A STUDY ON ESTIMATING OF SWEET CORN PRODUCTION USING CROP GROWTH SIMULATION MODEL WITH SATELLITE REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM TECHNIQUES, IN NAKHON RATCHASIMA PROVINCE, THAILAND

S. Baimoung[1] and T. Oki[2]

Abstract

This study aims to meet for facilitating, correlating, and estimating the unforeseen sweet corn production at various scale levels with initially starting at field scale area within The National Corn and Sorghum Research Center, Nakhon Ratchasima province in the northeast region of Thailand using the Crop Growth Simulation Model so-called "WOFOST" (De Wit *et al*, 1978**,** Keulen, H. Van, Penning de Vries F.W.T. and Drees, E. M., 1982, Kuneepong, P. *et al*., 1990, Rivero Vega *et al*., 2001). Coupling with integration of Satellite Remote Sensing in term of Normalized Difference Vegetation Index (NDVI) for Landsat-TM to classify sweet corn plantation area and productions, along with Geographical Information System techniques in form of all sweet corn plantation area boundaries, which were digitized and grouped according to their suitability to find out the appropriate actual yield. And extending these techniques to regional scale areas for potential yield estimating using the techniques of NDVI-NOAA satellites imageries, and lastly incorporating to global scale areas for climate change as El Nino, La Nina, and Normal events respectively (Kogan, 1998).

Finally, the validation of the output from sweet corn production estimating equations for El Nino, La Nina, and Normal events at global scale level coupling with the actual sweet corn yields of year 1998-2001 by districts of Dan Khun Tod, Khon Buri, Pak Chong, Pak Thong Chai and Wang Nam Kaew in Nakhon Ratchasima province are compared and correlated with each other, and then the results have been shown on a very good compromising relationship in each own individual event.

Nevertheless, whenever this technique is applied on real implementation process for actual crop yield estimating then, what all users have to be a very awareness are as follow:- the limitation of applied crop growth simulation model usage, the problems of a quality and mixture classes of acquired satellite imageries, the significance of equation's coefficient error in each of up scaling step, and lastly the choosing of equation for each climatic events at the most certain period properly with expecting for a higher accuracy.

Keywords: Crop Growth Simulation Model "WOFOST"**,** Normalized Difference Vegetation Index (NDVI), El Nino, La Nina, and Normal events.

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

Introduction

Maize (generally used term as "corn products" or "*Zea Mays* var. *saccharata*) is one of the five major agricultural exports, *viz.*, rice, cassava, sugar, and rubber, of Thailand. In the last ten-year period, share of maize in country's total earnings from exports ranged from 8 to 10% (Source: Office of the National Economic and Social Development Board (NESDB), 16 December 2002). Because of its short and multiple growing seasons and definite harvesting period practiced by the farmers, estimation and expectation of potential production and yield become very difficult. This affect not only in implementing proper land use plans but also affects in formulating a sound policy of maize trade for the international market. Until now in Thailand, such estimation and monitoring works have been carried out based on the traditional statistical projection by some related government institutions.

To subsequently overcome these problems, a number of the substantial efforts have been contributed to elevate and stabilize sweet corn yield through breeding program on variety improvement, research findings on appropriate crop management, and interdisciplinary study on cropping systems. However, those findings are time consuming, expensive, site specifics, and the technology could only be transferred to the areas, where have a similar environmental conditions to those of the experimental sites. Consequently, The complexity of those environments such as different soil type and weather conditions can be apprehended with the use of Agrometeorological modeling or Crop Growth Simulation Model (CGSM), which is a powerful research tool in identifying and evaluating their impacts on crop growth and yield and couple with a suitable integration techniques of Remote Sensing and Geographical Information system (RS&GIS), for determining sweet corn potential yield across difference of soil types and weather conditions.

Research Objectives

The main objectives of this research work is to estimate the sweet corn (maize) production in Northeastern of Thailand using crop growth simulation and RS&GIS techniques with specific objectives as follow:

- To predict the sweet corn (maize) production at field scale using the crop growth simulation model with the observational data (crop, soil, and daily meteorological data).
- To estimate the sweet corn (maize) production in the plantation area at regional scale using the techniques of RS&GIS in terms of relationship between NDVI and Yields (LANDSAT and NOAA-AVHRR imageries).
- To estimate the sweet corn (maize) production for different climatic events such as El Nino, La Nina, and Normal years using the statistical analysis of relationship between NDVI and agricultural actual yields.

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

Resign Design

To achieve the objectives set forth, therefore, the study will be facilitated in formulating a comprehensive crop growth simulation at various levels namely: field scale, regional scale, and global climatic events scale lastly as the overall concept of research design shown on Figure1 with relating to the linkage of the framework for the study shown on Figure 2, which also has the limitation of data set at each scale as shown on Figures 3-4 respectively.

Methodology

To design and evaluate strategies for crop growth simulation and potential crop yield estimation, one of the greatest needs in for accurate indicators of this task, which must include environment and economic criteria in various levels. As this study aimed at estimate crop production on several scales, the framework of the study as aforementioned would be employed as follows;

Phase I: Field scale model validation

All data would have been were collecting from the site as shown on Figure 5 and in variety of sources in the form of digital, analog, tabular data, reports and field survey. The basic data used in the study were:

- The daily meteorological data of year 1999-2000
- The experimental field area
- Soil data
- Crop data
- The collected actual yield during growing period.
- LANDSAT-TM imagery of dated 11 January 2000

Therefore, to success the "WOFOST" simulated yield on this phase, the flowcharts of data processing and the used method for field scale will be carried out as presented in Figures 6 respectively. In addition to, also for the computation of NDVI values for Landsat-TM imagery, the flowchart of data processing for RS&GIS integration techniques, the used method and equation would have been shown on Figure 7.

Phase II: Scaling up to Regional scale estimation as Nakhon Ratchasima province by RS&GIS

Data were collected in variety of sources and the form of digital, analog, tabular data, reports, and field survey. The basic data used in this scale study were:

- LANDSAT-TM imageries of Nakhon Ratchasima province of dated 2, 18 February 1999 and 4, 11 January 2000.
- NOAA-AVHRR imagery of Nakhon Ratchasima province of dated 17 January 1999 and 4 January 2000 and 10-days composite imageries during May-July 2000.

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

- Soil map of Nakhon Ratchasima province showing the area where the sweet corns were planted.
- Sweet corn actual yields statistical report of from Department of Agricultural Extension of year 2000 in Nakhon Ratchasima province by district namely; Dan Khun Tod, Khon Buri, Pak Chong, Pak Thong Chai and Wang Nam Kaew.

For the computation of Landsat-NDVI and NOAA-NDVI value means, the ratio or a difference of reflectance values in the visible and the near infrared (NIR) region of the spectrum were condensed the multi-spectral information into one band to discriminate the vegetation condition and then, the relationship between these both of the accumulated NDVI value means would have been generated for estimating the actual yield in regional scale later on.

Phase III: Incorporating global climate event mode

In concerning with the global climate events namely: El Nino, La Nina and Normal events. All data would be used in this phase were:

- Climatic statistical report about El Nino, La Nina and Normal years during 1950-2002 from Climate Prediction Center, NOAA.
- NOAA-AVHRR NDVI imageries data set of Nakhon Ratchasima province during 1992-2000.
- Sweet corn actual yields statistical report from Department of Agricultural Extension of year 1997-2000 in Nakhon Ratchasima province by district namely; Dan Khun Tod, Khon Buri, Pak Chong, Pak Thong Chai, and Wang Nam Kaew respectively.

Lastly, the output of relationships between actual yields with the accumulated NDVI values means of NOAA-AVHRR imageries in regional scale phase would have been used to correlate with each of El Nino, La Nina, and Normal events correspondingly. Consequently, the new relationship in term of multiple linear regressions for estimating the sweet corn production on global scale between the sweet corn production on district level of Nakhon Ratchasima province, the accumulated NDVI values means of NOAA-AVHRR, and each of El Nino, La Nina, and Normal events would be generated in advance as required.

Results

Because of this study aimed at estimate the sweet corn production on several scale. So, the results would have been manipulated and focused on three scales namely: field scale, regional scale, and global scale, respectively.

For field scale

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

Results in term of modeling

The simulated yield from model output in term of total above ground dry weight product (TAGP) have been compared and correlated with the collected dry matter biomass actual yield from each replication in the study area. The result of these two data set has been shown in simple linear regression with correlation coefficient (γ) = 0.63, standard error (*SE*) = 659.905 kg/ha, which it could have been summarized that both of data set had a close relationship in the same direction and could be a representative for each other.

Result in term of RS&GIS techniques

The technique of NDVI would be employed to convert the Landsat-TM data of study area from False Color Composite imagery (FCC, R=4, G=3, B=2) to NDVI imagery. And the mean of NDVI values for each replication from C1-H5D would have been calculated later on. The results of the relationship between a simulated yield and the accumulated NDVI values mean of Landsat-TM data had been correlated in a simple linear regression with correlation coefficient (γ) = 0.97, standard error (*SE*) = 0.634 kg/ha, which it could have been summarized that both of data set had a very close relationship in the same direction and could be a representative for each other.

Solution of the relationship between actual yields and accumulated NDVI values mean of Landsat-TM data.

In conclusion for field scale, the final solution in form of simplified equations had been done using the relationship between equation 1 and 2. Finally, coming up with the simplified solution as equation 3.

For regional scale

Results of scaling up to regional scale in term of RS&GIS techniques

The accumulated NDVI values mean of NOAA-AVHRR data and of Landsat-TM data of year 1999-2000 have been employed to correlate between these two data set. The result had been shown in a simple linear regression relationship as equation 4 with correlation coefficient (γ) = 0.99, standard error (*SE*) = 0.0984 which it could have been summarized that both of data set had a very close relationship in the same direction and could be a representative for each other.

Solution of the relationship between actual yields and accumulated NDVI values mean of NOAA-AVHRR data

In conclusion for regional scale, the final solution in form of simplified equations had been done using the relationship between equation 3 and 4. Finally, coming up with the simplified solution equation, which was the yield estimating equation between actual yields

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

and accumulated NDVI values mean of NOAA-AVHRR imageries for regional scale as the equation 5.

Validation the final solution for regional scale

For validation the final solution of equation 5. Therefore, the NDVI 10-days composite imageries of NOAA-AVHRR that have been resized pixel resolution from 1.1 km to 30 m for better accuracy at district level of Nakhon Ratchasima province during May-July 2000 and would be calculated for the accumulated NDVI mean for each district with replacing for a value of Y_3 in equation 5 and then, the results would be coming up with X_1 as estimated yield (kg/ha) for regional scale, which had been summed up into 5 districts namely: Dan Khun Tod, Khon Buri, Pak Chong, Pak Thong Chai and Wang Nam Kaew respectively.

Lastly, these estimating values had been used for comparing with the local agricultural report from Department of Agricultural Extension for sweet corn actual yield on district level of Nakhon Ratchasima province that had been collecting during May-July of year 2000. The final results of a relationship between the estimated yield from equation 5 and collected actual yield from the field could have been shown in a simple linear regression with correlation coefficient (γ) = 0.981, Significance level .01%, *df* = 3, which it should have been summarized that both of data set had a very close relationship in the same direction and could be a representative for each other.

Results and discussions of incorporating global climate events

From the result of the final solution for regional scale, which had been assumed that it would be the represented solution for the estimating the sweet corn yield using the accumulated NDVI values mean of NOAA-AVHRR in large scale. To success in these challenging tasks, it needs to classify any natural events in the world, which had been concerning and effecting on the growth of sweet corn plantation in any area into three category events namely El Nino, La Nina, and Norma. In which each event would be effected on sweet corn yield in different impacts such as El Nino might be caused of more water like as flooding , La Nina as drought, and Normal as usual event respectively. Consequently, we had decided to use the climatic statistical report from Climate Prediction Center of U.S.A. of year 1992-2002, as guideline to consider the impact of climate conditions on sweet corn yield estimating by using the final solution that had been investigated for regional scale in this study as aforementioned was to up scaling incorporating with global events in each of El Nino, La Nina, and Normal lastly.

List of the sweet corn yield estimating solutions for Nakhon Ratchasima province with El Nino, La Nina, and Normal events as shown on Table 1.

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

General Solution for El Nino, La Nina, and Normal events

$$\mathbf{Y = \alpha\ Xi + \beta\ Zi + \gamma} \quad (6)$$

Where

Y : Estimated yield (kg/ha)

X_i : Accumulated NDVI mean value; i = 1-12

Z_j : Climatic event namely : El Nino (E), La Nina (L), and Normal (N) events respectively; j = E, L, N

α , β, γ : Constant

C_k : Crop stage on monthly basis from planting to harvesting Namely: S_k = starting month for planting, E_k = estimating month for crop yield; k = 1-12

Verification the final solution for incorporating global climate events

To verify the final solution for incorporating global climatic events of El Nino, La Nina, and Normal years, by comparing the sweet corn actual yield report by district in Nakhon Ratchasima province during 1998-2001 from Department of Agricultural Extension with each of El Nino, La Nina, and Normal years. Then, we found that the correlation between those two data set, which were shown in simple linear regression with correlation coefficient (γ) = 0.57, Significance level .01%, *df* = 3 for El Nino event in 1998, (γ) = 0.81, 0.91, Significance level .01%, *df* = 2, for La Nina events in 1999 and 2000, (γ) = 0.81, Significance level .01%, *df* = 2 for Normal event in 2001 respectively.

From these results of verification, which we had found that they could have been supporting and compromising with our assumption as aforementioned explanation by insisting that La Nina event would give the most highly correlation, followed by Normal and El Nino event solution respectively. It means that most of data set has a close relationship in the same direction and can be a representative for each other. Finally, in which the comparison of results between sweet corn estimated and collected yields by district in Nakhon Ratchasima province for all events during 1998-2001 namely; El Nino (E), La Nina (L), and Normal (N) also found that the tendency of two data set have some possible similarity and corresponding with each other as shown on figure 36.

Conclusions and Recommendations

Nowadays, the Royal Thai Government has been trying to issue a motto of Thailand so-called “Kitchen of the World” in meaning that all Thai crop production will be an engine to stimulate buying potential everywhere in the world for increasing the income of Thai government sectors. To work out this task, not only extending a number of crop plantation area, where is a specific location for sweet corn and other cash crop such as rice, sugarcane, cassava, pineapple etc., into a land suitability areas throughout country, but the related crop

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

production estimating techniques also need to develop and improve a new approaches for increasing more accuracy with successful when it is used to apply in the field reality.

Consequently, there are several kinds of techniques are used to estimate each crop production in planted areas of Thailand. These techniques can be initiated operationally at field scale; such as the “WOFOST ” model is one of the popular technique in this level, which is used in the most of country particularly among European communities. Apart of this, in currently this model has been used with successful in some countries of Asia continental like as The Philippines, India, Viet Nam, Sri Lanka and coming lastly for Thailand, which is a new issue that need to trial and implement continuously in order to improve and develop some approaches or conditions and changing for more accuracy and appropriate using for the environmental circumstance here.

In addition, also for estimating the crop production on regional and global scales in Thailand, the interdisciplinary of agrometeorology and the integration of remote sensing and geographic information system techniques are rather a new tool and challenging for initiating on the real area in this region and still need some improvement in the near future.

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[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

Tables

Table1. List of the sweet corn yields estimating solutions

C_k	Equation	Corr. Coeff.	Significance level, *df*
	El Nino events (E)		
$S_1, E_{2,3}$	$Y=5.250 \times 10^3 X + 3.0918 \times 10^4 - 1.174 \times 10^3$	0.99	.05%, 1
$S_2, E_{3,4}$	$Y=9.250 \times 10^3 X + 8.456 \times 10^3 + 9.55 \times 10^2$	0.83	.10%, 1
$S_3, E_{4,5}$	$Y=12892 \times 10^4 X + 1.56856 \times 10^5 - 1.0716 \times 10^4$	0.80	.10%, 1
$S_{10}, E_{11,12}$	$Y=4.385 \times 10^3 X + 5.4613 \times 10^4 - 4.371 \times 10^3$	0.95	.11%, 1
	La Nina events (L)		
$S_1, E_{2,3}$	$Y=1.8138 \times 10^4 X - 1.31072 \times 10^5 + 1.1076 \times 10^4$	0.56	.10%, 1
$S_2, E_{3,4}$	$Y=1.0370 \times 10^4 X - 8.2968 \times 10^4 + 8.347 \times 10^3$	0.93	.10%, 1
$S_3, E_{4,5}$	$Y=7.444 \times 10^3 X + 8.1920 \times 10^4 - 8.175 \times 10^3$	0.96	.10%, 1
$S_4, E_{5,6}$	$Y=5.473 \times 10^3 X + 4.9152 \times 10^4 - 4.183 \times 10^3$	0.99	.05%, 1
$S_5, E_{6,7}$	$Y=6.856 \times 10^3 X - 5.67132 \times 10^4 + 4.010 \times 10^3$	0.99	.05%, 1
$S_{10}, E_{11,12}$	$Y=3.336 \times 10^3 X + 1.14688 \times 10^5 - 6.924 \times 10^3$	0.62	.10%, 1
	(N)Normal events		
$S_3, E_{4,5}$	$Y=-4.779 \times 10^3 X + 6.533 \times 10^3 - 1.503 \times 10^3$	0.70	.10%, 1
$S_{10}, E_{11,12}$	$Y=6.765 \times 10^3 X - 5.0412 \times 10^4 + 1.897 \times 10^3$	0.95	.10%, 1

Figures

Figure 1. The overall concept of research design

Phase	Scale	Analysis	Data used
1	Field Scale	- Crop Growth Simulation Model "WOFOST" - Integration of RS&GIS techniques - NDVI analysis - Regression analysis	- Daily meteorological parameters; solar radiation, max-min air temp., relative humidity, rainfall and wind speed. - Soil mapping unit data - Crop data - Actual yield from the field - Landsat-TM 1 scene of year 2000
		↓	
2	Regional Scale	- Integration of RS&GIS techniques - NDVI analysis - Regression analysis	- Landsat-TM 4 scenes - 10 days NOAA-AVHRR 1 data set and 1 scene - Land use map, Soil map - Agricultural statistics
		↓	
3	Global Scale	- Integration of RS&GIS techniques - NDVI analysis for El Nino, La Nina, and Normal events - Regression analysis	- El Nino, La Nina, and Normal events statistics - NOAA-AVHRR for 35 scenes - Land use map, Soil map - Agricultural statistics

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
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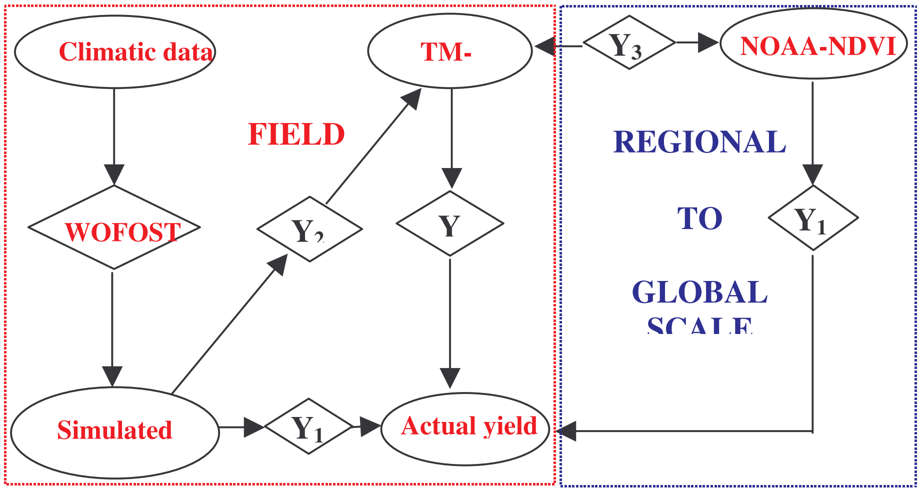
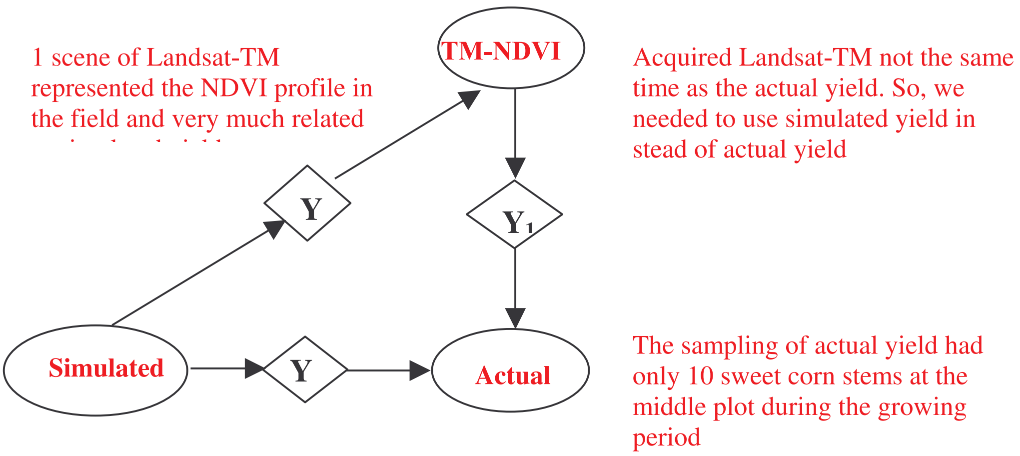
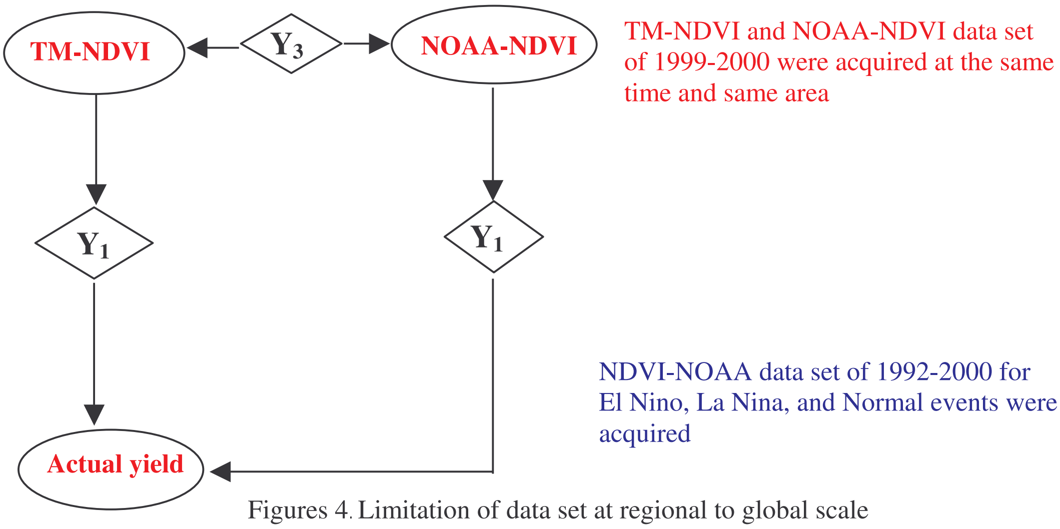


Figures 2. Linkage of the framework for this study



Figures 3. Limitation of data set at field scale



Figures 4. Limitation of data set at regional to global scale

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
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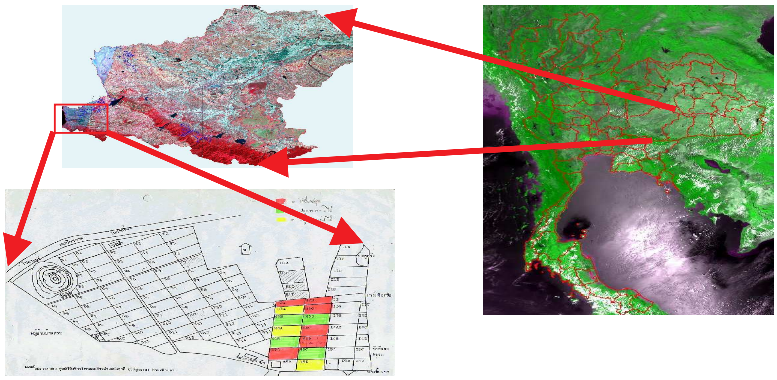


Figure 5. Location of the study area

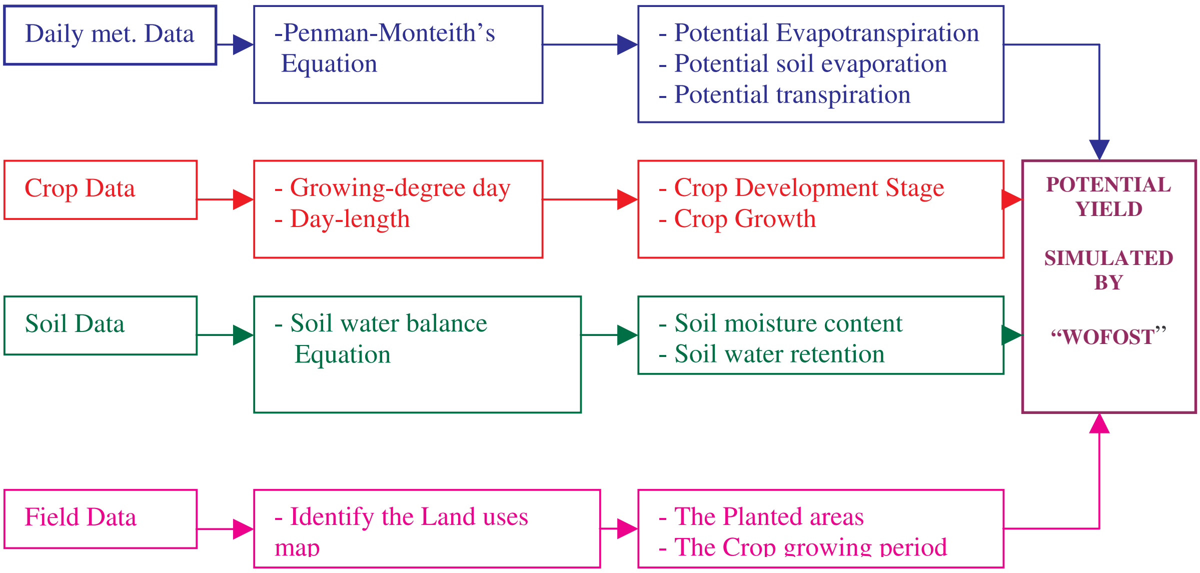


Figure 6. Flow chart of data processing for WOFOST model

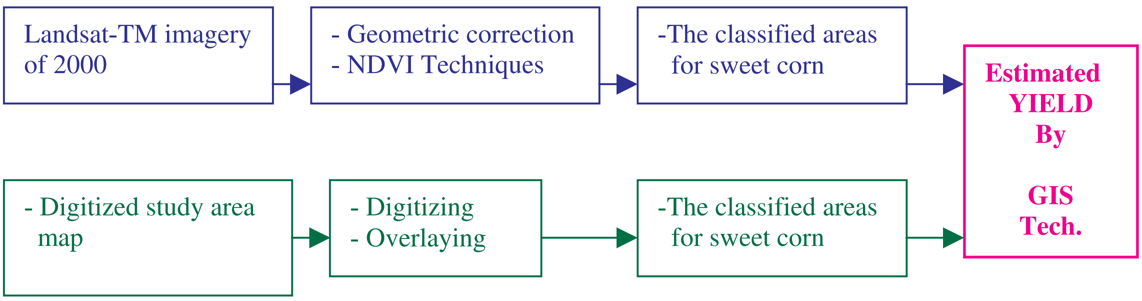
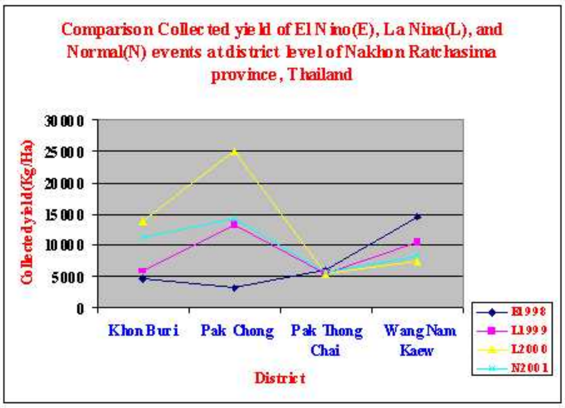
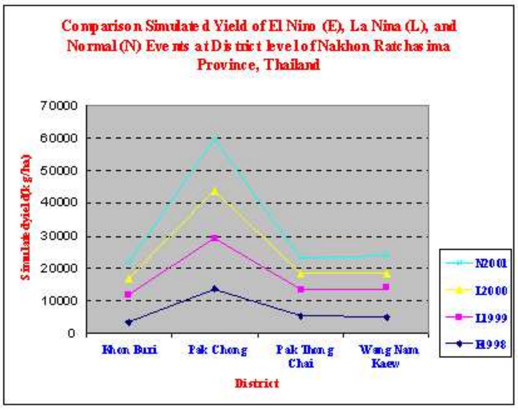


Figure 7. Flow chart of data processing for RS&GIS Integration Techniques

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp

Figure 36.Comparison sweet corn estimated and collected yields of El Nino, La Nina, and Normal events at district level of Nakhon Ratchasima province of year 1998-2001





Equations

$$Y_1 = (3.6 \times 10^{-1})X_1 + 4.785 \times 10^3 \quad (1)$$

Where Y_1 : Actual yield in term of dry matter biomass (kg/ha)
X_1 : Simulated yield (kg/ha)

$$Y_2 = (1.0 \times 10^{-4})\ X_2 + 18.8 \times 10^{-1} \quad (2)$$

Where Y_2 : Accumulated NDVI values mean of Landsat- TM data
X_2 : Simulated yield (kg/ha)

Solution: $$Y_1 = (3.56 \times 10^2)Y_2 + 4.116 \times 10^3 \quad (3)$$

Where Y_1 : Actual yield (kg/ha)
Y_2 : Accumulated NDVI values mean of Landsat imageries

and $$Y_3 = (4.8 \times 10^{-1})\ X_3 + 5.2 \times 10^{-2} \quad (4)$$

because $Y_2 = X_3$

Both were the same accumulated NDVI values mean of Landsat-TM data

Final solution: $$Y_1 = (7.42 \times 10^2)\ Y_3 + 4.078 \times 10^3 \quad (5)$$

Where Y_1 : Actual yield (kg/ha), which would become estimated yield later on for the next step.
Y_3 : Accumulated NDVI values mean of NOAA-AVHRR imageries for regional scale.

[1]S. Baimoung, Thai Meteorological Department, 4353 Sukhumvit Rd., Phrakanong, Bang Na, Bangkok 10260, THAILAND, somchaib@tmd.go.th
[2] T. Oki, Institute of Industrial Science, University of Tokyo, 4-6-1Komaba, Meguro-Ku, Tokyo 153-8505, JAPAN, taikan@iis.u-tokyo.ac.jp