2.3. Dynamic Site Specific Management Aspects

The rice crop in the Mekong delta consumes about 400,000 tones of nitrogen, 180,000 tones of phosphorous and 120,000 tones of potassium (Chu and Pham, 2007). The right recommendations for nitrogen fertilizer applications for longer duration varieties (120 days) are 10-15 days after sowing (DAS), 30-35 DAS and 65-75 DAS and 7-10 DAS, 15-22 DAS, 37-40 DAS for shorter duration varieties (90-110 days). Varieties with less than 90 days duration are referred to as ultra short (Pham, 2005). The recommended rates of phosphorous are 40 to 80 kg/ha for alluvium soils and 60 to 80 kg for acid sulphate soils (Chu and Pham, 2007).

The rice farmers apply more nitrogen fertilizer than the recommended 80-120 kg/ha. Each nitrogen fertilizer dose is applied uniformly to the whole field 4 to 7 times per cropping season. This routine however does not consider spatial and temporal variations of crop growth as changing environmental factors highly affect nitrogen supply dynamics from the soil to the crop (Xue and Yang, 2008). As a result there is a spatial and temporal imbalance between the demand and the supply of nitrogen which combined with leaching and volatilization has diverse effects on the environment. These effects on the environment include ground water pollution together with the cumulative transportation of chemical pollutants from the Mekong river basin to the South China Sea where the Mekong River drains its waters. Further more, the rice farmers perceive that there is more nitrogen in the sediment during the dry season (Chu and Pham, 2007). They therefore apply more nitrogen fertilizer in the wet season when there is flooding. This all implies that the different cropping systems in the delta provide a high risk of environmental degradation. High temperatures and relative humidity combined with high nitrogen applications are conducive factors that spread and increase of the 'yellow leaf' disease of rice in the delta (Cao and Luu, 2000).

2.3.1. Soil Conditions in the Delta

In the Mekong Delta, 700,000 ha are affected by saline and acid sulphate soils (Nguyen and Do, 1977). Acid sulphate soils occur extensively in the Plain of Reeds along the Cambodian border, in the Ha-Trien plain and the Trans Bassac lowlands. The strong soil acidity results from oxidation of accumulated sulphides in the sediments. Salinity is caused by salt water intrusion during the low flow period of the Mekong River in the dry season and the high tidal range of approximately 3 m along the South China Sea coast. Also, irrigation water intake in the upstream areas enhances salt water intrusion during the dry season. The saline soils have a pH that is neutral to slightly acidic but relatively high in exchangeable sodium percentage (Nguyen and Do, 1977).

2.3.2. Salinity Stress and Tolerance in Rice

Salinity is one of the major problems limiting rice production in the delta. Salinity stress reduces the plant's photosynthetic capacity which eventually lowers its biomass production (Munns, 2002). In rice, salinity stress and tolerance varies with the stage of the crop's phenology and the ambient weather conditions. For instance rice is salt tolerant during tillering and very sensitive during the seedling stage and at flowering. It is more salt sensitive at high light intensity and low relative humidity (Moormann and Breeman, 1978; Pearson and Ayres, 1960).

2.3.3. Acidity Stress and Tolerance in Rice

Iron toxicity in acid sulphate soils under flooded conditions is the major growth limiting factor for rice. In the dry season, oxidation of pyrite (iron sulphide) lowers the pH wherever the groundwater table drops below the depths at which the soil contains pyrite. However in the Mekong delta when the soils are flooded, oxidation of pyrite and other sulfidic or sulfuric compounds that lead to acidification does not take place. Furthermore, flooding has the effect of flushing acid soils and depositing fertile sediment into the floodplains due to reduction and leaching which de-acidifies the soil at some sites (Cao, 1998). Rice plants are in general moderately tolerant to acid soils, but show a wide genotypic variation in tolerance to severely acidic soils. Semi-dwarf indicas like the ones grown in the Mekong delta are more susceptible than tropical/temperate japonicas which are usually tolerant (Okada and Fischer, 2001).

2.4. Crop Growth Simulation Models

Crop growth simulation models have been extensively used as valuable tools in agricultural research (Bouman and van Laar, 2006). Crop modeling systems reviewed by Bannayan *et al.,* (2007), are designed to:

- Provide a deeper understanding of the physiological concepts that underlie plant growth and development with substantial improvement on the prediction of the realization of different genotypes
- Assist in analyzing the growth and development of crops and the environmental variables to which they are exposed.
- Predict how the changes in the environment will affect the growth and development and impact on yield.
- Predict the response of a target crop for various environments by changing one or multiple environmental variables.
- Provide support for crop improvement, especially plant breeding where predictions of differences between cultivars in response to different environments still need improvement.

2.5. Remote Sensing Tools for Crop Growth Modelling

2.5.1. Vegetative Indices

The physical fundamentals of reflection of solar radiation from single leaves to complete vegetation canopies are now relatively well understood. Models, describing reflection of red, green, and near-infrared radiation and showing considerable information about crop biomass owing to the contrast between soil and vegetation (Goudriaan, 1977; Bunnik, 1984) have also been widely studied.

In remote sensing, vegetative indices, (VI) are dimensionless radiometric measures computed from reflectance as digital number (DN). They function as indicators of relative abundance and activity of green vegetation such as leaf area index, percentage of green cover, chlorophyll content, biomass and photosynthetic activity. Vegetative indices capture sensitivity to plant biophysical parameters showing a linear response that is sensitive over a wide range of vegetation conditions that can be measured at the ground to facilitate calibration and validation. They normalize external effects such as sun angle, viewing angle, and the atmosphere for consistent spatial and temporal comparisons. They also normalize internal effects such as canopy background variations (soil, litter, under storey vegetation), canopy structure, leaf inclination angle, woody components and senescent vegetation components. (Clevers *et al.,* 1991;Bouman, 1995).

The most commonly used VI is the Normalized Difference Vegetation Index (NDVI), is the normalized ratio of the red and near infrared reflectance and takes the form;

$$NDVI = \frac{\rho NIR - \rho Red}{\rho NIR + \rho Red} \qquad (1)$$

Its values range between +1 and -1. NDVI has been used to monitor phenological patterns of the earth's vegetative surface, and of assessing the length of the growing season and dry-down periods (Huete and Liu, 1997). NDVI is useful for assessing the health and density of vegetation. NDVI values near 0 indicate very sparse vegetation. Dense vegetation is indicated by NDVI values approaching 1. By using a time-series of NDVI observations, one can examine the dynamics of the growing season and monitor phenomena such as drought. NDVI is chlorophyll sensitive and has been found to be highly correlated to the leaf area index (LAI) of paddy rice fields (Xiao *et al.,* 2002d).

Leaf area index (LAI) is defined as the sum of area of all leaves divided by the ground area above which the leaves have been collected (Yoshida, 1981). Leaf area index (LAI) is one of the major determinants of crop photosynthesis as it primarily determines the interception rate of solar radiation of a crop. LAI development associated with nitrogen accumulation in leaves determine the nitrogen content per unit leaf area (LNC, g m^{-2} leaf) which is one of the major determinants of radiation-use efficiency (Sinclair and Horie, 1989). LAI dynamics involves two major processes, LAI development associated with crop growth and the other is its decrease with leaf senescence (Yoshinda *et al.,* 2007). Leaf senescence links plant nitrogen dynamics to LAI dynamics, as they are closely related (Yin *et al.,* 2003).

3. Materials and Methods

3.1. Study Area

The study area covered 10 provinces of the Mekong River Delta of Vietnam, namely, Can Tho, Kien Giang, An Giang, Bac Lieu, Tra Vinh, Dong Thap, Tien Giang, Ben Tre, Soc Trang and Long An (Figure 1), at latitude -N8^{0}33"- N 11^0 00" and longitude E104^{0}27" –E106^{0}49". The delta is located at the downstream end of the Mekong River Basin. The Mekong River is the longest river in Southeast Asia and originates from the Tibetan plateau. It flows for 4,800 km and is divided into two basins, the upper Mekong Basin and the lower Mekong Basin. The former covers China and Myanmar while the latter covers Lao PDR, Thailand, Cambodia and Vietnam to the South China Sea, where it discharges on average 475,000 million m^3 of water per year. The whole Mekong Basin catchment covers an area of 795,000 km2 (MRC, 2003).

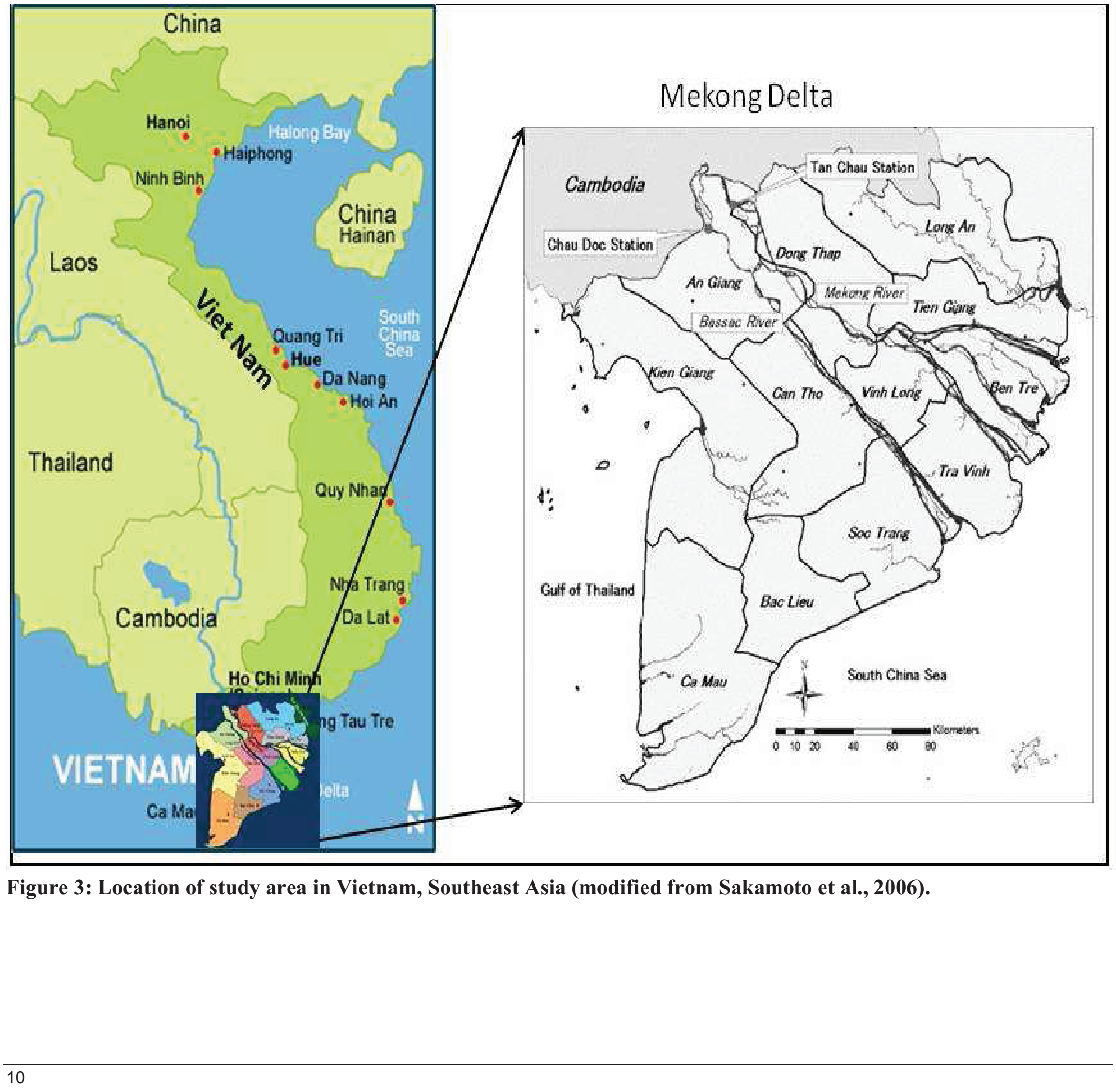


Figure 3: Location of study area in Vietnam, Southeast Asia (modified from Sakamoto et al., 2006).

3.2. Primary Data Collection

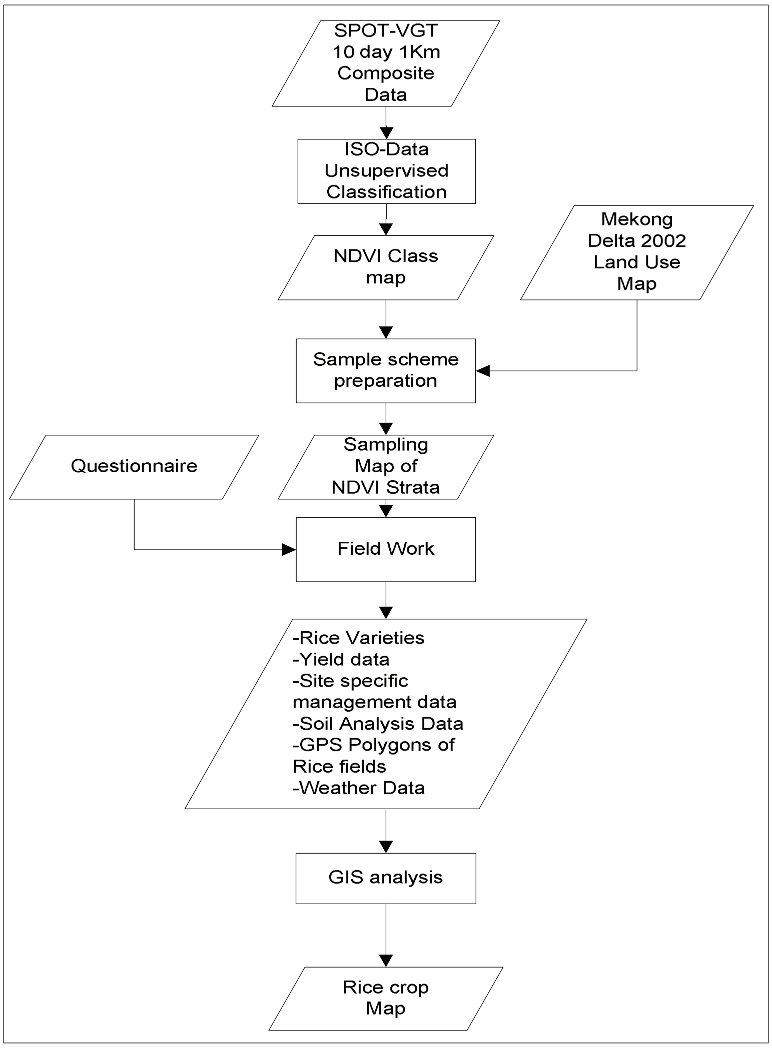


Figure 4: Methodological flow chart of primary data collection

3.2.1. ISO Data Unsupervised Classification and Sample Scheme Preparation

10 years (1998-2008) of stacked SPOT-VGT NDVI images were classified to a range of pre-set classes (10 to 100) through the unsupervised ISODATA clustering method of ERDAS to identify the optimal number of classes to be defined. The selected unsupervised classified map was then compared with a 2002 land use map (Appendix1) and a stratified random sample scheme was prepared.

SPOT 4 and 5, carry the vegetation and the High-Resolution Visible and Infrared (HRVIR) sensors. SPOT 4 was launched in March 1998. The Vegetation sensor provides daily images of the global land surface at 1 km spatial resolution (2250km swath width) offering three standard products to users namely: P (physical), S1 (daily synthesis) and S10 (10-day synthesis). S10 is a maximum value composite over each 10-day period resulting in three 10-day composites per month: days 1–10, days

11–20 and day 21 to the last day of a month (Kamthonkiat *et al.,* 2005). NDVI data are calculated for each of the S10 products, using the surface reflectance values of bands B2 and B3 (CNES, 2003) and takes the form;

$$NDVI = (B3-B2) / (B3+B2) \quad (2)$$

Where, B2 is red and B3 is NIR.

3.2.2. Field Work

118 rice fields were sampled by stratified simple random sampling according to the NDVI class map (Figure 5). 5 to 7 fields were selected per strata and for each field interviews were conducted with the farmers owning these fields. (Check list of the interview is as in appendix 2).The basic information on collected data is:

- Yield data of the first cropping season and the varieties grown from farmer interviews Information on the yield and yield components of these rice varieties was obtained from Cuu Long Delta Rice Research Institute, CoDo, Can Tho, Vietnam. These were used to calibrate the variety specific aspects of the model.(Appendix 5)
- Site specific management aspects were planting and harvesting dates, seeding rates, sowing method, seed quality, fertilizer application and timing.
- Field boundaries digitized with a hand held IPAC running ARCPad with a global positioning system to digitize the latitude/longitude of corners of the field to form polygon shape files. Digitizing was done by walking along the sides of each field or rowing by boat under conditions of heavy flooding.
- Soil samples (top soil) taken from each field with the use of a simple soil auger for the purpose of determining its pH and salinity. (Method of soil analysis in the Appendix 4).
- Weather data (2003-2008) from nine meteorological stations in the surveyed area was collected and used as an input parameter for the weather data file during model calibration. (The map of Mekong delta showing the meteorological stations are in Appendix 3.)

3.2.3. GIS Analysis

A rice crop map was generated from the interviews, showing the crop calendar of the sequential rice cropping system in the delta using ArcGIS 9; ArcMAP version 9.3 software. The map also shows spatial distribution of rice varieties, the flooding regime and the soil related problems experienced in the Mekong Delta.

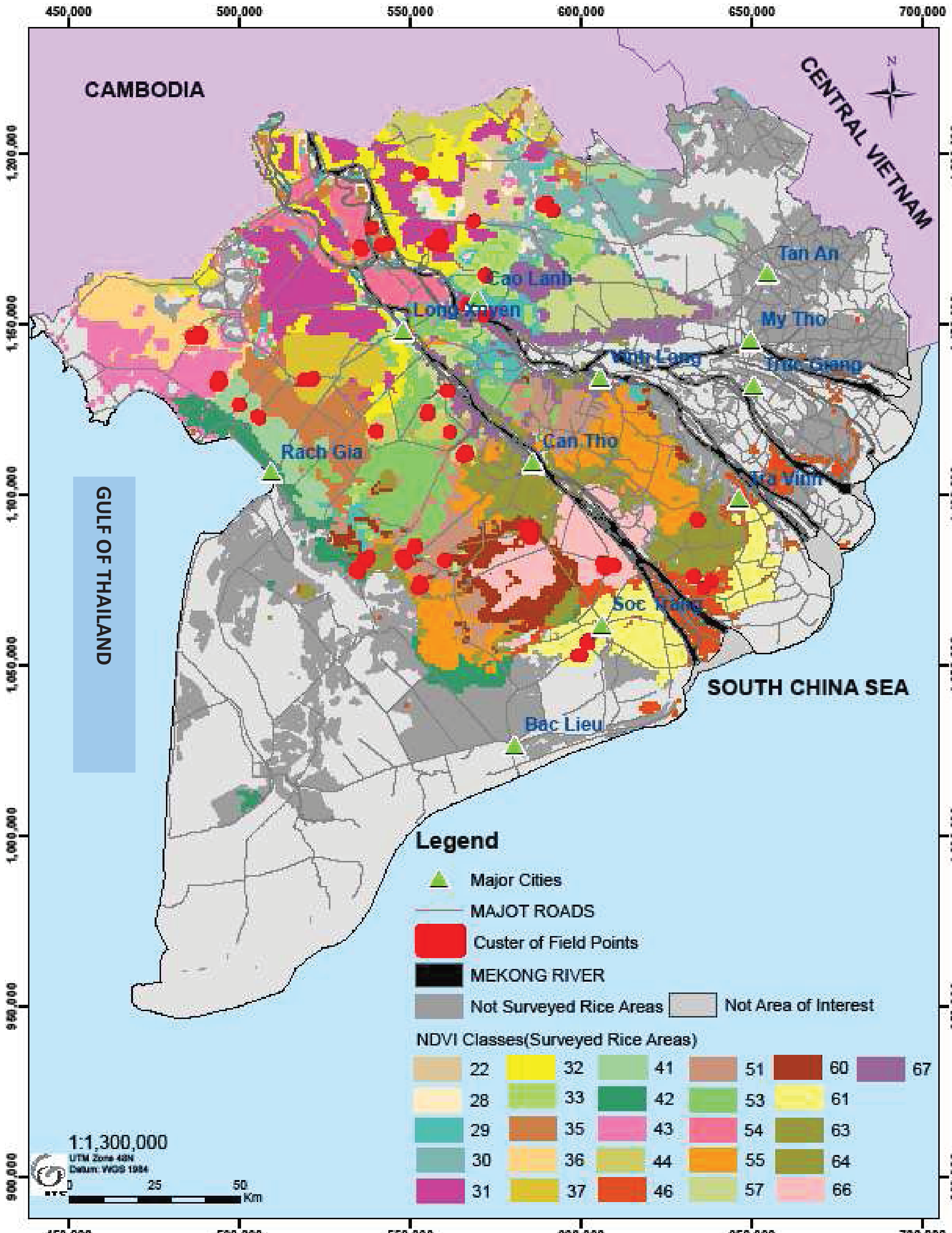


Figure 5: NDVI class map showing sample points

3.3. Leaf N and LAI Remote Sensing Based Indices

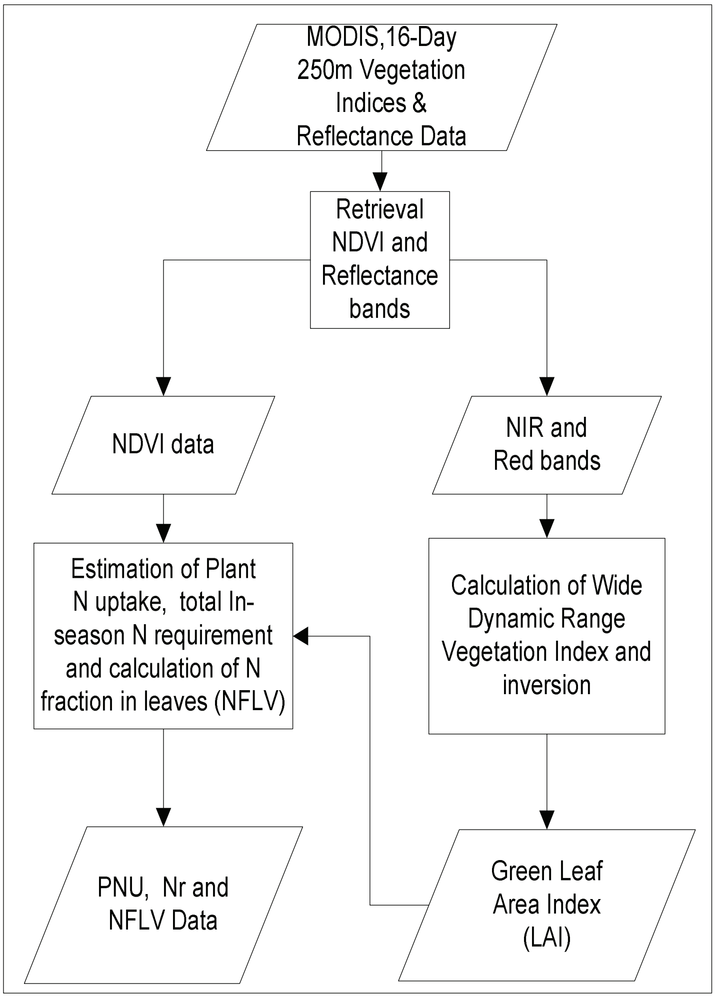


Figure 6: Methodological flow chart of remote sensing based indices

3.3.1. Retrieval of NDVI and Reflectance Bands from MODIS

Remote sensing data was obtained from the analysis of VI's developed for the Moderate Resolution Imaging Spectroradiometer (MODIS), recently launched onboard the Terra platform (Justice *et al.,* 1998). The Moderate Resolution Imaging Spectroradiometer (MODIS) remote sensing data available in three spatial resolutions, 250m 500m and 1km. Measured are the visible, NIR, and SWIR (Short Wave Infra-red) in bands 1 to 7, used to monitor vegetation dynamics. Level 0 data contains raw radiance values which are processed into MODIS Level 2 products and corrected for atmospheric contamination. These are immediately mapped into the Sinusoidal projection and gridded into 10-degree units called tiles. The Vegetative index products rely on the level 2 daily surface reflectance product (MOD09 series) whose algorithms ingest the level 2G (gridded) surface reflectances and temporally composite these, to generate the 16-day, 250/500m or 1km VI products, (MOD13Q1). The VI output file contains; 16-day NDVI and EVI values, 16-day QA for NDVI and EVI, the residual red (band 1), near-infrared (band 2), middle-infrared (band 6), and blue (band 3) reflectances and view zenith, solar zenith, and relative azimuthal angles from the selected, composited pixels (Justice *et al.,* 1998). The periods taken were between, 30th September 2007 – 22nd Feb 2008, which covered the growing season of the first rice crop in the Mekong Delta.

3.3.2. Calculation of Wide Dynamic Range Vegetation Index and Inversion

The green leaf area index was estimated from the method developed by (Gitelson *et.al.,* 2007). It inverts the relationship between the Wide Dynamic Range Vegetation Index (WDRVI) and LAI. WDRVI was found, to accurately estimate LAI across a much greater LAI range than the NDVI, assessing even slight variations in LAI, especially during early stages of plant stress. The WDRVI is derived from the red and near-infrared (NIR) regions, which are represented in MODIS' two 250-m spectral bands and takes the form;

$$WDRVI = (\alpha \times \rho NIR - \rho Red) / ((\alpha \times \rho NIR + \rho Red)$$

Where $\alpha = 0.2$ and ρNIR and ρRed are reflectance in the NIR and the red bands, respectively.

$$Green\ LAI = (WDRVI - a) / b$$

Where a and b are coefficients taking the form of 0.0204 and 0.1762 respectively.

3.3.3. Estimation of Plant Nitrogen Uptake (PNU), Total In-season Nitrogen Requirement (Nr) and N fraction in leaves (NFLV)

The Moderate Resolution Imaging Spectro-radiometer (MODIS) VI products was used to obtain the, the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI), at 250 m resolutions and 16-day compositing periods. (Table 3-2)

Table 3-1: Data description of MODIS NDVI

Data Item	Description
Resolution	250 meters
Image Size	21000 Pixels x 13000 Lines
Data format	Geo-tiff file with 8 bit Unsigned integer
Data Scaling	(NDVI * 200)+50 = values from 0 - 250 corresponding to NDVI range of -0.25 - 1

In rice, NDVI is an excellent predictor of early season plant N uptake before panicle initiation. It has been used by Xue and Young, (2008), to estimate site specific nitrogen topdressing recommendations and is known as the N fertilizer optimization algorithm (NFOA). In their approach, in-season estimate of predicted grain yield (INSEY) is calculated as

INSEY = NDVI/DAS,

NDVI = (ρNIR-ρRed)/((ρNIR+ρRed) (3)

where DAS is the days after sowing for direct seeded rice and NDVI is the normalized difference of the vegetation index, and ρNIR AND ρRed are the near infra red and red bands respectively.

After INSEY is known, the predicted potential yield (PGY kg/ha) is calculated by:

PGY = a x exp (b x INSEY) (4)

where a and b are 0.652 and 200 respectively and are parameters obtained by calibrating rice yield with the INSEY value.

The predicted grain N uptake (GNU, kg/ha) is then calculated by;

GNU= 1.9 x PGY/100 (5)

The predicted early season plant N uptake is (PNU, kg/ha) is calculated from NDVI by;

PNU = a + b x exp (c x NDVI) (6)

Where a, b, and c are 28.11, 1.824E-05 and 16.94 respectively and are parameters obtained by calibrating the plant N uptake with measured NDVI in rice.

Total in season nitrogen requirement, was calculated from

Nr = (GNU-PNU)/NUE (7)

Where Nr is plant N requirement

GNU is the predicted grain N uptake (GNU, kg/ha)

PNU is the predicted early season plant N uptake is (PNU, kg/ha) is calculated from NDVI

NUE is the nitrogen use efficiency (set at 0.40, the critical NUE of an in-season N application for high yield rice, Ling *et al.,* (2005).

N fraction in leaves was calculated from PNU using the principles of Yin *et al.,* (2000b, 2003b) that takes the form;

$L_N = (1/K_n)\mathrm{In}(1+K_nN_{Lv}/n_b)$ (8)

Where

N_{Lv} is the total leaf N in a fully developed canopy, L_N is nitrogen limited LAI.

K_n is the is the nitrogen extintion coeffiecient in the canopy, and has a value of ,0.917

and n_b is the crop specific minimum leaf nitrogen for photosynthesis and has a value, 0.537 (Yin *et al.,* 2000b).

In this study, N fraction in leaves on area basis (NFLV), was obatined by dividing N_{Lv} with corresponding LAI recorded on the same date. This is because LAI development associated with nitrogen accumulation in leaves determine the nitrogen content per unit leaf area (LNC, g m^{-2} leaf) (Sinclair and Horie, 1989).

3.4. Genotype x Environment Interactions

In order to analyze G x E interactions of rice varieties with the conditions in the delta, the farmers' fields were grouped in replicates if the sites were having the same condition in terms of soil type, rice variety and management aspects. Two most dominant varieties cultivated in the Mekong delta were selected. The SPSS (version16.0) statistical package was used to perform ANOVA on yield performance, plant N uptake before panicle initiation of all the varieties in different soil type's and namely acid, acid saline, neutral and saline soils which were considered test environments in this research. The effect of farmer N application on yield was also analyzed in the test environments. Then the performance of the two varieties was also tested. One of the varieties, IR50404 was developed for the acid sulphate soils in the Mekong delta, while the other (Jasmine 85) is more susceptible to these soils, but is popular among the farmers for its high grain quality and aroma. Arithmetic means for different replications were computed for the rice varieties and then used as model input parameters for ORYZA2000. POSTHOC tests were done to produce multiple comparisons between the means. Local varieties and neutral soils were considered controls in this analysis.

3.4.1. Performance of Rice Varieties

Information obtained from interviews with the farmers of the rice growing region of the delta was consolidated and the yield report was analysed using SPSS statistical package. A pie chat was constructed to show the abundance of rice varieties grown in the delta. In order to obtain proper statistical analysis, the grouping of rice varieties was rearranged. For instance, traditional varieties grown at only four sites were grouped and labelled as local varieties. The sites that grew the same varieties were considered replicates of the variety in question. To minimise bias 3 or 4 replicates were randomly selected from the sites growing the most dominant varieties. A one way ANOVA was used to test whether the yield performance of rice varieties in the delta was significantly different and therefore cultivar specific. The local varieties were considered to be the controls. To visualize the performance of these varieties, bar graphs of the means were plotted and error bars were constructed from their standard error from the mean. The effect of the soils types on yield were also tested using ANOVA.

3.4.2. Site Specific Management Aspects

The effect of these on yields was compared so as to obtain the optimum levels to calibrate the crop model. The temporal aspects of N application on remote sensing applications was derived by investigating the multi-temporal effect of N application on NDVI and the effect of different N doses on yield of rice. To find out whether plant N uptake derived from NDVI was cultivar specific ANOVA was used to test for significant differences at panicle initiation. It has been shown that NDVI predicts plant N uptake more accurately at panicle initiation in rice (Xue and Young, 2008). Local varieties were considered the controls.

3.5. Model Calibration

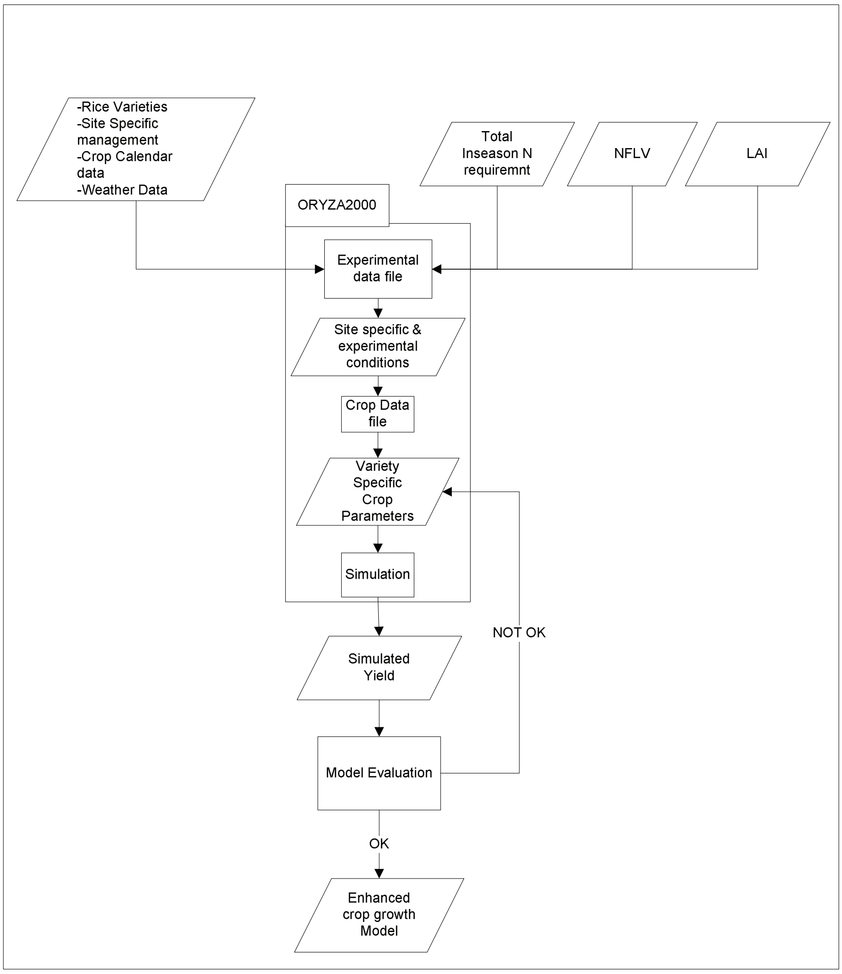


Figure 7: Methodological flow chart of model calibration

3.5.1. ORYZA2000

A popular rice growth model ORYZA2000 (Bouman and van Laar, 2004), (figure 9) is used in this study. Its mode of operation is based on a daily calculation scheme of the rate of dry matter production of plant organs and phenological development and simulates these rates throughout the growing season. ORYZA2000 partitions carbohydrates produced between roots, leaves, stems and panicles using experimentally derived portioning factors as a function of development stages. These carbohydrates are as a result of maintenance respiration requirements subtracted from gross assimilation rate which obtains net daily growth expressed in kg carbohydrate $ha^{-1}d^{-1}$.

Leaf Area Index (LAI), radiation and temperature are used to calculate the total daily rate of canopy CO_2 assimilation. This assimilation is integrated over the day and over all leaf layers in the canopy. This integration is based on an assumed sinusoidal time course of radiation during the day and on an exponential extinction of radiation within the canopy. On the other hand leaf N content on area basis determines the photosynthesis of single leaves which also depends on the radiation intensity, stomatal CO_2 concentration and temperature (Bouman and van Laar, 2006). In ORYZA2000, the actual crop N uptake is restricted by a maximum physiological uptake rate of the plant and available mineral N in the soil. The available fertilizer N is calculated as application rate multiplied by a potential (or maximum) recovery fraction, defined as a function of crop development stage, with relatively low values at transplanting and high values at panicle initiation. Leaf N concentration affects leaf photosynthesis rate and leaf expansion rate, while the total amount of N in the crop affects the rate of leaf senescence after flowering (Yin *et al.,* 2003).

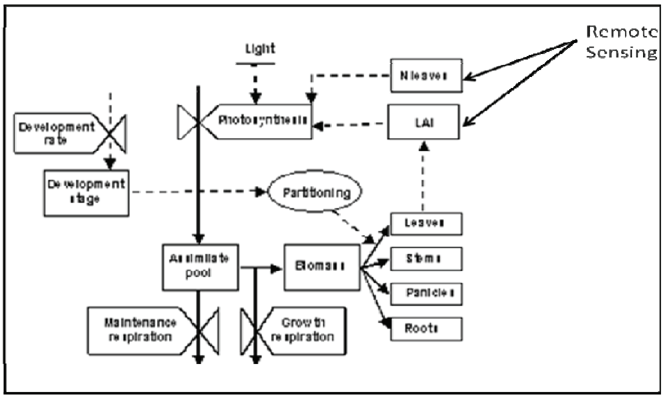


Figure 8: The ORYZA2000 model improved from ORYZA1 (source: Bouman and van Laar, 2004), calibrated with LAI and N fraction in leaf from remote sensing data.

3.5.2. Experimental Data File

Input parameters for ORYZA2000 were derived from data sets of the first cropping season (October 2007-March 2008) of the rice fields of the Mekong delta. Due to the availability of weather data in terms of sunshine hours (h d^{-1}), minimum temperature (TMMN, ^{0}C), early morning vapour pressure (VP;Kpa), and mean wind speed (WN;ms^{-1}), the Penman equations were preferred as they are the most accurate ones (Van Kraalingen and Stol ,1997). The timer data was set at start year of 2007 and time 273 (1 October) and finish year as 2008 while indicating the station number closest to the fields. Figure 10 below shows a general trend in the mean monthly photoperiod (daily sunshine hours) and maximum temperature during the growing season in all the nine meteorological stations. Environmental model input requirements were: geographical latitude, daily weather data (radiation, minimum and maximum temperature). Planting density and dates of sowing were introduced along with the weather data. (Transplanting shock variables were ignored as all the farmers practiced direct seeding).

Due to lack of measured data, weight of roots, stems, green leaves and storage organs (panicles), partitioning coefficients for roots, shoots, stems, leaves and storage organs, number of plants per hill, number of hills m^{-2}, values from the experiments of IR72 (Kropff *et al.*, 1994), were used. The choice of these assumed values was done taking into consideration the values for IR72 at similar developmental stages (Kropff *et al.*, 1994, Swain *et al.,* 2007), (Figure 11). Default values were maintained in the model for the other model input parameters. Integrating remote sensing techniques into ORYZA2000 was done as explained by (Bouman, 1995), which included;

- The updating of a state variable of the model (e.g., LAI) derived from remote sensing known as 'forcing strategy'
- The adjustment of an initial condition to obtain a simulation in agreement with the remote sensing derived observations;
- The re-calibration of the model, i.e., the adjustment of model parameters to obtain a simulation in agreement with the remotely-sensed derived observations, known as re calibration of the model or 're-parameterization' strategy;

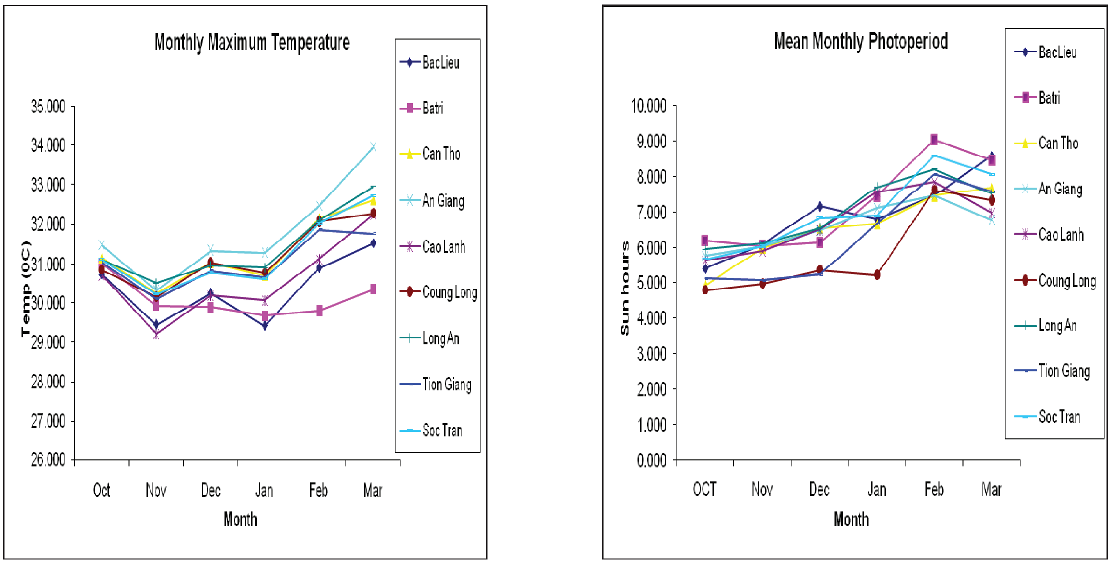


Figure 9: Monthly maximum Temperature and photoperiod through the growing season used to calibrate the weather input file in ORYZA2000.

3.5.2.1. Site Specific Nitrogen used in Model Calibration

ANOVA showed a significant difference between yield and N doses applied farmers with F = 2.511 and P<0.05 at P=0.037. The highest yields were attained at the doses of 61-80kg/ha and the least yields were attained at higher levels of N application doses. POSTHOC comparisons showed a significant difference in yield between 61-80kg/ha N doses with 81-100kg N/ha, 101-200kg N /ha and > 200kg N /ha at P= 0.009, 0.003, 0.041 respectively which are significant at P<0.05. These N aspects were used to calibrate the site specific nitrogen inputs of the model (Figure 11).

3.5.3. Crop Data File

The growing period of the rice crop was divided into four main phenological phases (Figures 11 and 12):

i) Basic vegetative: From DVS (developmental stage) 0 (seedling emergence) to DVS, 0.4 (start of photoperiod sensitivity).

ii) Photoperiod sensitivity: from DVS, 0.4 (start of photoperiod sensitivity) to DVS, 0.65 (panicle initiation).

iii) Panicle formation: from DVS, 0.65 (panicle initiation) to DVS, 1.0 (first flowering).

iv) Grain filling: from DVS, 1.0 (first flowering) to DVS 2.0 (physiologic maturity) maturity (Kropff *et al.,* 1994, Bouman *et al.,* 2001, Swain *et al.,* 2007).

DRATES program was used to estimate developmental rates for rice varieties from the planting dates, panicle initiation, flowering, and maturity for each genotype in each field site. Nitrogen parameters were set at 0.30 to 0.75 for minimum and maximum development stage respectively. The soil mineralization was set at 0.8kg N $ha^{-1}d^{-1}$, (Aggarwal *et al.,* 1997) and calculated maximum N uptake by the crop was set at 8 kg ha^{-1} d^{-1} (Peng and Cassman, 1998). Maximum relative leaf growth rate was set at 0.0085^{0} cd^{-1} , (Kropff *et al.,* 1994). Site specific N recovery rates in the ORYZA2000 was calculated by dividing total in season N requirement obtained from NDVI under site specific fertilizer applied by the farmer and the nitrogen fertilizer application rate (Bouman and van Laar, 2006). Recovery of N was set at 0.35 at seeding and 0.75 at panicle initiation (Aggarwal *et al.,* 1997).

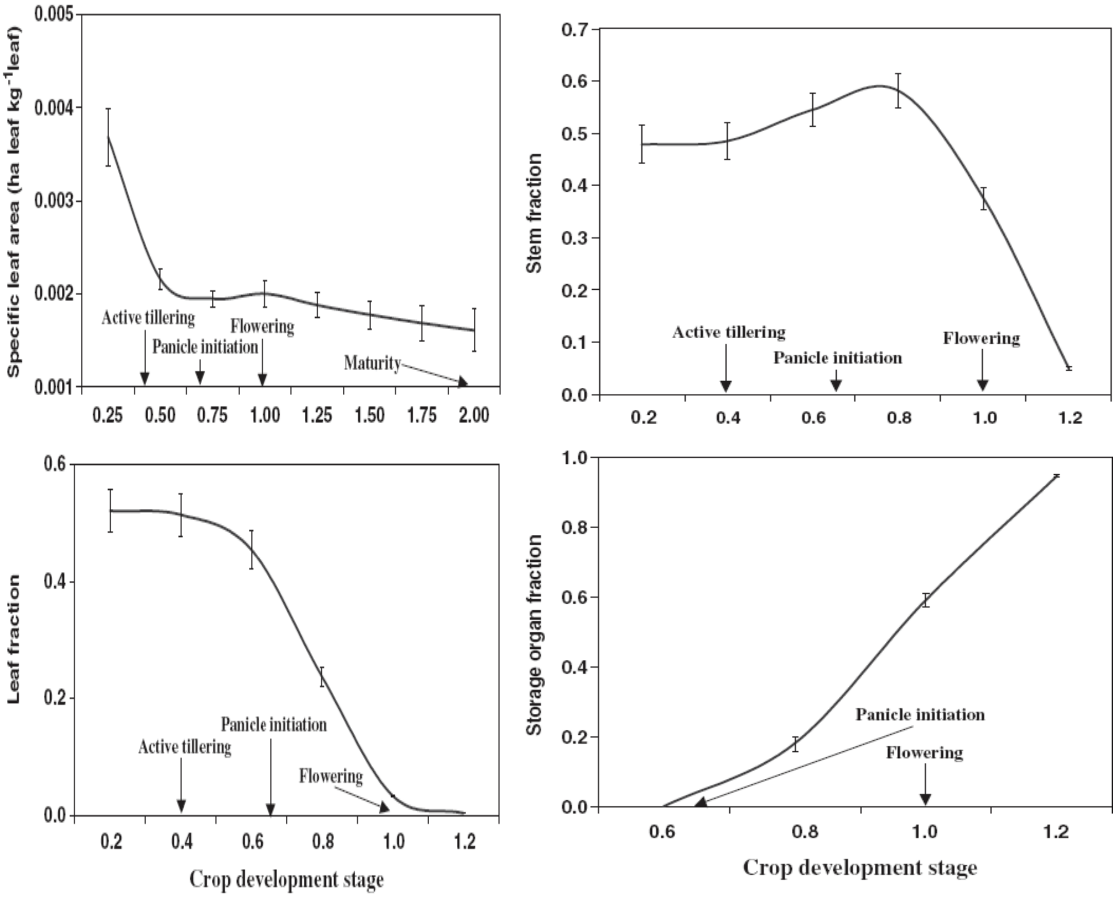
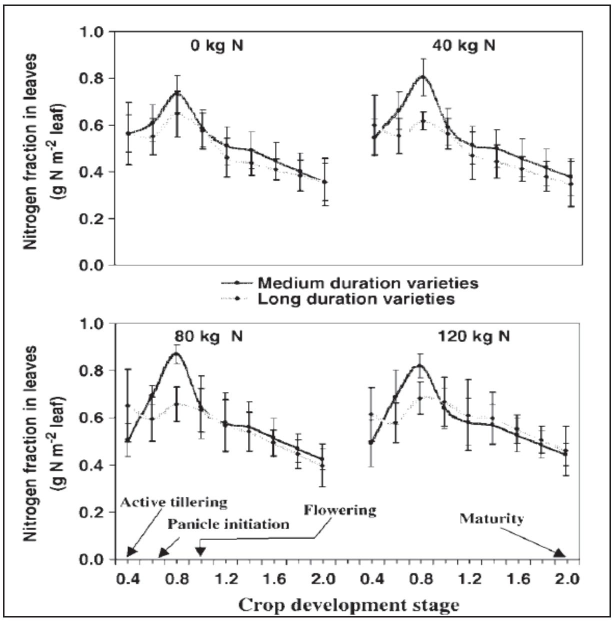
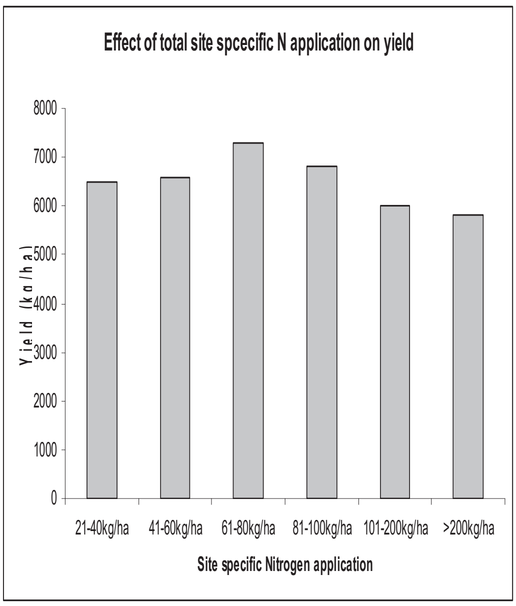


Figure 10:Input parameter values for specific leaf area and fraction of shoot dry matter allocated to leaves, stems and storage organs as a function of crop development stages used to calibrate the ORYZA2000 model for the rice varieties. (source; Kroppf *et al.,* 1994; Swain *et al.,* 2007).





- b)

Figure 11: Variation of N fraction in leaves as a function of crop development stages used as input parameters in ORYZA2000 for rice varieties (source: Swain *et al*: 2007) and site specific N.

In ORYZA2000, the option for simulating LAI and NFLV from remote sensing was switched to forcing (Table 3-3, 3-4). Measured Leaf N content on area basis and LAI recorded on the same date, and the option for simulating from remote sensing was switched to forcing as shown in (Tables 3-3 and 3-4).

Table 3-2:Measured data for model calibration and comparison and an option to force measured LAI during simulation

LAI Observed		
Year	Date of MODIS Data	LAI
		Per site
		Per variety
		Per variety Per soil type
*LAI_FRC = 0 ! No forcing LAI_FRC = 2 ! Forcing		

Table 3-3: Measured Leaf N content on area basis (NFLV; g N m-2) leaf area data for model calibration and comparison and an option to force measured NFLV during simulation

NFLV Observed		
Year	Date of MODIS Data	NFLV
		Per site
		Per variety
		Per variety Per soil type
*NFLV_FRC = 0 ! No forcing NFLV_FRC = 2 ! Forcing		

3.5.4. Simulation

In this study the variance explained by the initial model run by site (all fields) was considered to be genotype specific and thus the simulation by genotype and genotype by environment was expected to account for this variation. When this was not so, the initial model was iterated with the previous model outputs until the accuracy of predictions were improved.

ORYZA2000 was simulated in two stages. In the first stage, observed and initial model input parameters in the ORYZA2000 were used and the model ran for all the sites with each genotype and the two genotypes in each test environment. From the output, simulated yield for each site and combination of genotype and test environment were recorded. In the second stage the output from the initial model would be iterated with the output model parameters until prediction of yield was improved. Each site was considered as a single experiment and simulated individually with the specific genotype and crop management aspects obtained from field observations, namely;

Plant height, planting and harvesting date, maturation days, N fertilizer and application times, weather data from nearest meteorological station, Seeding rate.

The potential yield of rice was simulated in three groups, namely; all the rice fields (by site), for all the sites that grew IR50404 and Jasmine 85 in that cropping season (by genotype) and for the sites that grew IR50404 and Jasmine 85 in the different soil types (Genotype x soil type), namely; acid, acid saline, saline and neutral soils.

3.5.5. Model Evaluation

The calibrated models were run for all the sites then for both IR50404 and Jasmine 85. The simulated yields were plotted against observed values in 1:1 scatter plots. The R^2 was computed to determine the accuracy of predictions made by the ORYZA2000 model. For the genenotype x soil type (G x E), the least square means of yields obtained from the ANOVA in the different environments were used. Bar graphs were used to illustrate the accuracy of predictions of the observed and simulated yields in all the soil types.

3.6. Sensitivity Analysis

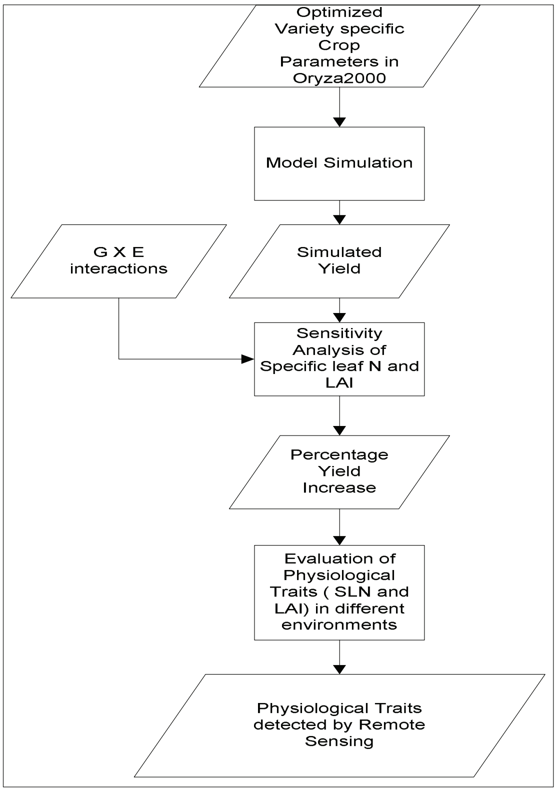


Figure 12: Methodological flow chart of Sensitivity analysis

3.6.1. Dynamics of LAI and Specific Leaf N

To test the sensitivity of remote sensing derived LAI and Specific Leaf N to yield prediction, the dynamics of these two traits were emphasized in the models' calibration as photosynthesis is greatly influenced by these two aspects and therefore biomass production. Sensitivity analysis was done as explained below;

- **Light extinction coefficient**

Light interception by the crop from sunlight is determined by the leaf area index (LAI) and the efficiency with which this light is used in photosynthesis depends on the leaf nitrogen content, (Bouman *et al.,* 2001) and it has been shown (Casanova *et al.,* 1998) that the light extinction coefficient (k) in rice, increases from 0.35 during the vegetative stage to 0.47 at panicle initiation and 0.62 post heading. In the crop data file of the calibrated model the light extinction coefficient (k) was reduced to 0.35 at vegetative stage for rice, increased to 0.47 at panicle initiation and increased further to 0.62 for post heading.

- **Temperature and Solar radiation**

A high LAI at heading has been found to increase yield as it causes a larger solar radiation interception ratio and N accumulation in rice has also been shown to increase with increasing temperature or intense radiation which in turn causes a large biomass accumulation (Takahashi *et al.,* 1976, Hirokawa *et al.,* 1993, Katsura *et al.,* 2008). N accumulation is also variety specific (Katsura *et al.,* 2008) as confirmed from plant N uptake obtained from remote sensing (Section 3.4.3, Figure 12 & 13). In the calibrated model the relationship between N accumulation and temperature were mimicked by increasing temperature in the early growth stages by 1^0C at 10 and 20 days after sowing for each field in the weather data file and maximizing LAI at heading. High temperatures at flowering have been shown to reduce yield when experienced at flowering as high temperatures induce spikelet sterility (Krishnan *et al;* 2007). Thus to improve the yield simulation in the initial model the daily maximum temperatures in between the periods when the varieties were flowering (70DAS) (Le Toan *et al.,* 1997) were reduced from 32^0C (Section 3.5.2) to 28^0C (Krishnan *et al;* 2007) as this was the period when the rice crop was flowering.

- **Seeding rates**

The effect of mutual shading in rice plants at high seeding rates was also taken into account during the simulation. High seeding rates have been shown to lower the photosynthetic rate per total leaf area (Osada, 1963) and increases respiration with total leaf area, which has a negative effect on yield (Yamada *et al.,* 1955). Thus the sites that had been underestimated but had high seeding rates as high as 300-400kg/ha were reduced to 100kg rice seed/ ha as recommended by IRRI (De datta and Nantasomsaran, 1991).

3.6.2. Maximization of SLN and LAI at Specific Phenological stages

To determine the physiological differences between the two rice genotypes that determine their ability to produce biomass and eventually yield in different environments, effects of maximizing LAI and specific leaf N at flowering were studied and partitioning coefficient of shoot dry matter to panicles between flowering and maturity on yield and biomass production of the genotypes (Manneh *et al.,*20 07). Maximum values for these three traits within the range of values observed in the genotypes at each growth stage were substituted in the calibrated model for each genotype in each environment and the model was then run. The percentage increase in yield and biomass over those of the calibrated ORYZA2000 model by maximizing LAI and specific leaf N were computed. The stronger the percentage of improvement in yield of a genotype, with a maximum increase in one of the traits meant that, that environment oppressed the expression of those traits. This would confirm whether simple remote sensing techniques can be used to determine the physiological deficiencies of rice genotypes with regards to SLN, LAI and yield in the different soil types of the Mekong delta.

4. Results

4.1. Primary Data Collection

4.1.1. Rice varieties

The rice farmers in the Mekong Delta grow a wide range of rice cultivars. From the 118 interviews taken, IR50404 was the most dominant cultivar grown in the delta during the first cropping season and had been planted in 45% of the sites, while 13 % grew rice cultivar, Jasmine 35. Traditional varieties included Butin, Neplun and ST5. Figure 13, below shows the abundance of varieties grown in the Mekong Delta.

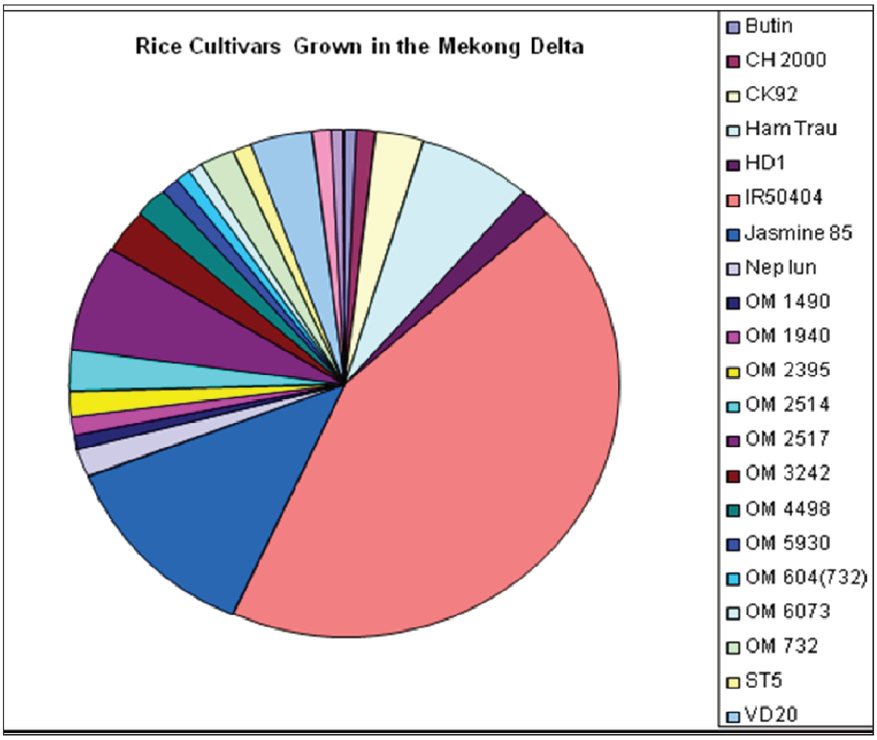


Figure 13: Rice varieties grown in the Mekong delta

4.1.2. Yield Data

Rice farmers in the Mekong delta measure yield in two forms. They report it as dry yield or wet yield. The former being a harvest that has been cut manually by a sickle and sun dried before selling it and the latter is sold just after harvest without sun drying. They measure yield quantity in what they refer to as 'big labour days' and 'small labour days'. Big labour days are equivalent to 1300 square meters of land and small labour days are 1000 square meters of their field patches.

4.1.3. Yield response of rice varieties

Results from the ANOVA showed that there were significant differences between the mean yield of the varieties (F = 3.020 with $P = 0.034$). The mean yield was 6000kg/ha. Error bars were plotted from standard error of the mean to visualize significant differences between the rice varieties (Figure 14). OM 3242 had the lowest yield response and the margin difference with CK 92 was by 2000kg/ha and OM 732 was 1500kg/ha. However the most dominant varieties, Jasmine 85 and IR50404 had similar mean yields of 6000kg/ha.

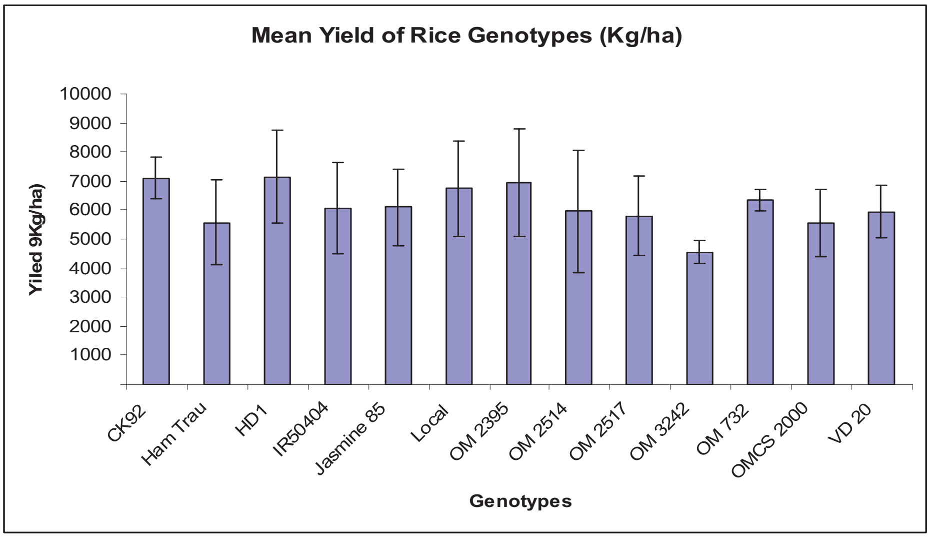
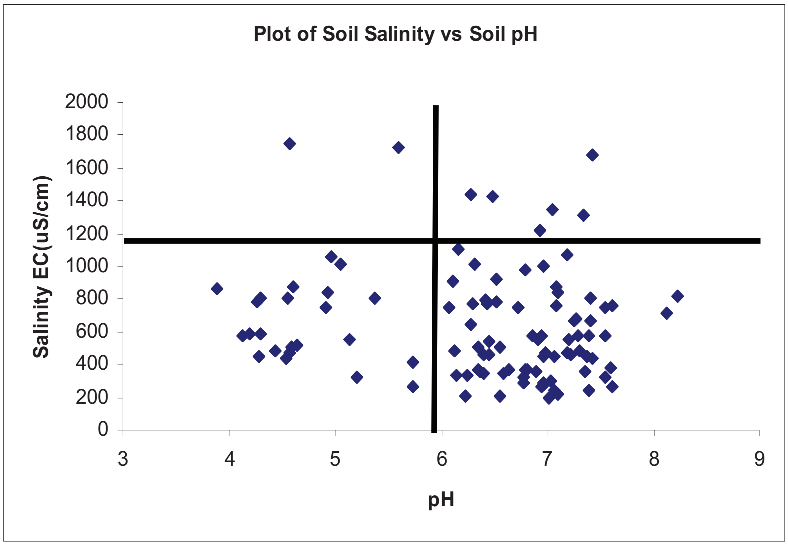


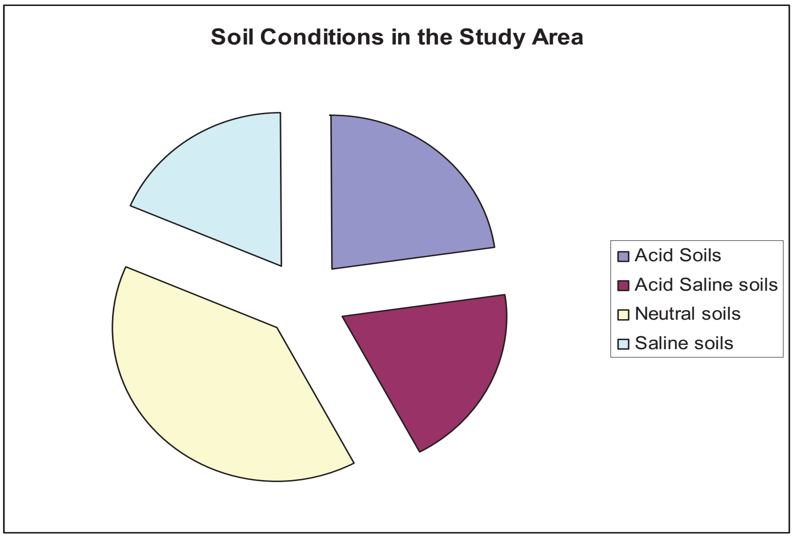
Figure 14: Yield performance of rice varieties grown in the Mekong delta

4.2. Soils in the Mekong Delta

The delta has a wide variation in soil types. This study considered the soil under pH 6 to be acidic and above 6 was neutral (figure 15a). Saline soils were those above Ec1200 uS/cm. The soils whose values fell in both categories were labeled, acid-saline. The distribution of soil in the study area is shown in figure 15b). 39% of the sites were covered by neutral soils, sites with saline soils were 19%, acid soils, 23% and acid saline soils were 20%. The most dominant variety, IR50404 was grown 31% in the acid sites and 31% in the neutral sites, while 24 and 13% of this variety was in acid saline and saline soils respectively.



a)



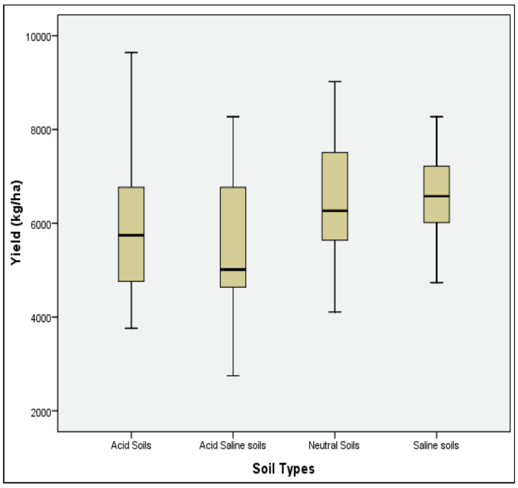
b)

Figure 15: Plot of Electrical conductivity of soil and pH (a) ; Pie chart of soil types in the study area (b)

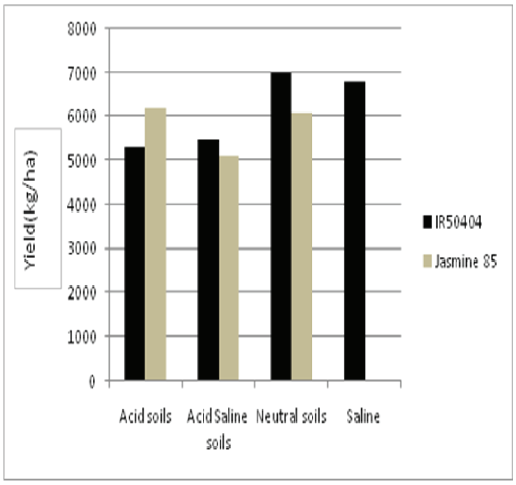
4.3. Genotype x Environment Interactions

4.3.1. Yield Distribution of Rice varieties in different soils types

A box plot was used to show yield distribution in all the soil types (Figure 16 a). The yield distribution is between 5000kg/ha and 7000kg/ha between the soil types. Analysis of variance showed that there was a significant difference between mean yield and soil types at $F = 3.020$ and P=0.0034 which is significant at, $P<0.05$. POSTHOC comparisons showed a significant difference at $P<0.05$, between the mean yields obtained in the acid saline soils with neutral soils and saline soils at P= 0.019 and P = 0.008 respectively.



a)



b)

Figure 16: (a) Yield distribution in different soils types. *Acid n = 22, acid saline n = 19, neutral n = 38, saline n = 18,* **(b) Yield of IR50404 and Jasmine 85 in different soil types**

The performances of Jasmine 85 and IR50404 were greatly influenced by the soil types as shown in figure 16 (b). Their yields were compared at acidic, acid saline, saline and neutral soils sites except Jasmine 85 was not planted by farmers in saline soils. IR50404 had the highest yield in the neutral soils and followed sequence; neutral soils > saline soils > acid saline soils > acid soils, while Jasmine 85 had the highest yield in the acid soils and followed the sequence; acid soils > neutral soils > acid saline soils.

4.3.2. Nitrogen dynamics and NDVI

Multi-temporal application of N fertilizer by farmers had a significant effect on NDVI as shown in figure 17 below. The NDVI was higher after 30 days after sowing (DAS) than after 10DAS at all levels of N applied by farmers. NDVI however was stable at low levels of N doses but fell significantly at higher levels of N doses, The difference between the required N from NDVI was subtracted from the site specific N applied by farmers and the result showed that farmers were applying more N in the acid and acid saline soils as shown in Figure (18). The excess N was as high as 8000kg N and 6000kg N in acid and acid saline soils respectively. The least was in the saline soils and yet was as high as 1500kg N.

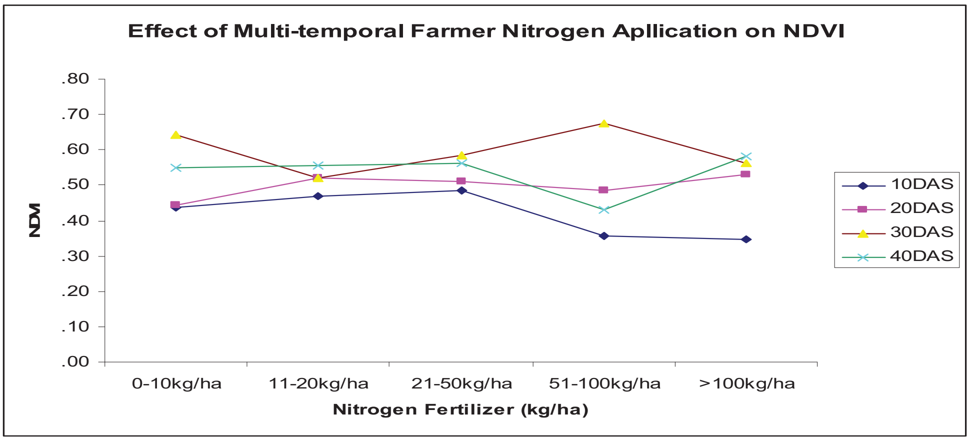


Figure 17: Effect of Multi-temporal N application on NDVI

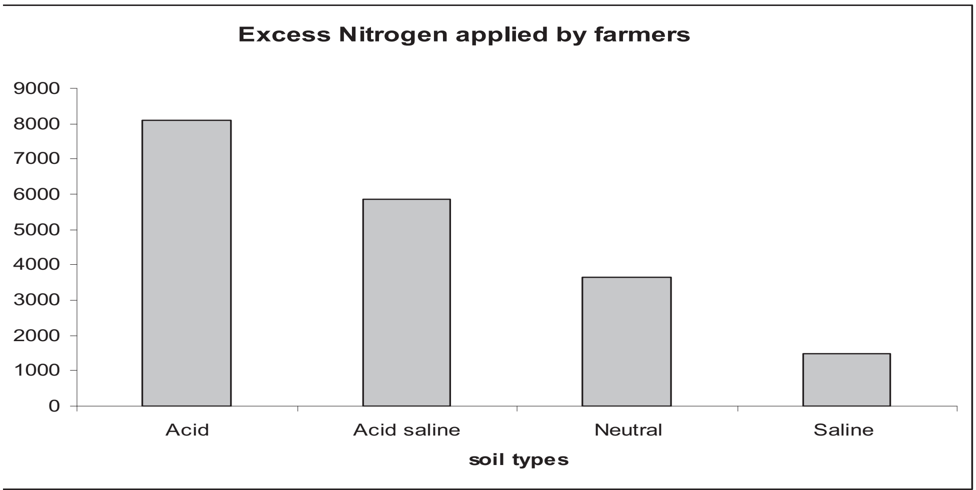
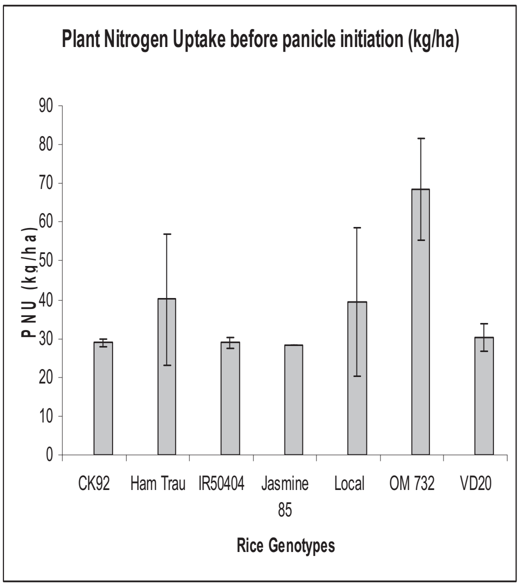
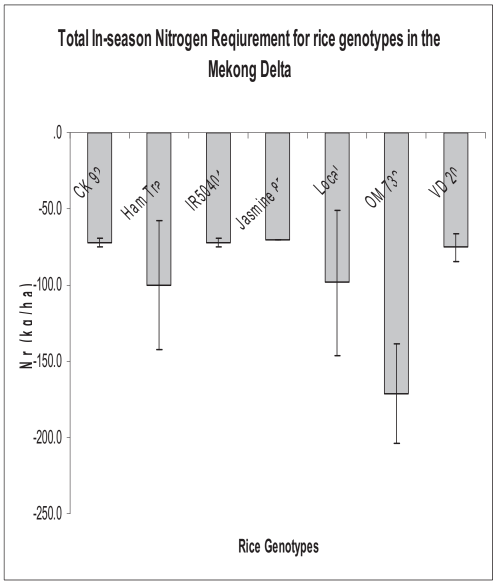


Figure 18: Excess Nitrogen applied by Farmers.

4.3.3. Genotype Specific in-Season Plant Nitrogen Uptake

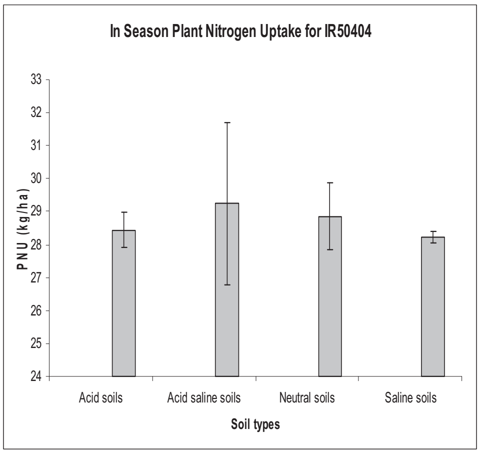
Analysis of variance showed that there were significant varietal differences (P<0.05) with in season plant nitrogen uptake obtained from NDVI with F= 4.114, P=0.021 and R^2 = 0.70. (Figure 19 a) total in season N requirement (Figure 19 b). IR50404 showed stability cross environments, while Jasmine 85 however was not stable in the different soil types. POSTHOC comparisons showed a P value of 0.025 between acid saline soils and acid soils. A P value of 0.006 was found between acid saline soils and neutral soils in Jasmine 85.





a) b)

Figure 19: (a) Variety specific in season plant N uptake before panicle initiation (b) Variety specific total in season N requirement calculated from NDVI (Errors bars show standard error from the mean).



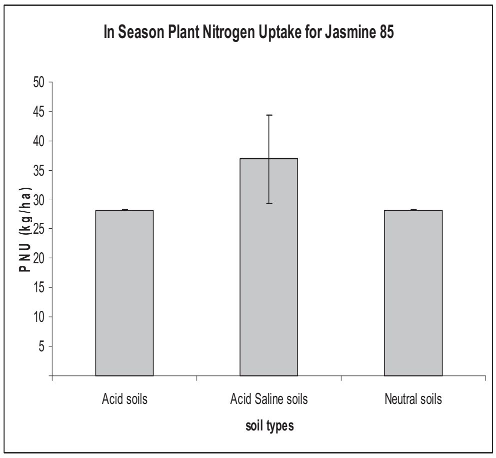


Figure 20: Variety specific in season plant N uptake before panicle initiation for IR50404 and Jasmine 85 in different soil types (Errors bars show standard error from the mean).

4.4. Rice Crop Map of the Mekong Delta

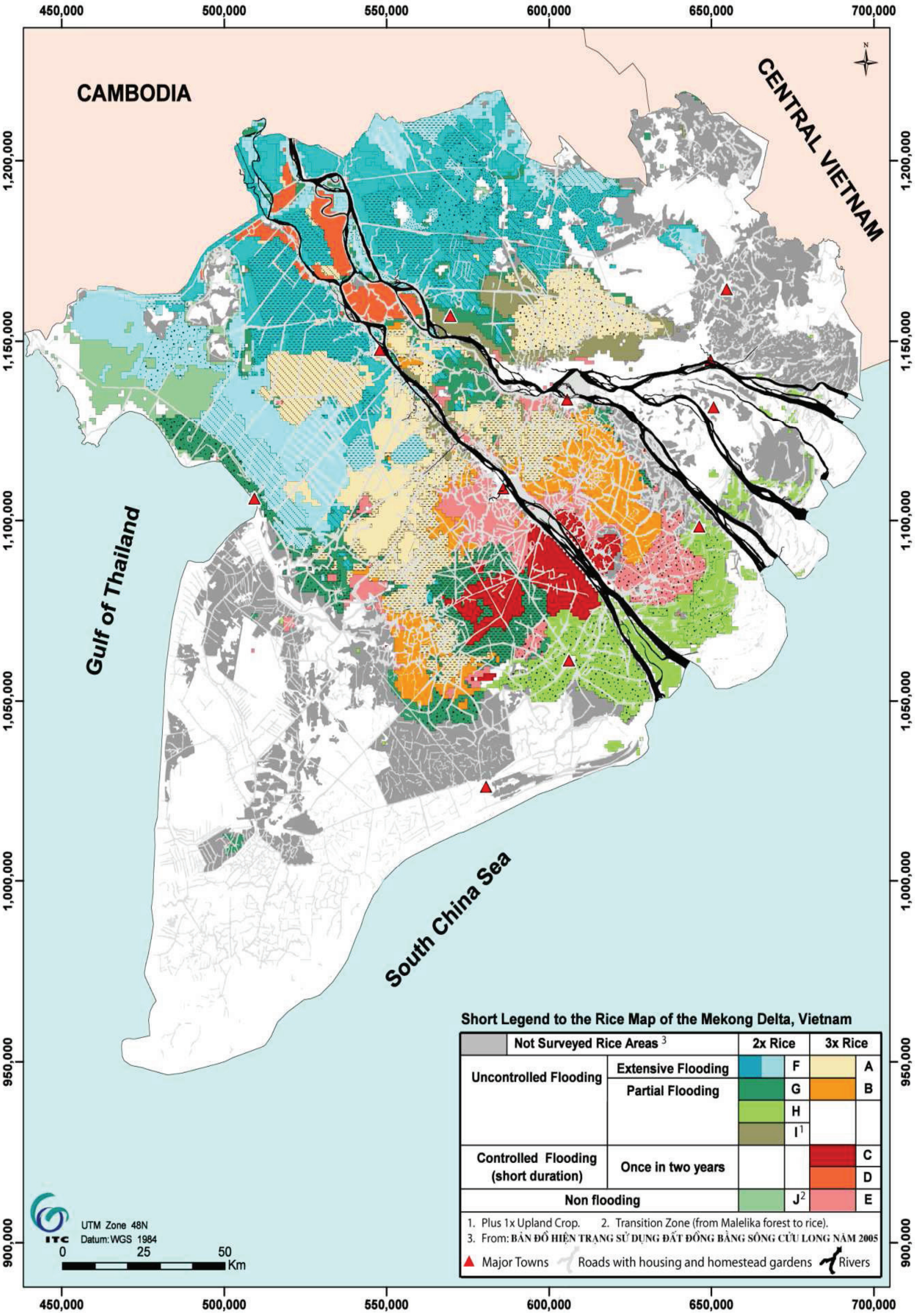


Figure 21: Rice crop map

4.4.1. Legend of the Rice Crop Map

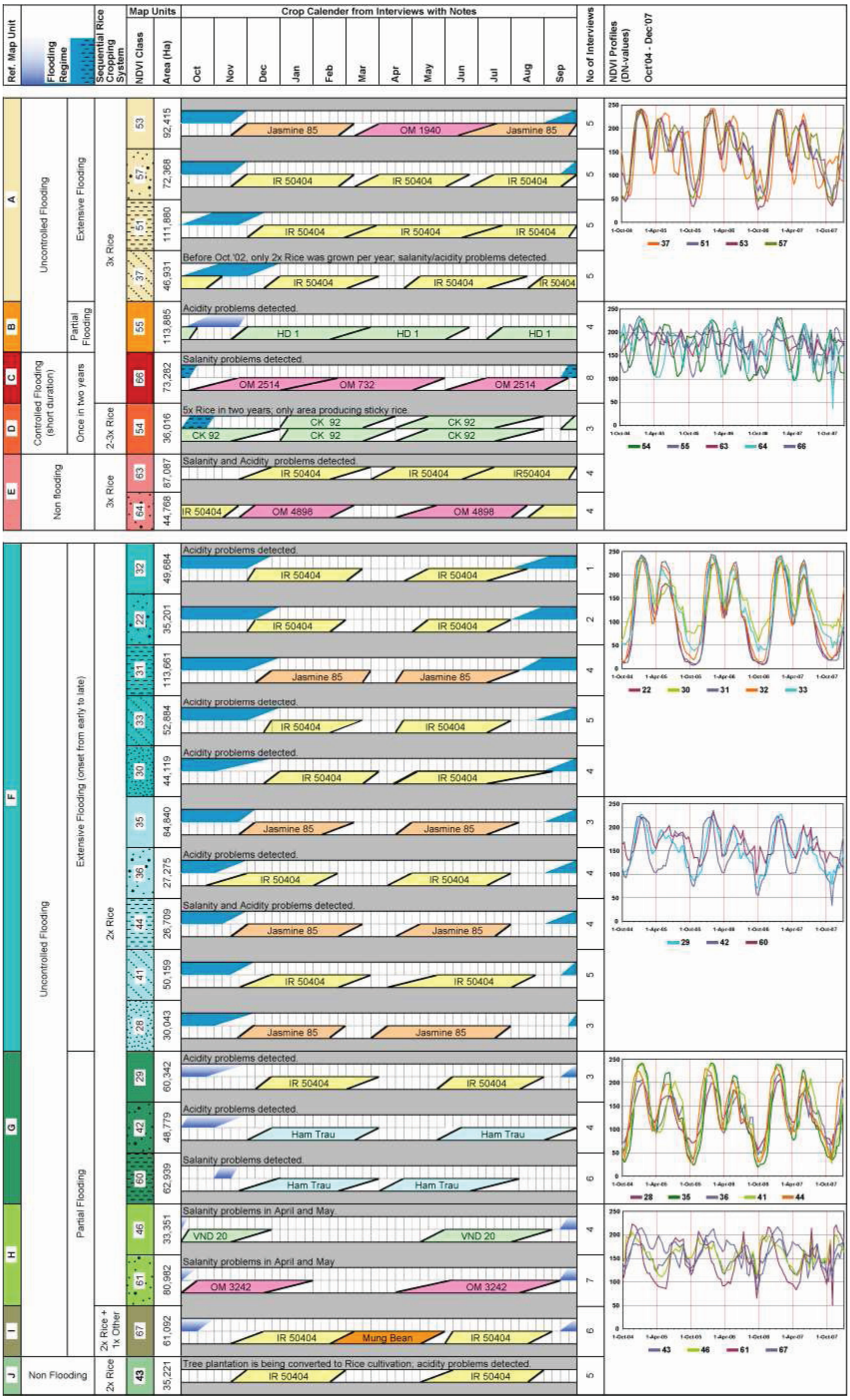


Figure 22: Legend of rice crop map

4.5. Evaluation of the Enhanced Model

Table 4-1: Regression parameters showing the relationship between simulated and observed yields of the Initial Model.

		n	Regression equation	R^2	F value	*P*	Mean	SD	SE
Site Specific	All genotypes	97	y = 0.9673x	0.6809	212.93	**	6022	1780	994
Genotype specific	IR50404	45	y = 0.5819x	0.7984	114.904	**	3684	812	370
	Jasmine 85	12	y = 0.922x	0.8821	87.60	**	5534	1879	656

*Significantly different at P<0.01**, significantly different at P< 0.05**

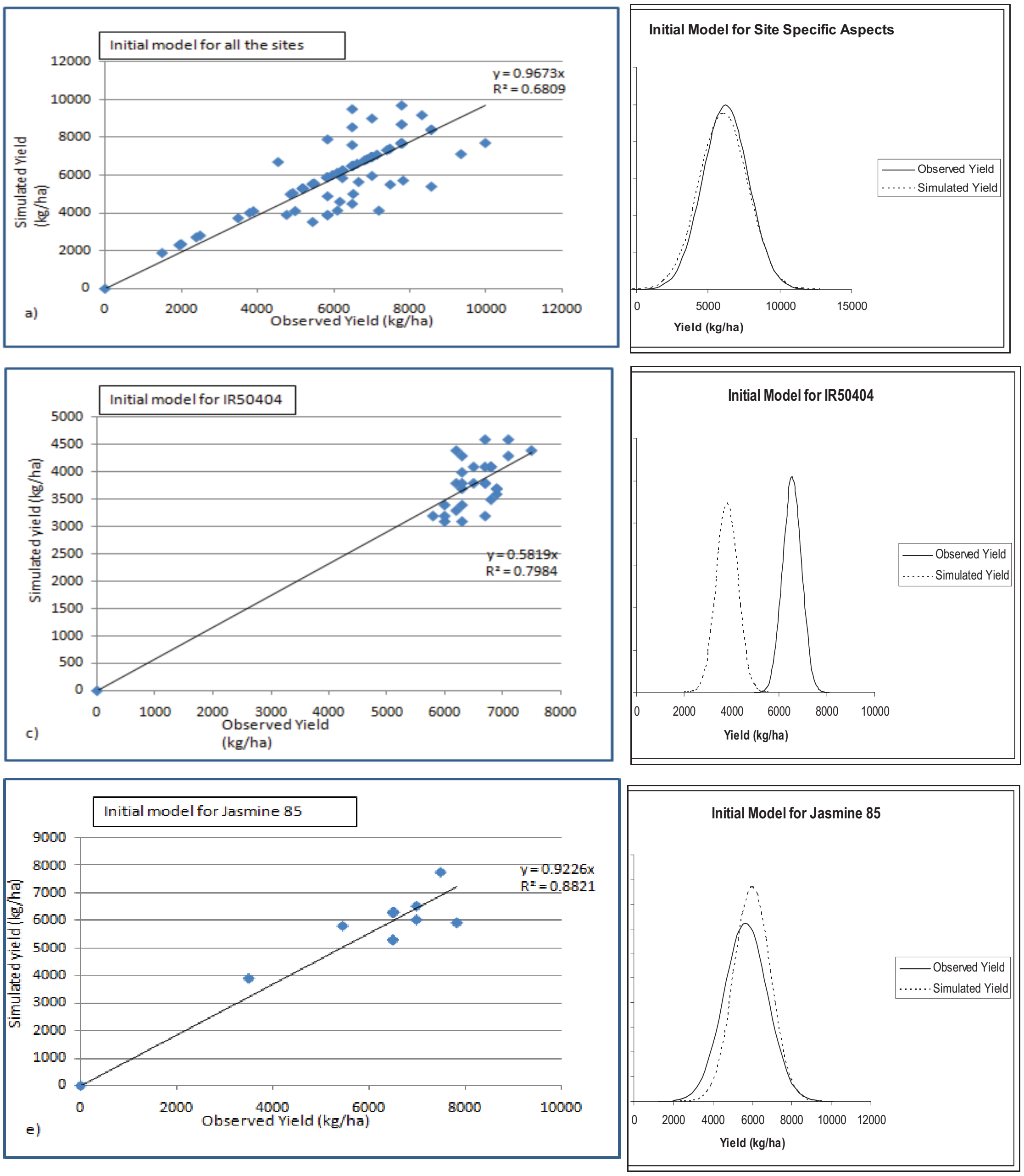
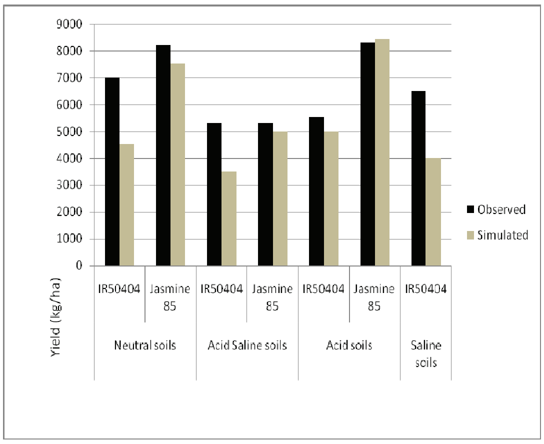


Figure 23: Plots of observed yields against simulated yields (a) and normal curves (b) for the calibrated model for IR50404

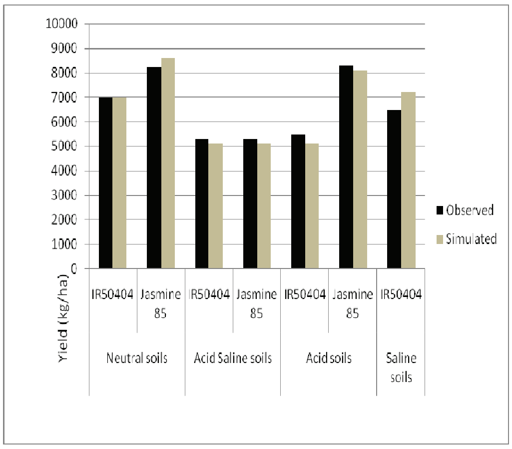
Linear regression was used to relate the value of simulated yield to observed yields (Table 4-1). When the model was simulated in all the three categories (by site for all the varieties, genotype specific for IR50404 and Jasmine 85), the standard errors of estimate were lower than the standard deviation and the R^2 were, 0.681, 0.798, 0.882 for all the sites, IR50404 and Jasmine 85 respectively. This implied that the enhanced model explained almost 70% of the variation of the predicted yield for all the sites, 80% for Jasmine 85 and 88% of the variance of the predicted yield for IR50404. However for IR50404, the simulated yield was grossly under estimated with a mean yield of 3600kg/ha and the normal curve away from the mean (Figure 23c). Though the enhanced model only explained 70 % of the variance for the site specific calibration, the mean yield was similar to the observed mean as shown by the normal curve in Figure 23(a). The normal curve for Jasmine 85 was shifted slightly away from the observed mean but the peak of the simulated was slightly higher implying it successfully explained the variance at R^2= 0.88.

4.6. Evaluation of the Enhanced Model for G x E Interactions

The model for the G x E interaction (Figure 24) underestimated the yield of both varieties in all the test environments except, Jasmine 85 was over estimated in the acid soils. From the observed yield data set, IR50404 had the highest yield in the neutral soils and followed sequence; neutral soils > saline soils > acid saline soils > acid soils, while Jasmine 85 had the highest yield in the acid soils and followed the sequence; acid soils > neutral soils > acid saline soils. The calibrated model predicted a highest yield performance in the neutral soils for both varieties. IR50404 was well estimated in the neutral soils and followed the sequence; neutral soils > saline soils > acid soils > acid saline soils. Jasmine however was over estimated in the neutral soils and followed the sequence acid soils > neutral soils > acid saline soil.



a)



b)

Figure 24: Simulated and observed yields of IR50404 and Jasmine 85 grown under different environments in the initial model (a) and calibrated model (b).

4.7. Sensitivity Analysis

Table 4-2 Regression parameters showing the relationship between simulated and observed yields of the calibrated Model.

		n	Regression equation	R^2	F value	*P*	Mean	SD	SE
Site Specific	All genotypes	97	y = 0.9879x	0.9019	212.93	**	6135	1654	994
Genotype specific	IR50404	45	y = 1.0884x	0.8064	114.904	**	6084	1654	520
	Jasmine 85	12	y = 0.9441x	0.9141	155.757	**	5948	2075	656

*Significantly different at P<0.01**, significantly different at P< 0.05**

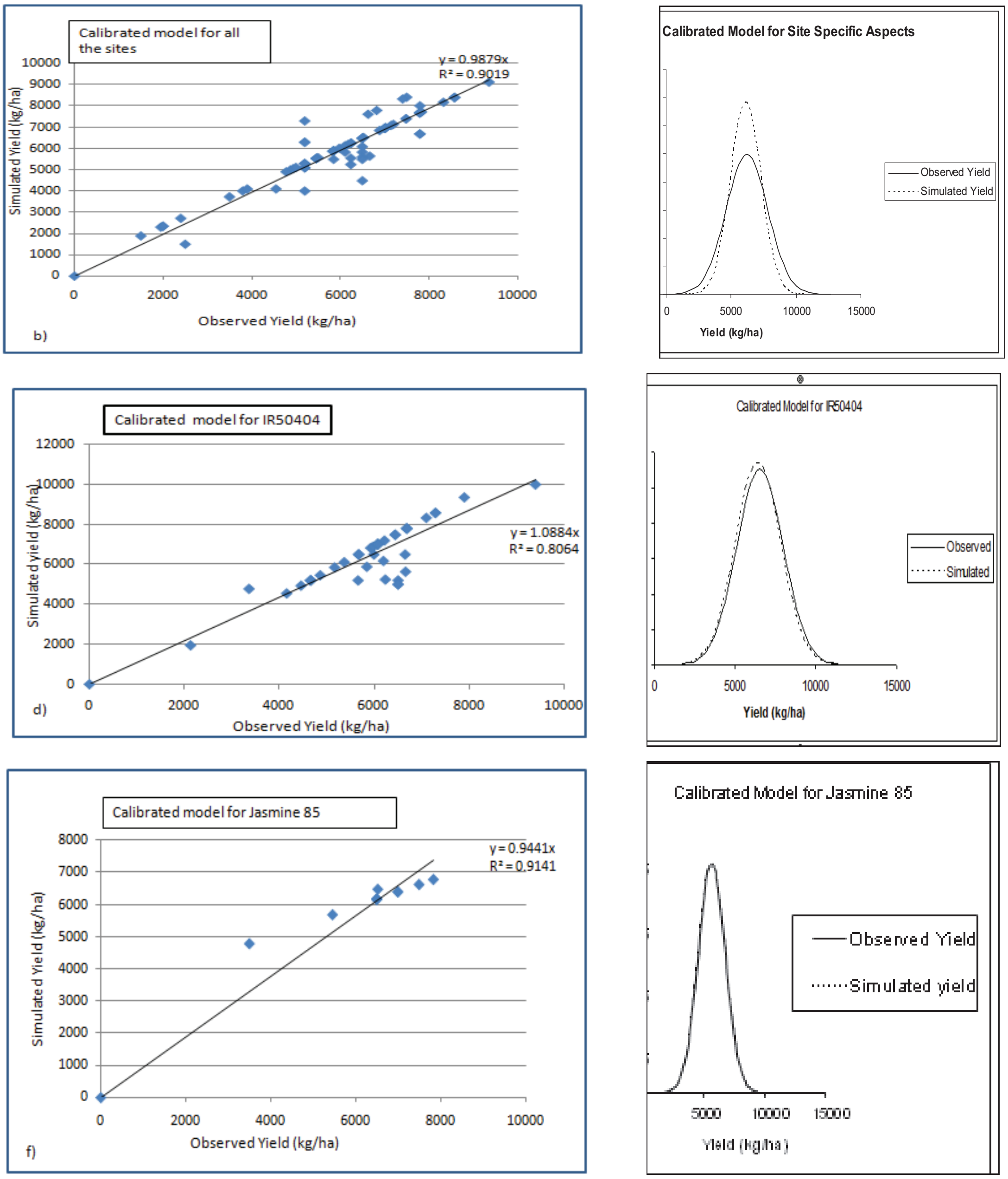


Figure 25: Plots of observed yields against simulated yields (a) and normal curves (b) for the calibrated model for IR50404

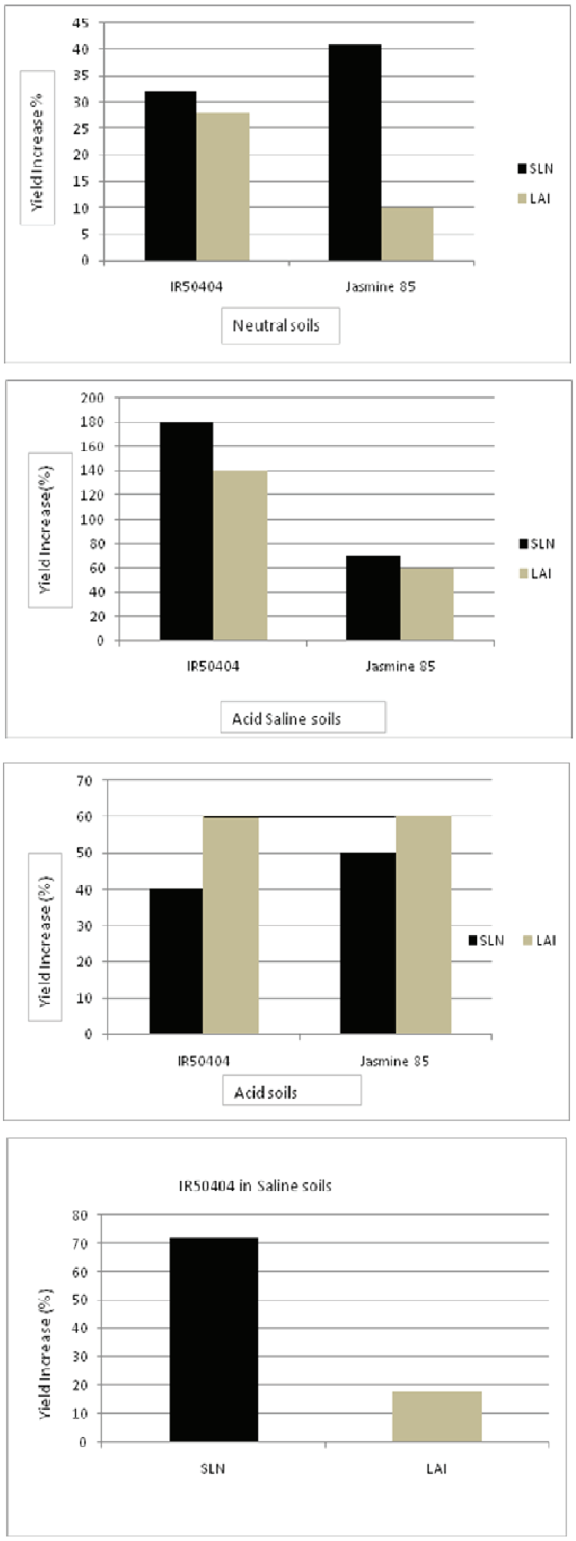


Figure 26: Potential yield increase (%) for IR50404 and Jasmine 85 after substituting maximum genotypic values in each environment for observed values of SLN and LAI at panicle initiation.

4.7.1. Dynamics of LAI and Specific Leaf N

The sensitivity of remote sensing derived LAI and Specific Leaf N to yield prediction, by adjusting factors affecting the photosynthetic activities of rice with respect to crop phenological stages, had a resultant yield increase from the initial model (Figure 25). When the model was simulated in all the three categories (by site for all the varieties, genotype specific for IR50404 and Jasmine 85), the standard errors of estimate were al lower than the standard deviation and the R^2 were, 0.90, 0.81, 0.91 for all the sites, IR50404 and Jasmine 85 respectively (Table 4.2). The normal curves of the simulated yield shifted more towards the mean of the observed yields. The potential yield increase was 14% for the site specific model, 0.6% for IR50404 and 2% for Jasmine 85. However, the prediction of IR50404 was greatly improved, with the mean of 6100kg/ha from to 3600kg/ha.

4.7.2. Maximization of SLN and LAI at Specific Phenological stages

The highest potential yield increase was in the acid saline soils for both SLN and LAI in both genotypes but especially IR50404 (Figure 26). The lowest potential yield increase was in the neutral soils. SLN had a larger influence on the potential yield increase than LAI in all the soil types except in acid soils. The effect of SLN was generally higher in IR50404 in acid saline soils and saline soils than Jasmine 85, however LAI for IR50404 was lowest in the saline environment than in any other environment. In the acid soils the potential yield increases in both varieties were generally low for both LAI and SLN. However it was much lower in IR50404 for SLN than it was for Jasmine 85 for this trait. The potential increase for LAI was the same in both varieties but higher than SLN.

5. Discussion

5.1. The Enhanced Crop Growth Simulation Model

The enhanced model well explained the observed dynamics of leaf area index and nitrogen fraction in leaves obtained from red (R) and near-infrared (NIR) regions, represented in MODIS' two 250-m spectral bands. It explained almost 70% of the variation of the predicted yield for all the sites, 80% for Jasmine 85 and 88% of the variance of the predicted yield. The potential yield increase was 14% for the site specific model, 0.6% for IR50404 and 2% for Jasmine 85 from the sensitivity analysis. Such predictions show that it is possible to include dynamic site specific management aspects and genetic parameters from remote sensing based techniques in a crop growth simulation model and satisfactorily predict yield in different rice genotypes. For site specific aspects the model predicts a higher potential yield increase and smaller yield increases (0.6% for IR50404 and 2% for Jasmine 85). This shows a cumulative effect of varietal differences.

5.1.1. Leaf Area index and Specific leaf N from Remote Sensing

The output of the simulation confirms that physiological traits such as photosynthesis rate and nitrogen uptake are closely related to yield (Hu *et al.,* 2007, Shan *et al.,* 2005) and LAI and leaf N content are traits that may be used in elevation of yield potential in breeding programmes (Chen *et al.,* 2008). The use of these traits to integrate genetic aspects into crop growth simulation modeling and improve prediction of final yield at the end of the growing season shows that remote sensing techniques can be important tools in introducing cultivar characteristics greatly influenced by the environment in gene based modeling for rice.

The output of the simulation has also shown that ORYZA2000 crop growth simulation model can be enhanced through the use of the dynamics of photosynthesis based on leaf area index and specific leaf nitrogen from remote sensing to explain the effect of G x E interactions to yield. For instance, there was a high G x E interaction between yields of genotypes in the different soil environments. Higher yields were obtained in the saline soils than in the acid soils but the combination of the two aspects (acid saline) significantly lowered yield in all the varieties. From sensitivity analysis the highest potential yield increase was in the acid saline soils for both SLN and LAI and genetic improvement can be emphasized in these traits for this environment. The lowest potential yield increase was in the neutral soils meaning that both genotypes were not deficient in the traits (SLN and LAI) in this particular environment. This was also confirmed with both genotypes registering the highest yields in the neutral soils.

The considerably high SLN for IR50404 in the saline environment than LAI implies that IR50404 is a salt sensitive genotype and is deficient in the trait of SLN for this environment and this could be the reason why the calibrated model overestimated its yield in the saline environment. Genetic improvement for this variety should be directed to SLN than LAI. This phenomenon agrees with studies that salt stress enhances the synthesis of N- containing compounds in leaves (Faustino *et al*., 1996) and reduces photosynthesis (Chattopadhayay *et al.,* 2002) which affects prediction of yield of rice genotypes in simulation models such as ORYZA2000. Such physiological changes are likely to affect salt sensitive cultivars of rice than tolerant ones (Manneh *et al.,* 2007) this could explain the over estimation of yield of this genotypes in the saline environment by the model and yet maintained a high level of SLN. Phenotypic responses of rice cultivars to salinity stress are genotype specific and are influenced by QTLs. Tolerant genotypes tend to exclude salt from flag leaves and developing panicles (Yeo and Flowers, 1986). QTLs for ion exchange (q NAUP-3) and green leaf area index (q LAI-3) have both been mapped on chromosome 3 in an Iranian rice population (Sabouri and Sabouri, 2008; Nejad *et al.,* 2008).

In the acid soils both genotypes are generally more deficient in the trait for LAI than SLN. This could be the reason why the model under estimated their yields in these environments. The lower potential yield increase for IR50404 confirms that this genotype is acid tolerant than Jasmine 85 although the latter had the highest yield in this environment from observed yield data than the former. This could be attributed to the limited number of replicates that Jasmine 85 had for this environment. For Jasmine 85, SLN and LAI had a generally low but similar yield increase in both the acid and acid saline soils, implying that it also acid tolerant. The farmers seem to be aware of this fact and did not plant Jasmine 85 in the saline soils but only in the above mentioned environment.

5.1.2. Dynamic Site Specific Management aspects

5.1.2.1. Choice of Rice genotypes

It is a challenge for plant breeders to capture dynamic site specific management aspects during genetic improvement of crops as they are dependent on varying environmental conditions that also include management choices made by farmers, who are faced by a wide range of alternatives. For instance, this study discovered that in the Mekong delta, the spatial attribute of long and short duration varieties depended on the temporal aspects of the flooding regime of the Mekong River. Some of the longer duration varieties such as the local varieties and CK92 (‘sticky rice’) had a higher yield than some shorter duration varieties. However, long duration varieties were grown in a single or double crop system in areas where the flooding receded once or twice a year. The shorter duration varieties would be cultivated to up to seven cropping seasons in a period of two years in areas with shorter flooding regimes. Another site specific aspect was the dominant varieties grown in the delta during the cropping season between October 2007 and March 2008 were IR50404 and Jasmine 85. However the presence of these varieties is also gender specific. Male farmers prefer IR50404 for its high yield and shorter duration while female farmers prefer Jasmine 85 for its high grain quality and aroma that fetches high prices for this variety (Truong Thi Ngoc *et al.,* 2007). IR50404 is a mid duration improved indica-type variety from IRRI (International Rice Research Institute in the Philippines). It is popular for making rice noodles and griddle cakes and is generally considered of low grain quality but high yielding (Vietnam business finance, 2008). It is more tolerant to the acid sulphate soils and brown plant hopper in the delta while Jasmine 85 is more susceptible.

5.1.2.2. Nitrogen Fertilizer Application

Total in-season N requirement estimated from remote sensing was able to quantify the environments that had excess N applied. The sequence of this estimation was acid > acid saline > neutral > saline while the general yield performance was in the sequence neutral > saline > acid > acid saline. This showed that where more nitrogen was estimated, negatively affected yield in the different environments. Farmers applied more N in the acid and acid saline soils and obtained the lowest yields in these soil types. This implies that remote sensing can be used as a tool to recommend in season fertilizer rates to farmers in the Mekong delta. This supports studies by (Xue and Young, 2008) that in rice, NDVI can be used, to estimate site specific nitrogen topdressing recommendations. The low yields in these environments (acid and acid saline soils) could also be attributed to the fact that flooding has the effect of flushing acid soils and depositing fertile sediment into the flood plains (Cao, 1998), therefore high N fertilizer rates are not only detrimental to yield but also unnecessary and costly with diminishing returns to both the farmer and the environment.

5.1.2.3. Planting Dates

The under estimation of IR50404 in ORYZA2000, by the enhanced model seemed to be systemic. This was attributed to the high maximum temperatures in October, as most of all the farmers that grew IR50404 had a similar planting dates ranging from 24th-27th of October 2007. These maximum temperatures were as high as 34^{0}C at this period and during the approximated flowering period between January and February of 2008 (Section 3.4.3, Figure 9). Such high maximum temperatures have been found to significantly reduce yield of rice as spikelet sterility is induced by high temperatures (Krishnan *et al*., 2007). Maximizing the value of the extinction coefficient at panicle initiation and reducing maximum temperature to 28^{0}C at flowering resulted in a potential yield increase all three categories.

The simulation shown that temperature, contributes significantly to yield performance in rice through its effect on phenological development rate or growth duration and spikelet sterility (Prasad *et al.,* 2006) and yield an be increased by adapting sowing dates to make temperatures more favourable during grain filling and reducing on seeding rates to 100 kg/ha.

6. Conclusion and Recommendations

6.1. Answers to Research Questions

Research Question 1: Can genetic parameters that reflect impacts of site specific management aspects be integrated into a remote sensing based crop growth simulation model and accurately predict yield?

Answer: Evaluation of the enhanced model explained 70% of the variation of the predicted yield for all the sites, 80% for Jasmine 85 and 88% of the variance of the predicted yield for IR50404.

Research Question 2: How can a remote sensing based crop growth simulation model be calibrated with genetic parameters that reflect impacts of site specific management aspects?

Answer: The experimental data file of ORYZA2000 can be used to include site specific management aspects and the crop data file can be used to include the genetic parameters as functions of developing stages and the remote sensing variables switched to forcing.

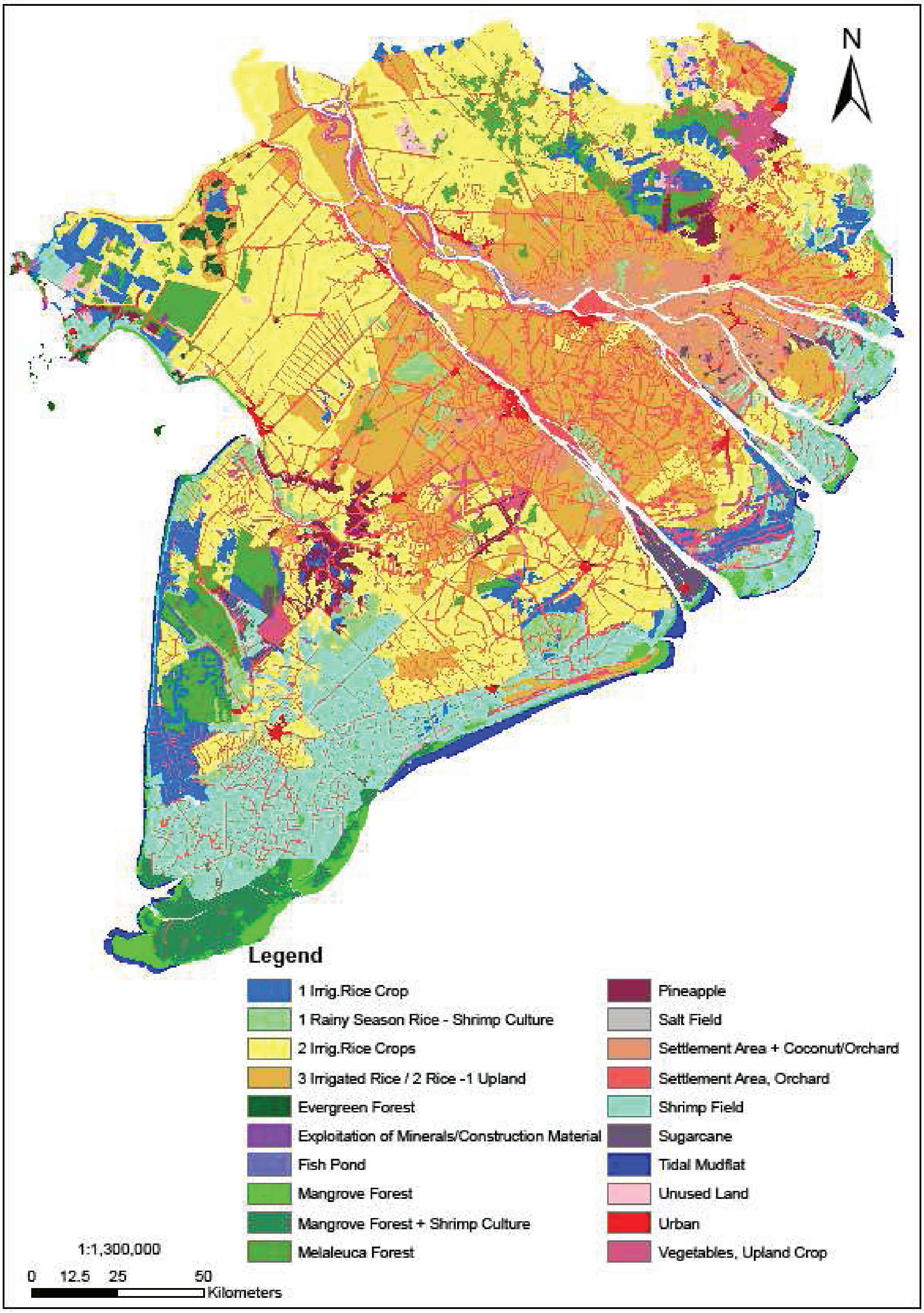
Research Question 3: Can remote sensing based techniques be used to detect physiological traits of rice genotypes?

Answer: The output of the simulation and sensitivity analysis shows that and LAI and leaf N content can be obtained from remote sensing techniques and can be important tools in introducing cultivar characteristics greatly influenced by the environment in gene based modeling for rice and are traits that can be used in elevation of yield potential in breeding programmes

6.2. Overall Conclusion

Generally, there was a yield gap of at least 2000kg/ha between the farmers' yield and the on station yield for these genotypes (Appendix5). This yield gap is attributed to both the impact of weather variability on crop production and site specific crop management options. The crop growth simulation model, calibrated with genetic aspects from remote sensing based techniques and dynamic site specific aspects can reduce on the duration of costly multilocational trials aimed at improving rice varieties in different environments. Remote sensing based techniques can also be used as a decision making tool for plant breeders to develop rice varieties with specific general adaptation to genotype x environment interaction occurring in rice yields in the range of environments including site specific management aspects that are based entirely on farmer decisions and weather conditions. This study therefore, recommends a more participatory approach in breeding programmes between farmers and plant breeders. It also recommends that farmers reduce the levels of N applied in the acid and acid saline soils these high inputs can be detrimental in stress environments under changing weather conditions.

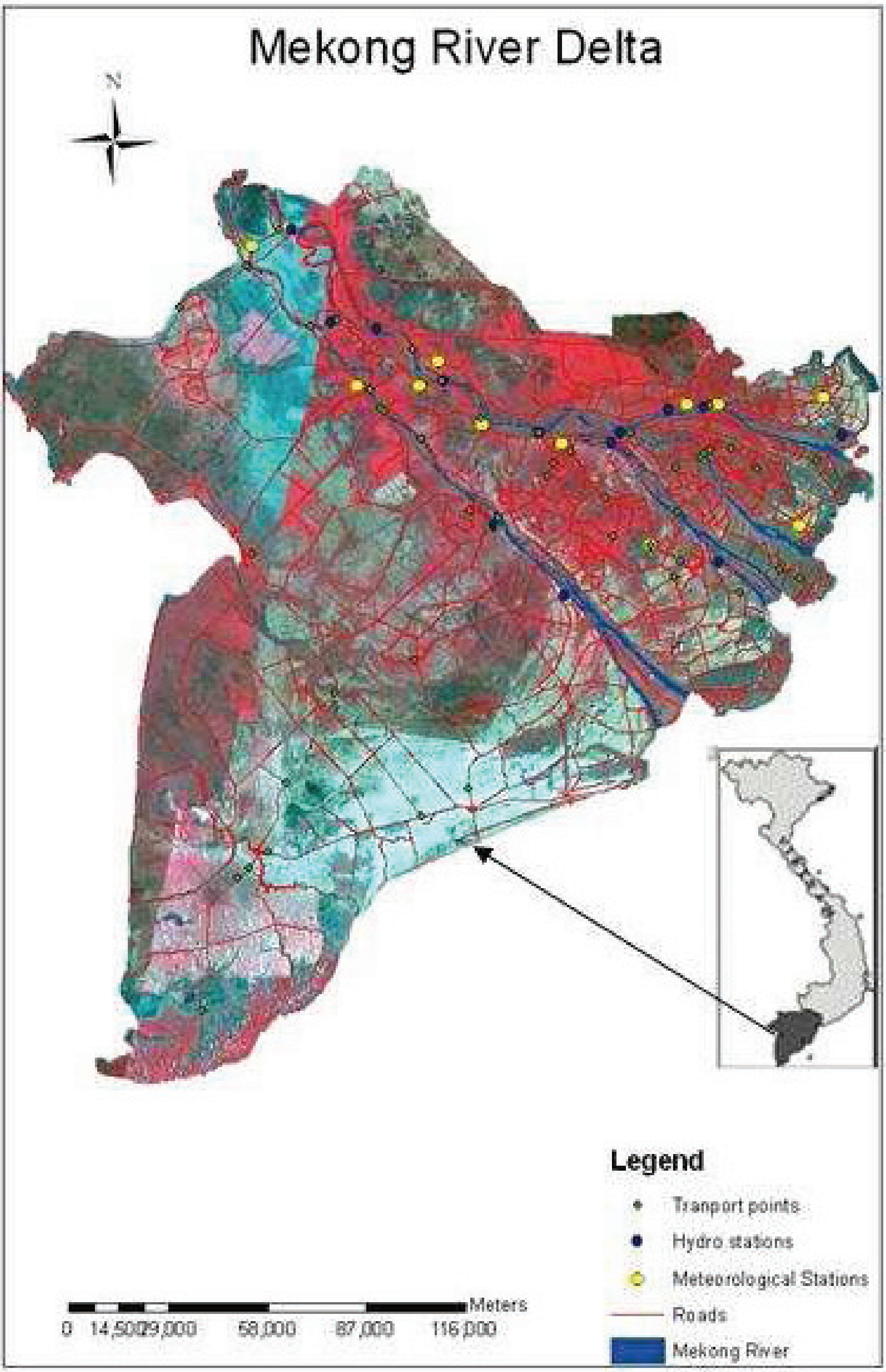
Appendix 1: Mekong Delta Land use Map of 2002



Appendix2: Checklist of the data collected from the field.

Questinnare Number	------------------------
Crop Calender	Planting date Rice genotype planted Harvesting date
Site Specific Managent Aspects	Seeding rate Sowing method Seed quality (Certification) Time of fertilizer application Type of ferlilizer applied Ammount of fertlizer applied
Yield	Yield obtained (kg/ha) Harvesting method Yield sold (kg/ha) Expected yield
In Season Problems	Pests Diseases Soil Water management Weather Yield loss Problem management
Soil	Acidity Salinity Acid - Saline Neutral

Appendix 3: Map showing Meteorological stations in the Mekong delta



Appendix 4; Soil Analysis

Salinity

The soil samples were transferred to plastic trays for air drying at room temperature. Proper labeling was done carefully to avoid errors during transfer. Large plant residues were removed. Soluble salts in the samples were determined by measuring the cations and anions in water extracts. Salinity of the soil was assessed by electrical conductivity of the extract. The saturation extract method was preferred because it gives a better representation of field conditions (ISRIC, 1993).

Preparation of the Extract

Apparatus; Filter funnel, Buchner funnel with small suction / receiving flask (50 or 100ml),vacuum pump (electrical water jet, Polyethylene bottles, wide mouth, 250ml and a reciprocating shaking machine. Reagents; 0.1g of 0.1% Sodium hexametaphosphate $(NaPO_3)_6$ solution in water diluted to 100ml and Thymol.

200g of fine earth was placed into 500ml plastic beakers with a snap tight lid. Crystal thymol was added to reduce bacterial growth and just enough water was added to saturate the sample. The sample was then stirred gently with a spatula while adding water and soil to reach a condition of saturation. The condition of saturation was confirmed by free water not collecting on the surface when the beaker is tapped on the bench, glistening of the paste as it reflects light and slightly flowing of the paste when the beaker is tipped. The beakers were left to stand overnight and two beakers with 50 ml of water to stand as blanks. The next day the paste was checked on the above criteria. The paste was transferred in Buchner funnel by using a hardened, low speed filter paper. Suction was applied to collect the filtrate. Turbid filtrate was returned to the funnel. After filtration pH was immediately measured in the extract. After filtration , the extract was diluted 10x and 100x by pippetiong5ml of extract into a 50 ml volumetric flask and 1ml into a 100ml volumetric flask respectively.1 drop of 0.1 % $(NaPO_3)_6$ solution to the remaining extract to prevent precipitation of $CaCO_3$.

Electrical Conductivity

Apparatus; Conductivity meter with dip cell and pipette cell. Reagent; 0.01M. Standard potassium chloride solution.

30ml standard 0.01M KCL solution were transferred to a 50ml beaker and the temperature measured. The pipette cell was rinsed and filled with standard KCL solution. The temperature compensation dial was set at measured temperature and the reading of the meter adjusted to 1.412mS/cm with cell constant dial (the specific conductivity standard 0.01 M KCL solution at 250C).

The temperature of the extract was measured the temperature compensation dial was set at this temperature (The reading was then automatically corrected to 250C). The dip cell was inserted in the extract and the conductivity was read.

pH Test

Apparatus; pH meter with glass-calomel combination electrode and a reciprocating shaking machine.

Reagents; 1M Potassium chloride solution, buffer solutions, pH 4.00, 7.00 and 9.00(or 10.00) to calibrate the pH meter with buffer solutions for the range in which it was measured.

20g of fine earth were weighed and placed in a 100ml polyethene wide mouth type bottle. 50ml of 1M KCl solution were added and the bottle caped. The mixture was shaken for two hours, and shaken again by hand once or twice before opening the bottle for measurement. The electrode was immersed in the upper part of the suspension and the pH was read when the reading had stabilized to a 0.1 accuracy unit.

Appendix 5: Yield and Yield component of rice varieties grown in the Mekong Delta

Variety	**Duration (days)**	**Plant height(cm)**	**1000 grain weight(g)**	**Yield (kg/ha)**	**Aroma (scale)**
OM2514	95-100	100-105	25-27	6000-8000	0
OM5930	95-100	100-105	25-26	5000-7000	0
OM3242	90-95	90-100	26-27	5000-7000	0
OM576	105-110	90-95	26-27	5000-8000	0
OM6073	95-100	95-100	26-27	5000-8000	0
OM2717	90-95	105-110	22-24	4000-7000	0
OMCS2000	93-95	93-95	25-26	5000-8000	0
OM1490	90-95	95-100	25-26	4000-7000	0
OM4498	90-95	95-100	25-27	6000-8000	0
OM2395	95-100	90-100	27-28	5000-7000	0
OM3536	90-95	90-100	26-27	4000-6000	0
HD1	95-100	95-100	27-28	5000-7000	0
ST5	110-120	110-115	27-28	4000-6000	1
IR50404	85-90	80-90	27-28	5000-8000	0
Jasmine 85	105-110	90-100	26-27	4000-8000	2

Source: Cuu Long Delta Rice Research Institute, CoDo, Can Tho, Viet Nam.

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