RICE CROP MONITORING SYSTEM
BASED ON MODELLING APPROACH

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BOGOR AGRICULTURAL UNIVERSITY
BOGOR
2012
STATEMENT

I, Yunus Bahar, hereby stated that this thesis entitled:

RICE MONITORING SYSTEM
BASED ON MODELLING APPROACH

is a result of my own work under the supervision advisory board during the period January until June 2012 and has not been published before. The content of the thesis has been examined by the advising the advisory board and external examiner.

Bogor, July 2012
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ABSTRACT

YUNUS BAHAR. Rice Monitoring System Based on Modelling Approach.
Under supervision by HANDOKO and IBNU SOFIAN

West java provinces is a central rice production in Java islands and contribute more than 30% of total rice production in Java islands. Even though the irrigation paddy field area dominant, the weather condition still influence rice production in that province. The objective of this study is design rice crop monitoring system based on weather variable and leaf area index which all the input derived by remote sensing and Numerical Weather Prediction (NWP). Combination several sources of active and passive remote sensing data with NWP data as an input for crop simulation model successful to monitor rice yields in West Java province. The rice crop yield during 2004 until 2008 is 52.9 Kw/ha, 46 Kw/ha, 40.7 Kw/ha, 52.7 Kw/ha, and 49.5 Kw/ha respectively. During 2004 - 2008, the error of the model ranged from 2.9% until 22.9% at West Java province while in regency level was varied from 0.2% until 49.3%. The coefficient of determination (r²) between result of the model with reference data was 0.7 in rice production analysis during 5 years simulation. Results of the model were more accurate in La-Nina. In El-Nino events, the farmer in several regencies such as Karawang, Indramayu and Bekasi uses irrigation to irrigate the paddy field. Consequently, the rice production not directly decreased in those regencies like simulated result of the model.

Keywords: El-Nino, La-Nina, crop simulation model
ABSTRAK

YUNUS BAHAR. Sistem Monitoring Padi berdasarkan Pendekatan Pemodelan. Dibawah bimbingan oleh HANDOKO dan IBNU SOFIAN

Provinsi Jawa Barat merupakan daerah penghasil padi utama di Pulau Jawa yang menyumbang lebih dari 30% total produksi padi di Pulau Jawa. Meskipun sebagian besar sawah di Jawa Barat merupakan sawah irigasi namun kondisi cuaca mempunyai pengaruh yang besar pada provinsi tersebut. Tujuan penelitian ini adalah merancang system monitoring tanaman padi dengan menggunakan data cuaca dan indeks luas daun yang diperoleh melalui penginderaan jauh dan prediksi cuaca numerik (NWP). Kombinasi beberapa sumber penginderaan jauh aktif dan pasif serta data prediksi cuaca numeric sebagai masukan dalam model simulasi tanaman berhasil dengan baik memantau produktivitas tanaman padi di Provinsi Jawa Barat. Produktivitas tanaman padi berturut-turut selama tahun 2004 sampai 2008 adalah 5.3 ton/ha, 4.6 ton/ha, 4.1 ton/ha, 5.3 ton/ha, dan 5.0 ton/ha. Selama tahun 2004 sampai 2008, persentase kesalahan prediksi oleh model berkisar dari 2.9% sampai 22.9% pada level provinsi sedangkan pada level kabupaten berkisar dari 0.2% sampai 49.3%. Nilai koefisien determinasi ($r^2$) untuk hasil model dengan data acuan adalah 0.7 dalam analisis produksi padi selama 5 tahun simulasi. Hasil model lebih akurat pada tahun La-Nina. Pada tahun El-Nino, petani di kabupaten Karawang, Indramayu dan Bekasi memanfaatkan irigasi untuk mengairi sawahnya. Akibatnya, produksi padi di kabupaten tersebut tidak secara langsung menurun seperti hasil simulasi model.

Keywords: El-Nino, La-Nina, model simulasi tanaman.
SUMMARY

YUNUS BAHAR (2012). Rice Crop Monitoring System Based on Modelling Approach. Under supervision by HANDOKO and IBNU SOFIAN.

Rice is a primary food for 95% of around 220 million people living in Indonesia. Climate variability such as El-Nino has been slowed rice production in Indonesia. A useful way to understand and provide quantification the effects of climate variability on crop yield is to simulate the growth of a crop using computer modeling. As an example of crop simulation model, Shierary-Rice model has tested and suggested to be applied in different locations in Indonesia. Shierary-Rice model is a mechanistic growth model describing the rice growth as a function of weather variables with physical and chemistry soil properties. However, conducting calibration procedure is critical for another study region.

Crop growth model have been used successfully in predicting crop yields at the field level. These models require numerous inputs that are specific to the crop, soil characteristics, management practices and local climatic conditions. These models have had limited use because fewer input are generally available at larger than field scales. Additionally, satellite remote sensing technology has been shown to be capable of providing certain crop characteristics and real-time snapshots changes in conditions affected by the weather related events. MODIS and MISR together allow for rich spectral and angular sampling of the reflected radiation field. The spatial resolution (250 m – 1 km) and temporal (daily) coverage of MODIS data offer potential for retrieval of crop biophysical parameters and improve accuracy in crop yield assessment.

The spatial and temporal variability weather conditions are important sources when applying crop simulation models over large areas. Integration several sources of active and passive remote sensing data with Numerical Weather Prediction (NWP) product is a way find timely weather variables as an input model for a crop yield system with sparse coverage of weather stations. The first objective of this study is developing system for monitoring growth and yield of rice crop based on weather variable and MODIS satellite imagery. Second, estimating and comparing rice crop yields with statistical data those are issued by Central Bureau of Statistics (BPS).

The system was test in West Java province which is located between longitude of 106° 22’ 13.8” E to 108° 50’ 1.8” E and latitude of 50° 54’ 49.6” S to 70° 49’15.5” S with the total paddy field area of approximately 2 million Ha where spread over 16 regency. The simulation was run in January and September over 5 year simulations in order to match with BPS data. The research integrated numerical model, remote sensing and Geographic Information System (GIS) as a system to monitor growth and development of rice crop. Rice simulation model adopted the shierary-rice model (Handoko 1994) that comprises three sub-models, development (phenology), growth, and water balance. Interaction among three sub-models was determined by daily fluctuation of weather elements. Input for daily weather variables such as temperature, Relative Humidity (RH), solar
radiation, wind and rainfall data during the period of five year (2004-2008) simulations came from NWP product and Tropical Rainfall Measuring Mission (TRMM) data. The temperature was corrected by adding DEM data. There are quantitative and qualitative technique used to validate results of the model.

All of weather variable was converted into ASCII format. The spatial resolution of weather variables was re-grid into 1 x 1 km. All of dataset including MODIS LAI were translated into XYZ format where X, Y, and Z were longitude, latitude, and value of data respectively. Monitoring rice crop would run in regency level. Further, all of dataset would uses as an input for running Shierary-rice model.

The coarse resolution of weather variables is able capturing climate variability West Java. The yearly temperature for 5 years varied from 10 °C until 26 °C. The minimum temperature associated with high elevation which it located on top of mountain while the maximum temperature founded near of low-land area. The yearly precipitation in the study area varied from 2143 mm to 2864 mm per years. The lowest yearly rainfall was found in El-Nino years (2006) while the highest was seen in La-Nina years (2008).

Reference data (BPS) shown the yield has increased 0.5 t/ha during 5 years. But the rate increased has slowed in period 2004 until 2005 and constant from year 2005 until 2006 year. The yield from the model fluctuated a lot and tended decreased over the period of 5 years. The differences between model and BPS in year 2004 is 0.2 t/ha, rises 0.5 t/ha in year 2005, becomes more than five times from 2004 with 0.11 t/ha in year 2006 and slow down with 0.6 t/ha in 2007. The close difference between model and BPS data found in 2007 with 0.1 t/ha. Based on the example of yield images in 2006 and 2008, was generated by the model. It shows a large visual contrast especially in the north region of West Java province between year 2006 and year 2008. In year 2006, the yields from Bekasi, Karawang, Subang, and Indramayu regency were varied starting from below 3 t/ha until 4 t/ha while in year 2008 it ranged from 3 t/ha until 5 t/ha.

Accuracy of the model to predict rice yield in El-Nino events differs from La-Nina events. The average error of prediction over West Java province in El-Nino years ranges from 16% to 22% whereas in La-Nina years it was below 12%. The average yields were multiplied by area-planted data from the respective government agency to estimate regency’s production. For rice production analysis over 5 years, the coefficients of determination ($r^2$) between model results and BPS data were 0.7. During La-Nina years, it coefficients increased 0.1 or 10 %. From the coefficients of determination, there is 30% variation of rice production wasn’t explained by the model especially to predict the rice production more than 800.000 ton. In El-Nino events, the rice production from the model is bigger with 28% in predict rice production more than 800.000 ton.

Effect of extreme El-Nino event on rainfall was clearly seen in year 2006. It effect was significant for growth of rice crop. It caused result of model very low compared by BPS data. Monthly rainfall in El-Nino year (2006) differs from and La-Nina year (2008). It seen rainfall data dramatic dropped in July until November 2006. Low of rainfall over 2 month caused growth activity of paddy not optimal that it decreased dry matter accumulation of rice crop.

Use of irrigation will add water availability thus bring opportunity for farmers to grow paddy at middle of the year that it will enter dry season.
condition clearly seen from temporal pattern of MODIS LAI in several paddy fields area over Karawang and Subang regencies which increased from in the beginning of June until reach the peak in the end of July.

Growing season activities in La-Nina year (2008) stepped back 2 weeks and 1 week from El-Nino year (2006) at Karawang and Subang respectively. Period of planting paddy in Bekasi regency is different with Karawang and Subang regencies. Temporal pattern of MODIS LAI showed initial first planting period start in the end of March while in second planting period begin in beginning of August.

Annual pattern of MODIS LAI was clearly seen in several locations. In clear sky or less of cloud cover, MODIS satellite is successful detect planting season in Karawang, Indramayu and Bekasi regencies. Planting season from three regency above is start in June until August. Usage of irrigation infrastructures by farmer causes rice crop grow well without supply water from rainfall at several dry months. It is explanation that the El-Nino event not directly decreased rice crop production in Karawang, Indramayu and Bekasi regency like already simulated by the model.

Keywords: El-Nino, La-Nina, crop simulation model
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A thesis submitted for the Degree of Master of Science in Information Technology for Natural Resources Management Study Program

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Hopefully, this thesis could give positive and valuable contribution for anyone who reads it.

Bogor, July 2012

Yunus Bahar
CURRICULUM VITAE

Yunus Bahar was born in Denpasar, Bali, Indonesia on July 1\textsuperscript{st} 1986, child of couple Bahar Asrul and Fatimah. He was finished his bachelor degree in Meteorology from Bogor Agricultural University, Faculty of Mathematics and Natural Science in 2009. From 2008 until now, he has been active as a lecture and assistant lecture in Diploma, Undergraduate and Postgraduate program Bogor Agriculture University. He was entered the IPB Graduate School in year 2009 and completed his master study in 2012. His final thesis is “Rice Monitoring System Based on Modelling Approach”. 
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I. INTRODUCTION

1.1 Background

Rice is a primary food for 95% of around 220 million people living in Indonesia. Although the national statistic shows that the total rice production in Indonesia has increased steadily over the last 20 years but the rate of increase slowed down in the El-Nino years (Meinke & Boer, 2002; Krinamurthi, 2003). A useful way to understand the effects of climate variability on crop yield is to simulate the growth of a crop using computer modeling. Crop simulation models which have been validated have become essential tools to assess climate variability impacts and to provide quantification for alternative decision options.

Crop growth models have been used successfully in predicting crop yields at the field level. These models require numerous inputs that are specific to the crop, soil characteristics, management practices and local climatic conditions. These models have had limited use because fewer inputs are generally available at larger than field scales. Additionally, satellite remote sensing technology has been shown to be capable of providing certain crop characteristics and real-time snapshots changes in conditions affected by the weather related events. Combining such growth models with input parameters derived from remotely sensed data provides spatial integrity as well as a real-time calibration to simulations of model parameters (Mass et al., 1988, Cleavers et al., 1994, Doraiswamy et al., 2004, Doraiswamy et al., 2005, Lunay and Guerif, 2005).

Shierary-Rice model is a mechanistic growth model describing the rice growth as a function of weather variables with physical and chemistry soil properties. The ability of the model to predict can be used as decision tools by the government (Handoko, 1994). Its ability to simulate rice growth based on interaction weather, water & nitrogen along growing season has been tested in Malang and suggested to be applied in different area (Rusmayadi, 1996). However, conducting calibration procedure is critical for another study region.

The launching of Terra satellite of EOS (Earth Observing System) project, with moderate resolution imaging spectroradiometer (MODIS) and multiangle imaging spectroradiometer (MISR) instruments onboard began a new era in remote sensing of the Earth system. In contrast to the previous single-angle and
few-channel instruments, MODIS and MISR together allow for rich spectral and angular sampling of the reflected radiation field. The spatial resolution (250 m – 1 km) and temporal (daily) coverage of MODIS data offer potential for retrieval of crop biophysical parameters and improve accuracy in crop yield assessment. Although Landsat TM data would be more suitable in areas where the field sizes are small, the temporal frequency and cloud cover limit the retrieval of crop biophysical parameters that are changing during the season. Biophysical parameters such as LAI retrieved from satellite-measured reflectance coupled with a crop yield model facilitate analyses of temporal and spatial variability of crop conditions and yield.

The spatial and temporal variability weather conditions are important sources when applying crop simulation models over large areas. Integration meteorological satellite with Numerical Weather Prediction (NWP) product is promising in find timely weather variables as an input model for a crop yield system with sparse coverage of weather stations (Roebeling et al., 2004; de Wit et al., 2010). The Tropical Rainfall Measuring Mission (TRMM) data is capable of providing daily rainfall. Furthermore, NWP products from NCEP/NOAA such as solar radiation, 2 m temperature, wind, and relative humidity (RH) are used as other input. Moreover Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) could be applied for correcting NWP which have poor spatial resolution.

1.2 Objectives

The two objectives designed for this research were:

1. To develop system for monitoring growth and yield of rice crop based on weather variable and MODIS satellite imagery.

2. To estimate and compare rice crop yields with statistical data those are issued by Central Bureau of Statistics (BPS).
II. LITERATURE REVIEW

2.1 Principles of Crop Growth Modelling

Crop growth model simulates growth and development of agricultural crops based on understanding of underlying physical and physiological processes (Bouman, 1995). The main inputs of this model were environmental factors such as solar radiation, temperature, water and nutrient availability (Cleavers et al., 1944). The daily biomass yield of crop can be calculated as a total biomass accumulation during the life cycle of the plant. Based on the Monteith (1981) formula, production of biomass depends on incoming photosynthetic active radiation that is converted into biomass via a light use efficiency factor and performance of plant canopy to intercept solar radiation. However, since the fraction of photosynthetic active radiation (PAR) is quite stable at 50% of the incident global radiation, it is much more practical to use global radiation. The amount of the fraction of intercepted light by canopy could be calculated with Beer law. According to Beer law, the incoming solar radiation in homogenous canopy decreases exponentially depending on plant canopy that quantify with Leaf Area Index (LAI) (Charles-Edwards et al., 1986)

\[ f = (1 - e^{-kLAI}) \]  

Where:

- \( f \) = fraction of intercepted radiation
- \( k \) = extinction coefficient for visible radiation
- LAI = Leaf Area Index

Daily assimilation of the crop will decrease in two ways. First, it used for the maintenance respiration and for the conversion to new structural plant materials. The net of daily assimilation will be partitioned to the various plant organs through a partitioning factor introduced as a function of the phonological development stage of the crop (Spitters, 1990).

2.2 Spatial Weather Variables from Remote Sensing

The spatial and temporal variability of weather condition are important sources of uncertainty when applying crop simulation model over large areas. Nowadays, three important sources of weather variables are often applied as described in more details in the next paragraph.
Weather variables are derived from weather stations and are interpolated to the locations where the crop model is applied. Although the density of weather stations in many areas is often quite high, many stations do not report in near-real time making them unsuitable for near-real time crop monitoring applications. Due to the limited density of weather stations, a considerable uncertainty is often present in gridded weather products derived from weather stations.

Weather variables can be provided by NWP models such as those applied by the European Centre for Medium Range Weather Forecasts (ECMWF) and The National Centers for Environmental Prediction (NCEP) together with National Center for Atmospheric Research (NOAA). NWP models long time suffered from poor spatial resolution as the grid resolution of the model is often in the order of 0.5 to 2 degrees. A more subtle problem of NWP model output was inconsistency in the time-series due to incremental upgrades of NWP model itself. Therefore, any biases in the time-series caused by NWP model upgrades will distort the analysis of historic time-series of simulated and reported yields. This problem has been recognized by the NWP community and has resulted in the reanalysis project such as ECMWF/ERA-ARTEMIS and NCEP-NOAA reanalysis from European and USA. Based on the research by de Wit $et$ $al$ (2010), NWP from ERA-INTERIM can be used to replace weather variables in the implementation of regional crop yield forecasting in Europe.

Meteorological satellites (MeteoSat) such as the NOAA-AVHRR series or the MeteoSat series are capable of providing timely and reliable meteorological variable for crop yields forecast (Roebeling $et$ $al$, 2004). MeteoSat particularly provides good opportunities with its 30 min. revisit interval and relatively (compared to NWP models) high spatial resolution. MeteoSat imagery can be used for deriving estimates of global and net radiation derived from cloud cover and albedo, daily minimum and maximum temperature derived from day and night surface temperature, and potential evapotranspiration derived from available radiation. Moreover, opportunities for rainfall estimates can be made available by integrating MeteoSat cloud cover estimates with rain gauge products.
2.3 MODIS LAI/FPAR Product and Algorithm

The algorithm consists of a main procedure that exploits the spectral information content of MODIS surface reflectance at up to seven spectral bands. A look-up-table (LUT) method is used to achieve inversion of the three-dimensional radiative transfer problem. Should this main algorithm fail, a back-up algorithm is triggered to estimate LAI and FPAR using vegetation indices. The algorithm requires a land cover classification that is compatible with the radiative transfer model used in the derivation of the product (Knyazikhin et al., 1999). The theoretical basis of the algorithm is given in Knyazikhin, Martonchick, Myneni, et al., (1998) and the implementation aspects are discussed in Knyazikhin at al. (1999). The brief explanations of the LUT-based method are summarized below.

2.3.1 Global Biome Map

Global vegetation is stratified into six canopy architectural types, or biomes, in our approach to LAI/FPAR retrieval. The six biomes are grasses and cereal crops, shrubs, broadleaf crops, savannas, broadleaf forests and needle leaf forests. These biomes span structural variations along the horizontal (homogeneous vs. heterogeneous) and vertical (single- vs. multi-story) dimensions, canopy height, leaf type, soil brightness and climate (precipitation and temperature) space of herbaceous and woody vegetation globally.

The biome map reduces the number of unknowns of the inverse problem through the use of simplifying assumptions (e.g., model leaf normal orientation distributions) and standard constants (e.g., leaf, wood, litter and soil optical properties) that are assumed to vary with biome and soil types only. This approach is similar to that adopted in many global models which assume certain key parameters to vary only by vegetation type and utilize a land cover classification to achieve spatialization. The assumption that vegetation within each 1 km MODIS pixel belongs to one of the six biomes impacts performance of the algorithm.

2.3.2 Input Uncertainties and Solution Distributions

The LAI/FPAR algorithm compares MODIS directional spectral reflectance comparable values evaluated from model-based entries stored in a look-up-table (LUT) and derives the distribution of all possible solutions, i.e., LAI and
FPAR distribution functions. But our problem, this is not the case. There are several problems related to this case that explain below.

First, two different locations in the input space can correspond to the same value of the output but different biome types, for example. The algorithm should account for differences in structure and optics of these biomes in a way that the same value of LAI is retrieved in both cases. Second, a point in the input space may correspond to multiple LAI values, because, for example, different combinations of LAI and soil types can result in the same value of canopy spectral reflectances. It means that the inputs do not contain sufficient information to localize a unique solution. Third, in the case of a dense canopy, its reflectance in one or several directions can be insensitive to various parameter values (e.g., LAI) characterizing the canopy because the reflectance of solar radiation from the underlying soil surface or lower leaf stories is completely obscured by the upper leaves. When this happens, the canopy reflectance is said to belong to the saturation domain (Knyazikhin, Martonchik, Diner, et al., 1998). Therefore, all LAI values greater than an input-dependent LAI value are valid solutions. Fourth, a unique solution cannot be expected in the general case of input uncertainties and algorithm imperfections. Thus, one can at best derive a distribution of possible solutions and characterize this distribution by its mean and variance. The dispersion of this distribution is an index of retrieval quality, and is in general larger than input uncertainties.

2.3.3 Energy Conservation as a Constraint

The number of valid solutions may be unacceptably large in view of simplifying assumptions in the algorithm and errors in input data. Therefore, the constraint provided by the law of energy conservation on the inverse problem is valuable in obtaining meaningfully localized solutions (Knyazikhin, Martonchik, Diner, et al., 1998). This principle is utilized in the MODIS LAI/FPAR algorithm as follows. The model-based LUT entries are BRFs parameterized in terms of basic components of the energy conservation law, namely, canopy transmittance and absorptance whose spectral variation can be explicitly expressed via the leaf spectrum and two canopies structure specific wavelength-independent variables. This facilitates comparison of spectral values of BRFs with spectral properties of
individual leaves, which is a rather stable characteristic of a green leaf. It allows the algorithm to admit only those LAI values for which the modeled BRFs agree with the energy conservation law at any wavelength of solar spectrum, thus allowing a significant reduction in the number of retrieved solutions.

2.3.4 Spectral Invariance

The extinction coefficient in vegetation canopies was treated by Ross (1981) as wavelength-independent considering the size of the scattering elements (leaves, branches, twigs, etc.) relative to the wavelength of solar radiation. This spectral invariance results in a relation between canopy transmittance, \( t(\lambda_0) \), and absorptance \( a(\lambda_0) \) at a reference wavelength \( \lambda_0 \) to transmittances \( t(\lambda) \) and absorptances \( a(\lambda) \) at all other wavelengths \( \lambda \) in the solar spectrum (Knyazikhin, Martonchik, Myneni, et al., 1998),

\[
\frac{1 - \omega(\lambda_0)p_t}{1 - \omega(\lambda_0)p_t} t(\lambda_0),
\]

\[
\frac{1 - \omega(\lambda_0)p_a}{1 - \omega(\lambda)p_a} \frac{1 - \omega(\lambda)}{1 - \omega(\lambda)p_q} a(\lambda_0)
\]

(2)

where \( \omega \) is the sum of leaf hemispherical reflectance and transmittance (leaf albedo); \( p_t \) and \( p_a \) are canopy structure dependent variables (therefore wavelength-independent but spatial resolution-dependent). The importance of these relations is two-fold. The size of the LUT is independent of the number of spectrally dependent inputs ingested by the algorithm since wavelength dependencies can be resolved from reference wavelength entries and knowledge of \( p_t \) and \( p_a \). Second, the scale dependence of the LUT, because of \( p_t \) and \( p_a \), facilitates validation of coarse scale retrievals with fine scale field measurements, as discussed later.

2.4 Coupling Crop Process models and satellite data

Same different ways in combining a crop model with radiometric observations (ground measurements or satellite data) were initially described by Maas (1998) and their classification was revisited by Delecolle et al. (1992). Four methods of data integration have been identified:
a) *The direct use of a driving variable* estimated from remote sensing information in the model;

b) *The updating of a state variable* of the model (for example, LAI) derived from remote sensing;

c) *The re-initialization* of the model, i.e., the adjustment of an initial condition to obtain a simulation in agreement with the remotely-sensed derived observations;

d) *The re-calibration* of the model i.e. the adjustment of model parameter to obtain a simulation agreement with LAI derived from the observations.

Most of those approaches were first implemented by Maas (1988) by using a simple growth model which simulated white maize. Despite being a simple model, it contains all the elements to demonstrate and compare the four techniques for using remotely-sensed information (Moulin et al., 1998).

The direct use of remote sensing data (i) to derive a driving variable is the simplest technique. This technique assumes that remote sensing data are available at an adequate time step (from daily to weekly). Due to cloud contamination and intrinsic properties of sensors and platform, this is rarely used in a large area but still appropriate in small-scale, ground-based studies using hand-held or vehicle-mounted remote sensing instruments.

Updating is (ii) also a relatively simple technique (Maas, 1988). It consists of updating at least one stage variable in the model using remote sensing data. The crop model requires a value for this state variable at each time. On the other hand, remote sensing estimations are available only at acquisition dates, generally less frequent than the model step. Gaps between dates must therefore be filled by some interpolation procedures.

Re-initialization and re-parameterization are more complex techniques capable of using infrequent observations. Their primary advantage is that all remotely-sensed observations are used to affect model performance, allowing cancellation of the effects of random errors in the data. Their main disadvantage is that they require more computer time, as compared to input or updating, to make an estimate. Since growth models typically have fewer state variables than
parameters, re-initialization would be easier to implement. However, re-parameterization is conceptually attractive because disagreement between model and observed growth is often due to inaccurate specification of parameter values. Re-initialization and re-parameterization would be appropriate for applications involving remotely-sensed observations from satellites and aircraft, as well as ground-based observations likely to contain significant random errors (Maas, 1988).

2.5 Different Rice Crop Models

CERES-Rice and ORYZA are two popular models that are widely used in several countries (Mall & Aggarwal, 2002). A considerable number of studies based on such models have been conducted in recent years in Asian regions, some of these works focused on the response of the whole country or continent to changing climate (Matthews et al., 1995), while some focused on different managements of resources. Both ORYZA2000 and CERES-Rice were tested and reported both models predicted satisfactorily leaf area, days to panicle initiation, days to flowering and grain yields and concluded that both models, are adequate for simulated rice growth and development, particularly ORYZA2000 can be used as an alternative research tool to assist management decision at field scale level in the Central Plain of Thailand (Wikarmpapraharn and Kositsakulchai, 2010).

2.3.5 ORYA Model

ORYZA2000 is the successor to a series of rice growth models developed in the 1990s in the project “Simulation and Systems Analysis for Rice Production (SARP). It is an update and integration of the models ORYZA1 for potential production (Kropff et al., 1994), ORYZA_W for water-limited production (Wopereis et al., 1996a), and ORYZA-N for nitrogen-limited production (Drenth et al 1994). Since the release of these models, new insights into crop growth and water-balance processes have been gained, new scientific subroutines developed, and programming standards and tools improved. These developments warranted a new release in the ORYZA series. Besides the scientific and programming updates, ORYZA2000 contains new features that allow a more explicit simulation of crop management options, such as irrigation and nitrogen fertilizer management.
In ORYZA2000, the rice crop has four phonological phases, viz., juvenile phase from emergence (development stage [DVS]=0) to start of photoperiod-sensitive phase (DVS=0.4), photoperiod-sensitive phase from DVS = 0.4 until panicle initiation (DVS=0.65), panicle development phase from DVS = 0.65 until 50% of flowering (DVS=1.0), and grain-fill phase from DVS = 1.0 until physiological maturity (DVS=2.0). Each of these four phases has variety-specific development rate constants (DRC).

The light profile within the canopy is calculated from the amount and vertical distribution of leaf surface area. The daily canopy assimilation rate is calculated by integrating the instantaneous leaf photosynthesis rate over the height of the canopy and over the day. The daily dry matter accumulation is obtained after subtraction of maintenance and respiration requirements. The dry matter produced is partitioned among the various plant organs as a function of phenological development, which is tracked as a function of ambient mean air temperature.

The water dynamics in the ORYZA model is accounted by water balance in 3 soil types. Those are poorly-drained lowland soil, regular upland, and well-drained upland. The water gains through rain and/or irrigations are accounted by evapotranspiration (ET) and percolation losses. Daily soil evaporation (E) and plant transpiration (T) from ET are met preferentially from ponded water layer, and then from top soil layer (for E) and all rooted layers (for T) in the absence of ponded water. The percolation from the puddled layers is calculated using an iterative procedure that makes use of hydraulic characteristics of plough sole and that of underlying non-puddled subsoil. All water input in excess of field capacity is drained from a layer with a maximum rate equal to saturated hydraulic conductivity (Ks) of the layer.

The evapotranspiration (ET) module computes potential evaporation rates from soil and plant surfaces for the main field crop using one of the three methods, namely, Penman, Priestley and Taylor, and Makkink depending on the availability of meteorological data. The effects of water limitations on crop growth and development are accounted by considering their effects on expansive growth, leaf rolling, spikelet sterility, assimilate partitioning, delayed flowering,
and accelerated leaf death. The stress factors for each of these processes are defined as a function of soil water tension in the root zone.

### 2.3.6 CERES-Rice Model

CERES-Rice, a physiological-based rice (Oryza sativa L.) model is a crop model contained in the Decision Support System for Agro-technology Transfer (DSSAT) developed by International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT). The model can estimate yield potential by combining the properties of crops, soil and weather. The model assumes complete control of growth limiting factors such as weeds, insects, diseases and other management variables (i.e., phosphorus, potassium, liming, etc.).

CERES-Rice calculates nine phenological events and stages including 5 above ground stages. The duration of each stage makes use of the concept of thermal time similar to ORYZA, with a base temperature of 9°C, optimal temperature of 33°C and a maximum temperature of 42°C.

CERES-Rice calculates net photosynthesis based on the constant radiation use efficiency, leaf area index, extinction coefficient and light absorption by the canopy. Temperature between 14 and 32°C is considered in the model as optimal for photosynthesis; beyond this range, it has a decreasing effect.

The one-dimensional soil water balance model computes the daily changes in soil water content by soil layer. The changes are due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, plant transpiration, and root water uptake. The soil requires parameters that describe its surface condition, water holding capacity and hydraulic conductivity. The model uses an overflow or "cascading bucket" approach for computing soil water drainage when a layer’s water content is above the drained upper limit. Drainage of water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth.

Evapotranspiration in the CERES-Rice also responds to increased CO2 by increasing stomata resistance. This effect is not likely to be important in the present study conducted for well-irrigated environments where water stress is insignificant. Soil and plant nitrogen (N) balance and the effects of N stress on crop growth and yield in CERES-Rice are similar to ORYZA, except that
components of soil N balance are considered in much greater detail and the thresholds of the N deficit effect on crop growth and development are different in the latter model.

Model CERES-Rice has been tested in Thailand and Indonesia. The model was used to simulate growth and yield of four common rice varieties in Thailand with the attention on rate and timing of N application (Kumar et al., 2010). In Indonesia, CERES-Rice predicted lowland rice yields quite well for different management options, with a coefficient of determination value of 87% (Amien, et al., 1999).
III. METHODOLOGY

3.1 Time and Location

The research was done from January until May 2012. The study area was West Java which is located between longitude of 106° 22’ 13.8” E to 108° 50’ 1.8” E and latitude of 5° 54’ 49.6” S to 7° 49’ 15.5” S with the total paddy field area of approximately 2 million Ha where spread in 16 regency (Figure 1).

![Figure 1 Location of study area (Geospatial Information Agency (BIG), 2003).](image)

3.2 Data Source and Required Tools

Input for daily weather variables during the period of five year (2004-2008) simulations came from NWP product and TRMM data. Temperature, Relative Humidity (RH), solar radiation, and wind data derived from NWP while daily rainfall variable was extracted from TRMM data. The temperature was corrected by adding DEM data. Crop parameter was provided by Shierary-Rice model (Handoko, 1994). The simulation was run in January and September over 5 year simulations in order to match with BPS data. Detail for data sources, software and hardware used in this research can be seen in Table 1 and Table 2.
Table 1  List of dataset

<table>
<thead>
<tr>
<th>No</th>
<th>Datasets</th>
<th>Data Format</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MODIS LAI/FPAR Product (MOD15A2)</td>
<td>Raster</td>
<td>NASA-DAAC</td>
</tr>
<tr>
<td>2</td>
<td>Daily rainfall</td>
<td>Raster</td>
<td>TRMM Project, Level 3B42</td>
</tr>
<tr>
<td></td>
<td>Daily Temperature, wind speed, RH &amp; solar radiation</td>
<td>Raster</td>
<td>NCEP Daily Global Analyses</td>
</tr>
<tr>
<td>3</td>
<td>Topographic Map (2003)</td>
<td>Vector</td>
<td>BIG</td>
</tr>
<tr>
<td>4</td>
<td>Digital Elevation Model</td>
<td>Raster</td>
<td>SRTM</td>
</tr>
<tr>
<td>5</td>
<td>Statistical Data</td>
<td>Non Spatial</td>
<td>BPS</td>
</tr>
</tbody>
</table>

Table 2  List of software and hardware

<table>
<thead>
<tr>
<th>Software</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.S. Visual Basic 6.0</td>
<td>programming numerical data</td>
</tr>
<tr>
<td>Arc GIS 9.3</td>
<td>visualizing and processing spatial data</td>
</tr>
<tr>
<td>Modis Tool</td>
<td>MODIS data processing</td>
</tr>
<tr>
<td>Grads 2.0 &amp; Climate Data Operator (CDO)</td>
<td>visualizing and processing net-CDF data</td>
</tr>
<tr>
<td>Microsoft Office</td>
<td>Non spatial data entry processing, reporting</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laptop and Printer</td>
<td>Software running &amp; printing device</td>
</tr>
</tbody>
</table>

3.3 Methodology

The research integrated numerical model, remote sensing and Geographic Information System (GIS) as a system to monitor growth and development of rice crop in West Java province. The general framework of the research can be seen in Figure 2.

![Figure 2: General method of the research.](image-url)
3.3.1 Geometric correction

There were three processes shall be applied in this step. First was spatial subset to specify the study area. The next was a resampling and followed by re-projection the imagery from Sinusoidal grid into geographic coordinate. All the processes were done automatically in command line interface by using MODIS tool.

3.3.2 Re-gridding

The spatial resolution of meteorological dataset which was used in the study was different. Daily rainfall was on 0.25 x 0.25 degree and the other was in 2.5 x 2.5 degree of grid size. Re-gridding process would convert spatial resolution dataset into 1 km x 1 km (0.00833 x 0.00833 degree) of grid size. This was done by using GRADS.

3.3.3 Converting weather and LAI data into XYZ format

All of the inputs for this system were translated into on XYZ format (a text format). X, Y and Z were longitude, latitude, and value of data respectively. Conversion into a text format was done by using CDO.

3.3.4 Geo-processing

Monitoring system would run one by one based on regency. Geo-processing would be performed to find and specify all the inputs into several files based on administrative boundary. This process was done by ESRI Arc GIS 9.3.

3.3.5 Rice Simulation Model

Rice simulation model adopted the shierary-rice model (Handoko 1994) that comprises three sub-models, development (phenology), growth, and water balance. Interaction among three sub-models was determined by daily fluctuation of weather elements such as temperature, solar radiation, and rainfall, relative humidity, and wind speed.

Development sub model

The phase of development was based on expected crop heat unit concept, with the assumption that the plant would not be affected by day length (neutral plants). Rice crop development occurs when daily air temperature (T) is higher
than the base temperature (To). Genesis phenology calculates from planting until maturity and were given a scale of 0 - 1, which has divided into five stages, consisting at seedling (s = 0), planting (s = 0.25), maximum shoot (s = 0.5), flowering (s = 0.75) and mature (s = 1.0) (Handoko, 1994).

**Calculation of development phase:**

Seedling – Planting : $s = 0.25 \frac{(T- T_{01})}{T_{U1}} \quad T > T_{01}$

Planting – Max shoots : $s = 0.25 + 0.25 \frac{(T- T_{02})}{T_{U2}} \quad T > T_{02}$

Max shoots – Flowering : $s = 0.5 + 0.25 \frac{(T- T_{03})}{T_{U3}} \quad T > T_{03}$

Flowering – Mature : $s = 0.75 + 0.25 \frac{(T- T_{04})}{T_{U4}} \quad T > T_{04}$

where 1, 2, 3, 4 are periods in genesis phenology. To and TU are base temperature and thermal unit respectively.

**b. Growth sub model**

Growth sub-model simulated the flow of photosynthetic biomass to the each organ of plants (roots, stems, leaves, and grain) and loss of respiration. The results of photosynthetic biomass were distributed into various organs of plants (leaves, stems, roots and grains). Distribution of biomass is a function of crop development and is calculates in the sub model development. Sub model also simulate leaf area development is expected through LAI.

**Biomass Production**

Potential biomass production was calculated in daily based on the amount of intercepted radiation ($Q_{int}$) by rice crop and the light use efficiency by canopies ($\varepsilon$). Intercepted radiation by canopies of plants ($Q_{int}$) was calculated using a beer law which is a function of incoming solar radiation ($Q_o$) and LAI. The calculation of biomass production can be seen below (Charles-Edwards et al., 1986):

$$GDM_p = \varepsilon Q_{int} = \varepsilon Q_o (1 - e^{-k \cdot LAI})$$  \hspace{1cm} (3)

Where:

- $GDM_p$ = Potential biomass production (kg ha$^{-1}$ d$^{-1}$)
- $\varepsilon$ = Light Use Efficiency (kg/MJ)
Potential Biomass production (GDMp) does not take water as a limiting factor. Actual biomass production is calculated by considering water availability has been simulated in the sub-water balance model as a water deficit factor (wdf), which is the ratio between the actual transpiration (Tsa) and maximum transpiration (Tsm).

**Respiration & Biomass Accumulation**

Actual biomass production (GDMa) allocated to the leaves, stems, roots, and grains that the comparison depends on the plant development phase (s). Most of the biomass accumulated in each plant organ will lost in the process of growth and maintenance respiration. Maintenance respiration is calculated from the weight function and the air temperature (McCree 1970 in Handoko, 1994). Changes in the weight of each organ (leaves, stems, roots and seeds), follows these equation:

\[
dW_x = \eta_x (l\text{-kg}) \ GDMa - km \ W_x \ Q_{10} \tag{4}
\]

Where:
- \(dW_x\) = Accumulation organ weight x (kg ha\(^{-1}\) d\(^{-1}\))
- \(GDMa\) = Actual biomass (kg ha\(^{-1}\) d\(^{-1}\))
- \(\eta_x\) = biomass proportion which allocated to organ x
- \(kg\) & \(km\) = growth and maintenance respiration coefficient
- \(W_x\) = organ weight x (kg ha\(^{-1}\))
- \(T\) = temperature (°C)
- \(Q_{10}\) = 2 \((T-20)/10\)

**Leaf Area Index (LAI)**

Lai was calculated from the ratio between daily leaf growth (Wleaf) and specific leaf weight (slw) as follows (Handoko, 1994):

\[
LAI = \frac{W_{leaf}}{slw} \tag{5}
\]

**Water balanced sub model**

Sub water balance model assumes rainfall is the only source of water. Rain (R) falls on vegetation canopy and some water is intercepted by the canopy. The amount of infiltrated water (inf) will enter into soil trough the pores of the soil until the soil layer becomes saturated. When the soil water content was saturated, the water will lost through as drainage.
Interception by canopy

The amount of intercepted water (Ic) by plants is calculated by Zinke (1967) in Handoko (1994) which is a function of daily rainfall (R) and LAI.

\[
Ic \quad (\text{mm}) = \min (0.4233 \, \text{LAI}, \, R) \quad 0 < \text{LAI} < 3
\]

\[
= \min (1.27 \, \text{LAI}, \, R) \quad \text{LAI} > 3 \quad (6)
\]

Infiltration and Drainage

The infiltration water (inf) is calculated from difference of between rainfall (R) and the intercepted water by canopy (Ic):

\[
\text{Inf} \quad (\text{mm}) = R \quad (\text{mm}) - Ic \quad (\text{mm})
\]

The calculated soil water content (θ (mm)) is greater than its field capacity (θfc (mm)), the excess water will lost as drainage (drain (mm)), which is calculated as:

\[
\text{drain} \quad (\text{mm}) = [\theta (\text{mm}) - \theta_{\text{fc}} (\text{mm})] \quad \theta (\text{mm}) > \theta_{\text{fc}} (\text{mm})
\]

\[
\text{drain} \quad (\text{mm}) = 0 \quad \theta (\text{mm}) \leq \theta_{\text{fc}} (\text{mm}) \quad (7)
\]

Evapotranspiration

Evapotranspiration potential (ETp) is calculated based on the Penman formula (Penman 1948 in the Handoko, 1994). ETp value is the upper limit of evapotranspiration maximum (Et). Maximum evaporation value (Em) and maximum transpiration (Tm) are a function of the maximum evapotranspiration earlier.

\[
\text{ETp} = \left\{ \Delta Qn + \gamma \, f(u) \, (es-ea) \right\} / \left\{ \lambda ( \Delta + \gamma ) \right\} \quad (8)
\]

\[
\text{Em} = \text{ETm} \quad (e^{-k \times \text{Lai}}) \quad (9)
\]

\[
\text{Tm} = (1 - e^{-k}) \times \text{ETm} \quad (10)
\]

Δ : slope water vapour curve (Pa K\(^{-1}\))

Q : net radiation (MJ m\(^{-2}\))

γ : psychrometric constant (66.1 Pa K\(^{-1}\))

f(u) : aerodynamics function (MJ m\(^{-2}\) Pa\(^{-1}\))

λ : specific heat to vaporization (2.454 MJ kg\(^{-1}\))

k : coefficient extinction

LAI : leaf area index

(es-ea) : deficit water pressure (Pa)
Actual Evaporation

Actual evaporation or soil evaporation \((E_s)\) calculates with Ritchie methods (1972) which comprises two phases. First phase, soil water content not becomes limiting factor and actual evaporation equal with maximum evaporation. In second phase, rate of evaporation is decrease as time function. In sort, two phases of actual evaporation can explain with following equation

\[
E_a = \begin{cases} 
Em & \Sigma E_s \leq U, \\
\alpha t^{-0.5} & \Sigma E_s > U,
\end{cases} \quad 0 > \theta_d
\]

and

\[
\theta = \begin{cases} 
\theta & \theta_d > \theta \\
0 & \theta \leq \theta_d
\end{cases}
\]

\[
\Sigma E_s \leq U, \\
E_a = 0,
\]

\[
\Sigma E_s \geq U,
\]

\[
0 \leq \theta_d
\]

\[
\theta = \theta_d
\]

\[
\theta = \theta_d
\]

\[
\theta = \theta_d
\]

\[
\theta = \theta_d
\]

Actual Transpiration

Actual transpiration \((T_{sa})\) is calculated based on maximum transpiration \((T_{sm})\) and soil water available in the root layer, where the upper limit is the maximum transpiration values \((T_{sm})\).

\[
T_{sa} = \begin{cases} 
T_{sm} + (0 - \theta_{wp}) / (\theta_{fc} - \theta_{wp}) & \theta_{fc} \geq \theta > \theta_{wp} \\
T_{sm} & \theta > \theta_{fc} \\
0 & \theta < \theta_{wp}
\end{cases}
\]

\[
\begin{align*}
0 &= \text{soil water content (mm)} \\
\theta_{wp} &= \text{permanent wilting point (mm)} \\
\theta_{fc} &= \text{field capacity point (mm)} \\
T_{sa} &= \text{actual transpiration (mm)} \\
T_{sm} &= \text{maximum transpiration (mm)}
\end{align*}
\]

3.3.6 Validation

There are quantitative and qualitative technique used to validate results of the model. Using a graph, the model will be compared against measurement using 1:1 line. The more points fit the line, the better model performance. The coefficients of determination \((r^2)\) used to measure proportion of variance from published data which can be explained by the model. The coefficient of
The determination is square of the Pearson correlation product. The formula for the Pearson correlation coefficient can be seen below:

\[ r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \]  \hspace{1cm} (13)

where,

- \( r \) = the coefficient of correlation
- \( x \) = the value of model output
- \( y \) = the value of published data

The error of prediction will be used to measure differences between model output and published data. The big differences will be caused the big error. The complete calculation for error of prediction can be seen below:

\[ E = \left| \frac{M - D}{D} \right| \times 100 \]  \hspace{1cm} (14)

where,

- \( E \) = error of prediction (\%)
- \( M \) = the value of model output
- \( D \) = the value of measured data.
IV. RESULTS

4.1. MODIS LAI Product in West Java Province

The annual pattern of MODIS LAI in paddy field area was shown clearly in Figure 3. Although in several data MODIS LAI fluctuated, but the cycle seen during 5 years. Fluctuated of MODIS LAI was caused by cloud cover. The higher cloud covers made the canopy radiation transfer model fail to estimate LAI. Consequently, a backup model was applied mainly during rainy season (Kim et al. 2005). Several factor influences performance of MODIS LAI are coarse resolution, effect of water background on the spectral reflectance, and the criteria which the algorithm retrieves information according to a predefined biome (Suarez, 2010).

![Figure 3 Annual pattern of MODIS LAI for year 2004 until 2008.](image)

4.2. Weather Condition in the Study Area

NCEP-NOAA and TRMM data were promising to get daily and timely temperature, RH, solar radiation, wind and rainfall variables. Figure 4 shows the yearly rainfall from 2004 until 2008. The yearly precipitation in the study area varied from 2143 mm to 2864 mm per years. During 2004, 2005 and 2007, the yearly rainfall was stable where the value was more than 2600 mm/year, but fell slightly in 2006 and 2008 with 2143 mm/year and 2374 mm/year respectively.
The temperature was corrected using elevation data which were derived from DEM data. According to Braak formula (1929) in Ritung et.al. (2007), the temperature in Indonesia will decrease by 6.1 °C regularly every increasing 1000 m above sea level. Figure 5 shows the yearly average of temperature for 5 years in West Java province. It varied from 10 °C until 26 °C. The minimum temperature associated with high elevation which it located on top of mountain while the maximum temperature founded near of low-land area.

Figure 5 Yearly average temperature from year 2004 until year 2004.

Daily relative humidity, solar radiation, and wind speed were directly used as an input of the model. The statistical downscaling was used to change the spatial resolution of those data into 1 x 1 km. Even though coarse resolution
influenced by the accuracy, it was suitable for regional crop yields forecasting over regions which have sparse weather station (de Wit et al., 2010). Table 3 gives the summary of weather variables such as temperature, RH, solar radiation, wind speed and rainfall in the study area.

Table 3 Average yearly temperature, RH, solar radiation, wind, and rainfall

<table>
<thead>
<tr>
<th>Year</th>
<th>Temperature (°C)</th>
<th>RH (%)</th>
<th>Solar Radiation (MJ/m²)</th>
<th>Wind (m/s)</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>23.8</td>
<td>84.8</td>
<td>13.0</td>
<td>2.9</td>
<td>2606</td>
</tr>
<tr>
<td>2005</td>
<td>24.1</td>
<td>84.8</td>
<td>12.2</td>
<td>2.8</td>
<td>2680</td>
</tr>
<tr>
<td>2006</td>
<td>23.8</td>
<td>84.8</td>
<td>13.1</td>
<td>3.2</td>
<td>2143</td>
</tr>
<tr>
<td>2007</td>
<td>23.8</td>
<td>85.6</td>
<td>12.6</td>
<td>3.1</td>
<td>2864</td>
</tr>
<tr>
<td>2008</td>
<td>23.7</td>
<td>85.9</td>
<td>12.7</td>
<td>3.3</td>
<td>2374</td>
</tr>
</tbody>
</table>

4.3. Yield Simulations

The simulations were run in 16 regencies in west Java during 2004 – 2008 with the assumption the paddy field area was constant. In each grid, the model simulates the rice yield every day along the life cycle of rice crop. The final yield in each grid will be aggregated to determine rice yield in regency level or the next level. Figure 6 shows comparison between model result and BPS report in West Java province. Reference data (BPS) shown the yield has increased 0.5 t/ha during 5 years. But the rate increased has slowed in period 2004 until 2005 and constant from year 2005 until 2006 year. The yield from the model fluctuated a lot and tended decreased over the period of 5 years. The differences between model and BPS in year 2004 is 0.2 t/ha, rises 0.5 t/ha in year 2005, becomes more than five times from 2004 with 0.11 t/ha in year 2006 and slow down with 0.6 t/ha in 2007. The close difference between model and BPS data found in 2007 with 0.1 t/ha.

Figure 6 Comparison of estimated yield and BPS report in West Java province.
Figure 7 shows an example of yield images in 2006 and 2008, was generated by the model. It shows a large visual contrast especially in the north region of West Java province between year 2006 and year 2008. In year 2006, the yields from Bekasi, Karawang, Subang, and Indramayu regency were varied starting from below 3 t/ha until 4 t/ha while in year 2008 it ranged from 3 t/ha until 5 t/ha.

Figure 7  Rice yield in year 2006 until year 2008 in West Java province.
In each regency, the average yields were multiplied by area-planted data (Figure 8) from the respective government agency to estimate regency’s production. The regency scatter diagram with line 1:1 between model results and the BPS reports from year 2004 until 2008 are shown in Figure 9. The regency scatter diagram indicated the model tends to underestimate production especially to predicting the rice production of more than 900,000 ton. Overall, the result of the model looks relatively good to predicting the rice production with the coefficient of determination ($r^2$) 0.7.

Figure 8  Planted Area from BPS data in 16 regencies in West Java province.

Figure 9  Comparison of rice production between model with BPS report.
4.4. Climate Variability on Rice Crop Yield

SOI has been used for determining El-Nino and La-Nina events. Figure 10 shows monthly SOI from official website of Bureau of Meteorology (BOM). It reported in 2004, 2005 and 2006, the Southern Oscillation Index (SOI) value dominated with negative or was associated with El-Nino event while in 2007 and 2006 it was positive or associated with La-Nina event (www.bom.gov.au). Although the value in the end of year 2005 until April 2006 was positive but the average of SOI in year 2005 and 2006 was negative. Further study in year 2006 shown weak El-Nino accompanied with positive Indian Ocean Dipole (IOD) and caused precipitation anomaly negative (Yulihastin et al., 2009).

Figure 10  Monthly values of SOI (www.bom.gov.au).

The comparisons between yield from the model result and BPS data in El-Nino years (2004, 2005, & 2006) are shown in Table 4. The impact of the El-Nino years on the predicted yields was seen clearly. The average yield of model constantly decreased by 0.6 t/ha per year while the BPS data remain stable. Consequently, the error of prediction increased from 15.9 % in 2004 to 22.0 % in 2006.
Table 4 Comparison of prediction yield between model prediction and BPS data in El-Nino years

<table>
<thead>
<tr>
<th>Regency</th>
<th>Year</th>
<th>Model (t/ha)</th>
<th>Error %</th>
<th>BPS (t/ha)</th>
<th>Error %</th>
<th>Model (t/ha)</th>
<th>Error %</th>
<th>BPS (t/ha)</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandung</td>
<td>2004</td>
<td>5.1</td>
<td>6.4</td>
<td>5.1</td>
<td>15.2</td>
<td>4.0</td>
<td>5.2</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>Bogor</td>
<td>2005</td>
<td>5.0</td>
<td>27.3</td>
<td>5.2</td>
<td>5.6</td>
<td>5.0</td>
<td>5.3</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Bekasi</td>
<td>2006</td>
<td>4.7</td>
<td>2.7</td>
<td>3.8</td>
<td>28.9</td>
<td>3.0</td>
<td>5.2</td>
<td>42.0</td>
<td></td>
</tr>
<tr>
<td>Ciamis</td>
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<td>5.8</td>
<td>9.2</td>
<td>5.5</td>
<td>5.3</td>
<td>3.8</td>
<td>5.4</td>
<td>28.6</td>
<td></td>
</tr>
<tr>
<td>Cianjur</td>
<td></td>
<td>6.2</td>
<td>29.6</td>
<td>5.2</td>
<td>4.9</td>
<td>4.8</td>
<td>5.0</td>
<td>4.7</td>
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</tr>
<tr>
<td>Garut</td>
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<td>0.2</td>
<td>5.0</td>
<td>5.1</td>
<td>3.7</td>
<td>5.0</td>
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<tr>
<td>Indramayu</td>
<td></td>
<td>4.2</td>
<td>22.9</td>
<td>3.6</td>
<td>34.5</td>
<td>3.1</td>
<td>5.3</td>
<td>41.2</td>
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<td>3.5</td>
<td>32.6</td>
<td>2.8</td>
<td>5.4</td>
<td>49.3</td>
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<td>5.3</td>
<td>12.9</td>
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<td>23.9</td>
<td>4.1</td>
<td>5.4</td>
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<tr>
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<td>24.9</td>
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<td>5.0</td>
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<tr>
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<td>5.0</td>
<td>4.2</td>
<td>4.5</td>
<td>15.9</td>
<td>3.7</td>
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<td>5.3</td>
<td>9.3</td>
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<tr>
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<td>5.0</td>
<td>5.2</td>
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<td>5.2</td>
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<td>16.1</td>
<td>4.1</td>
<td>5.2</td>
<td>22.0</td>
<td></td>
</tr>
</tbody>
</table>

Effect of extreme El-Nino event on rainfall was clearly seen in year 2006. It effect was significant for growth of rice crop. It caused result of model very low compared by BPS data. Figure 11 showed comparison of monthly rainfall in year 2006 and 2008. It seen rainfall data dramatic dropped in July until November 2006. Continuity of water supply is important in the beginning stage of rice development. Low of rainfall over 2 month caused growth activity of paddy not optimal that it decreased dry matter accumulation of rice crop.

Figure 11 Monthly rainfall in year 2006 and year 2008.
The table 5 shows the results of the model in La-Nina years (2006 & 2008). The highest error of prediction was found in Indramayu in year 2007 with 27.9% while the lowest error of prediction was found in Sukabumi at year 2008 with 1.4%. The average error of prediction from 16 regencies in West Java in year 2007 was lower than that in 2008. In overall, the error prediction of the model in El-Nino was higher than La-Nina event, or it can be said the model was good at predicting the yield in La-Nina events than that it El-Nino events.

<table>
<thead>
<tr>
<th>Regency</th>
<th>2007</th>
<th>2008</th>
<th>Error</th>
<th>2007</th>
<th>2008</th>
<th>Error</th>
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<td>16.9</td>
<td>4.3</td>
<td>5.8</td>
<td>26.3</td>
</tr>
<tr>
<td>Bogor</td>
<td>5.8</td>
<td>5.4</td>
<td>7.2</td>
<td>5.5</td>
<td>5.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Bekasi</td>
<td>4.8</td>
<td>5.4</td>
<td>10.8</td>
<td>4.5</td>
<td>5.5</td>
<td>19.4</td>
</tr>
<tr>
<td>Ciamis</td>
<td>5.7</td>
<td>5.8</td>
<td>1.6</td>
<td>5.6</td>
<td>6.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Cianjur</td>
<td>5.7</td>
<td>5.0</td>
<td>13.6</td>
<td>5.4</td>
<td>5.3</td>
<td>1.6</td>
</tr>
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<td>5.5</td>
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<td>5.6</td>
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<td>5.5</td>
<td>12.4</td>
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<td>5.7</td>
<td>18.5</td>
</tr>
<tr>
<td>Average</td>
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<td>5.4</td>
<td>11.2</td>
<td>5.0</td>
<td>5.6</td>
<td>12.3</td>
</tr>
</tbody>
</table>

Scatter diagrams of El-Nino and La-Nina years between model results and BPS reports are shown in Figure 12. The underestimate values are bigger in La-Nina than El-Nino years. In El-Nino events, the average of underestimate values is 28% in predicting the rice production of more than 800,000 ton. On the other hand, in La-Nina years, the model almost predicts much bigger than the actual production from BPS except in predicted rice production over Bandung regency. Predict of rice production in La-Nina events better than El-Nino events with $r^2 0.8$. 
Figure 12 Scatter diagram of rice production between model result and BPS report in El-Nino (a) and La-Nina years (b).

4.5. Effects Climate Variability in Bekasi, Subang and Karawang Regency

Decreased rainfall in El-Nino caused farmer to accelerated, waited for grow paddy or optimized irrigation. Use of irrigation will add water availability thus bring opportunity for farmers to grow paddy at middle of the year that it will enter dry season. It condition clearly seen from temporal pattern of MODIS LAI in several paddy fields area over Karawang and Subang regencies (Figure 13a and 13b) which increased from in the beginning of June until reach the peak in the end of July.
From Figure 13a and 13a, it seen growing season activities in La-Nina year (2008) stepped back 2 weeks and 1 week from El-Nino year (2006) at Karawang and Subang respectively. Period of planting paddy in Bekasi regency is different with Karawang and Subang regencies. Temporal pattern of MODIS LAI showed initial first planting period start in the end of March while in second planting period begins in beginning of August (figure 14).
Figure 14  MODIS LAI pattern in paddy field area at Bekasi regency.
V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The impacts of El-Nino and La-Nina in rice production were successfully monitored by the model. El-Nino event was found in 2004, 2005 & 2006 while La-Nina was found in 2007 and 2008. The model was relatively good to estimate yield in La-Nina than El-Nino event. During 2004, 2005 and 2006 of El-Nino events, 2006 contributed the highest error of prediction because in El-Nino years, the yield from BPS report remained constant while the simulate yield slightly dropped with 0.6 t/ha per year.

The results of the model were very good estimate yield at regency level with errors of prediction that varied from 0.2% until 49.3%. For rice production analysis, the coefficients of determination ($r^2$) between model results and BPS was 0.7. This indicates that 30% variation of rice production wasn’t explained by the model especially to predict the rice production more than 800,000 ton.

Results of the model were more accurate in La-Nina events than those of El-Nino events. In El-Nino events, the average of underestimate values is 28% in predict rice production more than 800,000 ton while the model always predict more bigger in La-Nina events excepts in predict over Bandung regency.

In clear sky or less of cloud cover, MODIS satellite is successful detect planting season in Karawang, Indramayu dan Bekasi regencies. Planting season from three regency above is start in June until August. Usage of irrigation by farmer causes rice crop grow well without supply water from rainfall at several dry months. It is explanation that the El-Nino event not directly decreased rice crop production in Karawang, Indramayu and Bekasi regency like already simulated by the model.

The system could monitor seasonal rice yield and production with minimum budget because most of the data used were available to be downloaded by public users.
5.2 **Recommendation**

- It is recommended to validate the model using observatories data in La-Nina or El-Nino years because the statistical report cannot show the effect of El-Nino and La-Nina events decreases or increased rice yield.
- It’s better to involve available ground weather data as an input of the model for future research.
- It’s recommended to enhance soil parameter data.
- Determine influence management practices such as sowing date & the high-yield rice cultivar usage.
- Enlarge the model to estimate seasonal rice yield for larger scale.
REFERENCES


Yuliahastin E., Nur F., and Trismidianto.


APPENDICES
Appendix 1  Rice yield in year 2004 and year 2005
Appendix 2  Rice yield in year 2007

Appendix 3  Topography map in West Java province (Source : DEM SRTM)
Appendix 4 Shierary-Rice module ver. 2.0 (Handoko, 1994)

**cuaca:**

\[
d = -23.4 \times \cos(2 \times \pi \times (ii + 10) / 365)
\]

\[
sinldp = \sin(lat \times \pi / 180) \times \sin(d \times \pi / 180)
\]

\[
cosldp = \cos(lat \times \pi / 180) \times \cos(d \times \pi / 180)
\]

\[
sinbp = \sin(-0.833 \times \pi / 180)
\]

\[
argp = (sinbp - sinldp) / cosldp
\]

\[
arcossp = 2 \times \arctan(1) - \arctan(argp / \sqrt{1 - argp \times argp})
\]

\[
dlenp = 24 / \pi \times arcosp
\]

**tekanan uap:**

\[
esatp = 6.1078 \times \exp(17.239 \times suhu / (suhu + 273.3))
\]

\[
ea = rh \times esatp / 100
\]

\[
vpd = esatp - ea
\]

**landaian tekanan uap (Pa/C):**

\[
delta = (47.139 \times \exp(0.055129 \times (suhu)))
\]

**radiasi gelombang panjang (MJ m^{-2} d^{-1}):**

\[
sangot = 58.75 \times (sinldp + cosldp)
\]

\[
nN = (sol / sangot - 0.16) / 0.62
\]

\[
Rlw = (2 \times (10^{-9}) \times ((suhu + 273.3)^4) \times (0.56 - 0.08 \times \sqrt{ea}) \times (0.1 + 0.9 \times nN))
\]

**radiasi neto (MJ m^{-2} d^{-1}):**

\[
Rn = (1 - alb) \times sol - Rlw
\]

**fungsi aerodinamik (MJ/C m^{-2} d^{-1}):**

\[
f1 = 0.64 \times (1 + 0.54 \times \text{angin} \times 1000 / 3600): \quad \text{`angin dalam km/jam}
\]

\[
\text{Evapotranspirasi maksimum}
\]

\[
ETm = (\delta \times Rn + f1 \times vpd \times 100) / ((\delta + \gamma) / \text{lhv})
\]

\[
Etm = (\delta \times Rn + f1 \times vpd \times 100) / ((\delta + \gamma) / \text{lhv}): \quad \text{`vpd dalam mb diubah jadi kPa}
\]

**Evaporasi:**

\[
\text{intersepsi tajuk, fint(Zinke, 1967), mm}
\]

\[
\text{If lai < 3 Then Fint = 0.4233 \times lai Else Fint = 1.27}
\]

**infiltrasi (INF),mm**

\[
inf = \text{ch} - \text{Fint}
\]

\[
\text{tsm = Etm} \times (1 - \exp(-k \times \text{lai}))
\]

**Evaporasi aktual**

\[
p = \text{inf}
\]

\[
\text{If CES1 > u Then GoTo stage2}
\]

**stage1:**

\[
\text{If p >= CES1 Then CES1 = 0 Else CES1 = CES1 - p}
\]
cumes1:

CEs1 = CEs1 + Esm

If CEs1 < u Then Es = Esm Else GoTo transition

transition:

Es = Esm - 0.4 * (CEs1 - u)

CEs2 = 0.6 * (CEs1 - u)

times = (CEs2 / alpha) ^ 2

GoTo bufferevap

stage2:

If p > CEs2 Then GoTo storm

times = times + 1
	timeso = times - 1

Es = alpha * Sqr(times) - alpha * Sqr(timesso)

If p > 0 Then GoTo rain

If Es > Esm Then Es = Esm

cumes2:

CEs2 = CEs2 + Es - p

GoTo bufferevap

storm:

p = p - CEs2

CEs1 = u - p

If p > u Then CEs1 = 0

GoTo cumes1

rain:

Esx = 0.8 * p

If Esx < Es Then Esx = Es + p

If Esx > Esm Then Esx = Esm

Es = Esx

GoTo cumes2

bufferevap:

If swc1 < 0.5 * wp1 Then Es = 0

Return

neraca_air:

transpirasi:

penyerapan air

swccrit = wp1 + 0.4 * (fc1 - wp1)

rew = (swc1 - wp1) / (swccrit - wp1)

If swc1 <= wp1 Then rew = 0.001

If rew > 1 Then rew = 1

'transpirasi aktual

Tsa = tsm * rew

Tsa = tsm * rew

If Tsa <= tsm Then Tsa = tsm

swc1 = swc1 + inf - Es - Tsa

If swc1 > (fc1 + 100) Then GoTo runoff

GoTo buffwbal
runoff:
runoff1 = swc1 - (fc1 + 100)
swc1 = (fc1 + 100)
buffwbal:
If swc1 < 0 Then swc1 = 0
If tsm > 0 Then wdf = Tsa / tsm
Return

perkembangan:
If s > 0.75 Then GoTo maturity
If s > 0.5 Then GoTo anthesis
If s > 0.25 Then GoTo tunas_max

gender:
If (suhu) > tb Then s1 = s1 + 0.25 * ((suhu) - tb) / TUat Else GoTo stage
If s1 > 0.25 Then s1 = 0.25
If s1 < 0.25 Then GoTo stage

max:
If (suhu) > tb Then s2 = s2 + 0.25 * ((suhu) - tb) / TUtm Else GoTo stage
If s2 > 0.25 Then s2 = 0.25
If s2 < 0.25 Then GoTo stage

anthesis:
If (suhu) > tb Then s3 = s3 + 0.25 * ((suhu) - tb) / TUanth Else GoTo stage
If s3 > 0.25 Then s3 = 0.25
If s3 < 0.25 Then GoTo stage

maturity:
If (suhu) > tb Then dsmat = 0.25 * ((suhu) - tb) / TUmat Else dsmat = 0
s4 = s4 + dsmat
If s4 > 0.25 Then s4 = 0.25
smat = smat + dsmat

stage:
s = s1 + s2 + s3 + s4
If (suhu) > tb Then TU = TU + ((suhu) - tb)
Return

Pertumuhan:
If s < 0.75 Then
    NG = 0
If s > 0.25 Then
    If s < 0.5 Then
        NL = 0.7; NS = 0.2; NR = 0.1
    Else
        NL = 0.7 - (0.6 / 0.25) * (s - 0.5)
        NR = 0.1
        NS = 1 - NL - NR
    End If
End If
Else
  NG = 0.7
  NS = 0.1
  NR = 0.1
  NL = 0.1
End If

slw = 127.68 * 10 ^ (0.00083617 * TU)  'dalam kg/ha
'radiasi intersepsi
If s >= 0.25 Then
  Sint = (sol) * (1 - Exp(-k * lai))
'produksi bahan kering potensial (kg ha-1 d-1)
gdmp = LUE * Sint * 10 ^ 4  'lue dalam kg/MJ, Sint dalam MJ/m2
  gdma = (1 - kg) * gdmp * wdf
'respirasi pemeliharaan (kg ha-1 d-1)
  Q10 = 2 ^ (((suhu) - 20) / 10)
  RmL = km * Q10 * LW
  RmS = km * Q10 * SW
  RmR = km * Q10 * RW
  RmG = km * Q10 * GW
'pembagian biomassa:
  dLW = NL * gdma - RmL
  dSW = NS * gdma - RmS
  dRW = NR * gdma - RmR
  dGW = NG * gdma - RmG
'biomassa:
  LW = LW + dLW
  LWi(ii, i) = LW
  SW = SW + dSW
  RW = RW + dRW
  GW = GW + dGW
TWi = LW + SW + RW + GW
If slw > 0 Then
  lai = LW / slw
  laii(ii, i) = lai
End If
Else
  Sint = 0
  lai = laiawal: LW = 0.25 * TWawal: SW = 0.25 * TWawal: RW = 0.5 *
  TWawal: GW = 0
End If
Return.