ESTIMATION OF THE RICE YIELD IN THE MEKONG DELTA USING SAR DUAL POLARISATION DATA

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ABSTRACT: Food security has currently become a key global issue due to rapid population growth in many parts of Asia, as well as the effects of climate change. For this reason, there is a need to develop a spatio-temporal monitoring system that can accurately assess rice area planted and rice production.

Changes in rice cultivation systems have been observed in various countries of the world, especially in the Mekong Delta, Vietnam. The changes in cultural practices have impacts on remote sensing methods developed for rice monitoring, in particular, methods using new generation radar data. The objective of the study was to estimate the rice yield using time-series Synthetic Aperture Radar (SAR) imagery.

Field data collection and in situ measurement of rice crop parameters were conducted in An Giang province, Mekong Delta in 2010. The average values of the radar backscattering coefficients that corresponded to the sampling fields were extracted from the TerraSAR-X StripMap (TSX SM) images taken during a crop season. The temporal rice backscatter behaviour was analysed for HH (Horizontal transmit and Horizontal receive), VV (Vertical transmit and Vertical receive), and polarisation ratio data. For rice yield estimation, the predictive model based on multiple linear regression analysis (Lam-Dao, N. et al., 2009a) between in situ measured yields and polarisation ratios attained good correlation and thus proved to be a potential tool for estimating rice production in the study area.

1. INTRODUCTION

A primary objective of rice monitoring is rice yield estimation. Accurate crop production estimates can provide important information for agricultural planners and managers in both regional and national scales. This information can be computed on the basis of an estimated yield and rice acreage.

Traditionally, estimates of rice planting area and productivity are based on ground survey data. It is often time-consuming and expensive. In the early 1980s, much attention was paid to using optical remote sensing for crop yield estimation all over the world. Remarkable achievements were obtained after many studies were carried out (Li et al., 2003). Nevertheless, because of the limitations of the data acquisition for optical remote sensing, it was very difficult to carry out real-time monitoring of crop growth and estimate rice yield promptly based on these methods. Hence, radar remote sensing is the obvious choice as the most appropriate data source for agricultural monitoring and crop yield estimating in large areas in the tropical and sub-tropical regions (e.g. Ribbes and Le-Toan, 1999, Li et al., 2003, Chen and Mcnairn, 2006).

There have been many studies on the use of radar remote sensing data to estimate the yield, including the yield estimation model (Lam-Dao, N., 2009b) based on multiple linear regression analysis between *in situ* measured yield and the polarisation ratios HH/VV of dual polarisation ASAR APP images (cycle of 35 days). This study is to estimate rice yield and finally rice production using TSX SM images with high spatial resolution (3 m), short repeat cycle (11 days) and the X-band (3.1 cm).

2. STUDY AREA AND DATA USED

In the Mekong Delta of Vietnam, the rainy season usually lasts for seven months from May to November, and floods annually occur starting from August. A dike system has been built and intensified in recent years to block the floodway into the fields during the flood season. This has increased the number of crops during the wet season from one crop to two crops of rain-fed rice, named Summer Autumn (SA) and Autumn Winter (AW) crops. In the dry season, an irrigated rice crop, Winter Spring (WS) has been grown.

The study area is the Cho Moi district of An Giang province (Figure 1), extending from 10^{o} 20’ to 10^{o} 35’ N latitude and 105^{o} 18’ to 105^{o} 35’ E longitude. Cho Moi district is an island surrounded by two branches of Mekong River (Tien and Hau rivers). Located about 190 km from Ho Chi Minh City, Cho Moi has an area of 369.62 square kilometres, with a population of about 369,443 people (AGSO, 2008).

a) b)

Figure 1. Location of An Giang province in the Mekong Delta (a) and Cho Moi in An Giang (b)
Source: http://gis.chinhphu.vn/

The TerraSAR-X data of X-band (9.65 GHz in frequency) that is used in the research with StripMap mode, HH&VV polarisation, incidence angle (34.9^{o} – 36.5^{o}), and ascending mode was available during Autumn-Winter 2010 crop season (Table 1). TerraSAR-X images have high spatial resolution of 3 m with a swath width of about 30 km, and a revisit interval of 11 days.

Table 1. Statistics of TSX SM HH&VV image acquisition date and days after sowing in Autumn-Winter 2010 crop in Cho Moi

Image No.	Date of image acquisition	Number of days after sowing
1	30/08/2010	8
2	10/09/2010	19
3	24/10/2010	63
4	04/11/2010	74
5	15/11/2010	85

3. METHODS

There are several steps for the pre-processing of multi-temporal TerraSAR-X StripMap mode data. The images were corrected for the incidence angle to the center; calibrating data with the calibration factor (Ks), speckle filter and conversion to the radar backscattering coefficient sigma naught (σ^{o}). This transformed TerraSAR-X images into intensity images expressed in σ^{o} in dB (decibel). Speckle filter was done to reduce the speckle effect in the images. In this work, enhanced Frost spatial filter has been applied to each image (Lopes, A. et al., 1990; Shi, Z. and Fung, K. B., 1994).

By using multiple linear regression analysis, the correlation between backscattering coefficients σ^{o} of multi-date TSX SM images acquired during the crop season and the *in situ* measured yield was derived. The distribution maps of estimated rice yield were then produced on the basis of that relationship. Consequently, rice production was finally estimated on the basis of these yield maps and rice/non-rice maps (Lam-Dao, N. et al., 2008) (Figure 2).

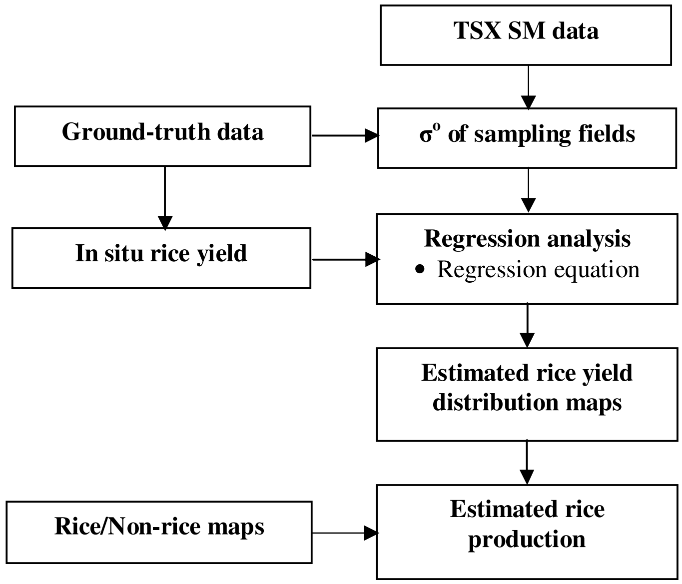


Figure 2. Methods used for rice production estimate

In this research work, rice parameters such as rice yield and sowing date of the sampling fields in AW 2010 of Cho Moi district were collected at 11 sampling fields with different seed varieties ranging from 95 to 105-day cycle. The method of multiple linear regression analyses between *in situ* measured yield and the backscatter coefficient of multi-temporal TSX SM images was used. To estimate the yield, at least three-date radar data of dual polarisation in the crop is needed. In AW 2010 crop five TSX SM images had been collected. Therefore, the research tried to use more than three and combination of them for better estimating the rice yield.

4. RESULTS AND DISCUSSION

In order to derive the relationship between rice yield and the polarisation ratio of multi-temporal TSX SM images for yield estimation, analysis of multiple linear regression was performed. In the case of three-date radar data used, the images should be acquired during the three growing stages of rice (vegetative, reproductive and ripening stages). As in the case 7, 8, 11 and 12, coefficient of determination of the HH/VV ratio higher than that in the case with absence of image acquired in the middle of the crop (such as the case 13, 14, 15, and 16). In the case of the images collected during the early and mid crop or mid and late rice crop, their coefficients of determination is higher than that of the case that absence image acquired in the mid crop (Table 2).

To estimate rice yield by using four or five-date data, the images need to be acquired in the three rice growing stages or in two first stages or two final stages. As in the case six, no radar images during the mid crop, a coefficient of determination is lower than that of the remain cases. We found that if more than three radar images are selected for multiple linear regression analysis, then the coefficient of determination is higher. Results of regression analysis of HH/VV pointed out that with three-date data distributed in the three stages (in the case 7 and 8) used also gives the coefficient of determination almost the same to the case of more than three used (Table 2).

Table 2. Correlation between HH/VV ratio and sample rice yield in AW 2010 crop of Cho Moi district

Case	Image combination	r^2
1	1, 2, 3, 4, 5	0.795
2	2, 3, 4, 5	0.795
3	1, 2, 3, 5	0.781
4	1, 3, 4, 5	0.779
5	1, 2, 3, 4	0.681
6	1, 2, 4, 5	0.494
7	2, 3, 5	0.781
8	1, 3, 5	0.765

9	3, 4, 5	0.754
10	1, 2, 3	0.659
11	1, 3, 4	0.623
12	2, 3, 4	0.614
13	1, 2, 5	0.494
14	2, 4, 5	0.401
15	1, 4, 5	0.379
16	1, 2, 4	0.088

In this paper, the rice yield was estimated for the cases 1 and 7 using five and three-date TSX SM data, respectively. Regression equations between in situ measured rice yield and polarisation ratio for case 1 and 7 in AW 2010 crop at Cho Moi district was formulated as follows:

$$Y_{Ra} = 0.0008*Ra_1 - 0.0414*Ra_2 + 0.0071*Ra_3 - 0.0009*Ra_4 + 0.0930*Ra_5 + 0.4949 \quad (1)$$
$$r^2 = 0.795,\ se_y = 0.18 \text{ ton/ha}$$

$$Y_{Ra} = -0.0422*Ra_1 + 0.0068*Ra_2 + 0.0969*Ra_3 + 0.4918 \quad (2)$$
$$r^2 = 0.781,\ se_y = 0.16 \text{ ton/ha}$$

where

Y_{Ra} : estimated rice yield (kg/m^2),
Ra_1 : polarisation ratio of first date image,
Ra_2 : polarisation ratio of second date image,
Ra_3 : polarisation ratio of third date image,
Ra_4 : polarisation ratio of fourth date image,
Ra_5 : polarisation ratio of fifth date image,
r^2 : the coefficient of determination,
se_y : the standard error for the y estimate.

The coefficient of determination and the standard error for the rice yield estimate in the case 1 and 7 were 0.795, 0.781; and 0.18, 0.16 ton/ha, respectively. It indicates that the relationship is positive and can be consequently used to predict the yield for all rice fields planted in AW 2010 crop season at the Cho Moi district.

The yield of rice fields was estimated on the basis of the correlation between *in situ* rice yield and polarisation ratios (Equation 1, 2) and classified into 17 yield levels, ranging from 0.5 to 10 ton/ha. The rice fields with estimated yield levels ranging from 5 to 7.5 ton per hectare were dominant and occupied 87.5% and 87.2% total of rice area planted in this crop season for the case 1 and 7, respectively (Table 3, 4).

Table 3. Yield estimation for AW 2010 crop in Cho Moi district using five-date polarisation ratio

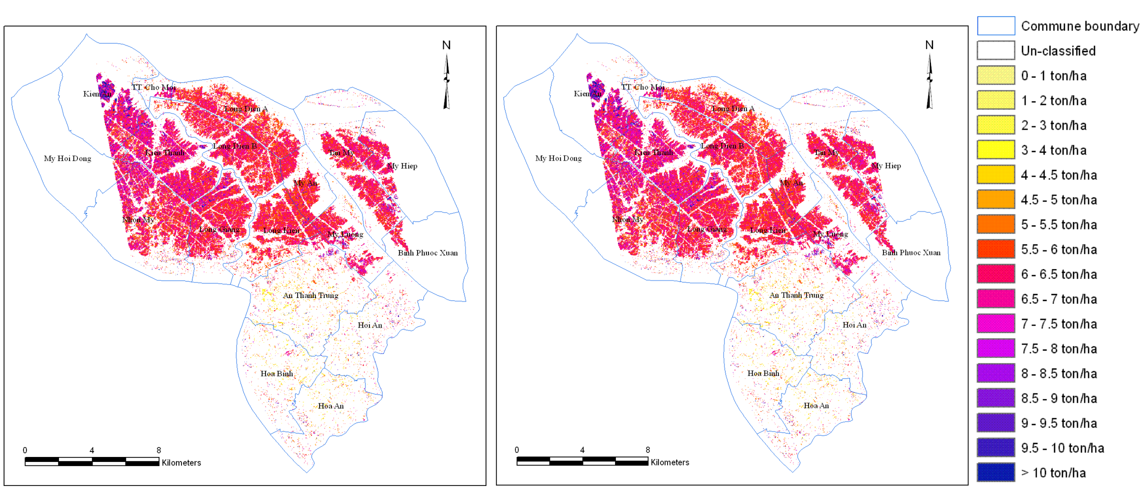
No.	Rice area (Ha)	Estimated yield (Ton/Ha)	Estimated production (Ton)	Percentage (%)
1	5.8	0.50	2.9	0.06
2	12.7	1.50	19.0	0.14
3	28.8	2.50	72.1	0.31
4	66.1	3.50	231.5	0.71
5	65.7	4.25	279.3	0.70
6	169.6	4.75	805.7	1.81
7	886.5	5.25	4654.0	9.48
8	2558.2	5.75	14709.8	27.36
9	2550.0	6.25	15937.6	27.27
10	1474.2	6.75	9950.5	15.77
11	714.2	7.25	5177.8	7.64
12	336.8	7.75	2610.6	3.60
13	170.1	8.25	1403.5	1.82
14	93.8	8.75	820.9	1.00

15	54.4	9.25	502.9	0.58
16	35.3	9.75	344.1	0.38
17	127.0	10.00	1269.8	1.36
Sum	**9349.3**		**58792.1**	**100.00**

Table 4. Yield estimation for AW 2010 crop in Cho Moi district using three-date polarisation ratio

No.	Rice area (Ha)	Estimated yield (Ton/Ha)	Estimated production (Ton)	Percentage (%)
1	6.1	0.50	3.0	0.06
2	13.3	1.50	20.0	0.14
3	29.9	2.50	74.8	0.32
4	66.6	3.50	233.0	0.71
5	66.1	4.25	281.1	0.71
6	173.8	4.75	825.4	1.85
7	874.8	5.25	4592.5	9.34
8	2512.1	5.75	14444.3	26.81
9	2546.4	6.25	15914.9	27.17
10	1500.9	6.75	10131.2	16.02
11	736.5	7.25	5339.6	7.86
12	348.8	7.75	2703.3	3.72
13	176.5	8.25	1455.9	1.88
14	96.3	8.75	842.6	1.03
15	56.1	9.25	519.1	0.60
16	36.0	9.75	350.7	0.38
17	130.3	10.00	1303.2	1.39
Sum	**9370.4**		**59034.6**	**100.00**

Distribution maps of estimated yield of the rice fields planted in AW 2010 crop at Cho Moi district using five-date and three-date polarisation ratios were plotted (Figure 3). Most of the rice fields with yield ranging from 5 to 7.5 ton/ha were distributed throughout the district.



a) b)

Figure 3. A distribution map of estimated rice yield in AW 2010 crop at Cho Moi district using five-date (a) and three-date (b) polarisation ratio data

The results of the above analysis using the multiple linear regression equation proved that the statistical model-based method worked very well in the case of AW 2010 crop at Cho Moi district where the relationship between in situ yield point data and polarisation ratio data was positive with the high correlation coefficient of 0.892 in case 1 and 0.884 in case 7.

5. CONCLUSIONS

The statistical model-based method worked very well in the case of Cho Moi district where the relationship between in situ measured yield point data and polarisation ratio data derived from multi-date TerraSAR-X StripMap images was positive with the high correlation coefficient.

Research results showed that the higher correlation between *in situ* rice yield and polarisation ratio data, when more polarisation ratio data is used for regression analysis and one of these ratios must be collected in the middle of the rice crop. The study also pointed out that at least three-date data of TerraSAR-X StripMap can be used to estimate the rice yield.

Further research should be done to assess the accuracy of predicted rice production, improve and validate the statistical model-based method for predicting the rice production in the study area, Mekong Delta using dual polarisation TerraSAR-X data.

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