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Temporal and Spatial Delineation the Rice Growing Stages for Cropping Calendar Estimation in the Southern of Vietnam using Remote Sensing

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ABSTRACT

Background: MODerate resolution imaging spectroradiometer (MODIS) is the crucial instrument aboard. It provides global maps of several land surface characteristics.

Method: The study uses MODIS to delineate the rice sowing and progress of the rice cropping calendar in the Vietnamese Mekong Delta. The study used multi-time series of normalized difference vegetation index (NDVI) images from 250 m spatial resolution MOD13Q1 images with 16-day combination to determine rice sowing/planting and harvesting schedules (from 01/01/2008 to 30/09/2009). Using 82 MODIS images, the study calculates the NDVI time series for rice sowing/transplanting stages in the Mekong Delta. Over time, the relationship between NDVI values and the rice cropping stages determines each cropping season starting and ending time.

Result: As a result, we delineate three (3) major rice cropping systems and eight (8) cropping seasons. In which Main Winter-Spring and Early Summer-Autumn and Late Main Winter-Spring and Main Summer-Autumn cropping seasons dominated. MODIS satellite images are efficient and helpful for determining the current state of rice evolution. It is suitable for the regional or national level, which can provide quick and low-cost information for managers and decision-makers to select the proper strategies for crop management.

Key words: MODIS, NDVI, Rice sowing, Transplanting, Satellite images, Season.

INTRODUCTION

Rice plays an essential role in ensuring food security and socio-economic stability in Vietnam. The country has nearly 89 million consumers and is a necessary source of income for more than 60 million agricultural producers in rural areas (ADB, 2012). However, rice production in the Mekong Delta (MRD) has increased continuously, averaging 0.02%/year in planted area and 0.04%/year in yield over the past 20 years (1995–20). 2015). During this period, rice production focuses on meeting production goals rather than improving quality. In 2020, the Government expected to slightly reduce and shift from increasing quantity to enhancing the quality and adding value to the rice value chain. (Nguyen, 2017). However, the rice pest outbreak has affected rice yield and production. Therefore, the Government needs to adopt the results to monitor and supervise each locality and early forecast rice pest situations at each level.

Usually, the Government adopts the monitoring for cropping season mainly by surveys, reports from local officers. However, it requires time-consuming funding and less accuracy. The techniques use remote sensing images to delineate natural features in many countries worldwide (Burrough, 1986). The results can monitor the sowing progress and cropping calendar on a large scale, thereby proposing solutions to manage the rice crop. The study mainly uses MODIS images as a source of data to develop the procedure to monitor the rice crop progress for cropping calendar estimation in the MKD.

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MATERIALS AND METHODS

The study area

The Vietnamese MKD (12% of the country's total area) is necessary for national food security (Cosslett and Cosslett, 2014, Anthony *et al*., 2015, Smajgl *et al*., 2015). Besides, approximately one-fifth of the Vietnamese population represents 17.6 million people GSOV, 2015). The delta is a tropical monsoon climate, with a dry season from December to May and a wet season from June to November (Cosslett and Cosslett, 2014). The MKD covers 39,000 km^2 (Fabrice and Kuenzer 2012).

The study was carried out at Cantho University, Vietnam, for images collection and processing during 2020. The University locates in the Centre of the Mekong delta (Fig 1)

The satellite images collection

The images collected from NASA, code MOD13Q1, the images spatial resolution of 250m and temporal resolution with the 16 days from 1 January (2008) to 14 September (2009), 4800 x 4800 pixels/image rectified. Eighty-two (82) images were collected. We developed the NDVI time-series images for Rice showing stages and cropping calendar determination. Red and Near-Infrared bands processed for calculation NDVI (Table 1).

The development of the normalized different vegetation index (NDVI)

NDVI is an active vegetation index for the global range of activities, partly due to its "rates" nature. It allows NDVI to filter out most of the noise caused by clouds, shade, changes in sun angle, topography and atmospheric conditions (Huete, A.R.; Justice C, 1999). The study use spectrum bands of visible, near-infrared, infrared and red to create NDVI. Besides, it differentiates the intermediate evaluation for characteristics of materials such as biomass, leaf area index and photosynthetic capacity seasonally. Those characteristics are relevant and highly dependent on the type of plant cover and weather, physiological characteristics, biochemical and pests. Thus, NDVI average in time series data is the primary tool to monitor changes in vegetation status, which can assist in understanding the impact of weather and climate on the biosphere. The calculation of NDVI shows as follows:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \quad ....(1)$$

The relationship between NDVI values and Rice growing stages

Because NDVI value of crops changing in a specific situation and the same direction. Based on Parida *et al.*'s (2008) research results, the proposed NDVI values are shown in Table 2.

Monitoring the rice sowing for cropping calendar delineation

The study calculates and delineates the time-series NDVI values to determine the relationship between NDVI indexes for Rice growing stages. The Low NDVI value at the early stage gradually increased and got peaked at the tillering stage. The NDVI value decreased when Rice began to mature and be harvested (Fig 2).

Data validation and accuracy assessment

The kappa coefficient of Cohen (κ) is a statistic formula to calculate inter-rater reliability (Intra-rater reliability) for qualitative (categorical) items (McHugh, 2012). However, some studies have recommended that assessing disagreement between items becomes conceptually more straightforward. (Pontius and Millones 2011).

Cohen's Kappa measures agreement between two raters, who classify N items into mutually exclusive C. The definition of κ is:

$$\kappa = \frac{p_o - p_e}{1 - p_e} - 1 - \frac{1 - p_o}{1 - p_e}$$

Where

p_o is the relative observed agreement among raters (identical to accuracy) and p_e is the theoretical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly seeing each category.

Among the rates, if there is no agreement other than expected (as given by p_e), $\kappa = 0$. Therefore, the statistic may be negative (Sim and Wright 2005), which means there is no effective agreement between the two reviewers.

The study collected 479 locations for validation during 2020 for accuracy assessment and comparison with the government statistical data of the interpreted year data.

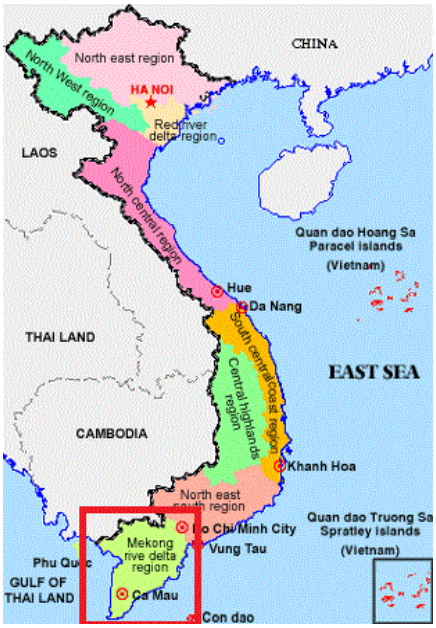

Fig 1: The Mekong river delta in Vietnam.

Table 1: The spectral bands of MODIS sensors used in the calculation of vegetation indices.

MODIS band	Wavelength (μm)	Resolution (m)
1	0.620 to 0.670	250
2	0.841 to 0.876	250

Table 2: Criteria used to classify land use (Parida *et al.*, 2008).

NDVI ranges	Land uses
NDVI> 0.74	Forest
0.74 <NDVI> 0.46	Irrigated crops
0.46 <NDVI> 0.20	Rainfed crops
0.20 <NDVI> 0.15	Fallow land
0.15 <NDVI> 0.05	Bare Soils
0.05 <NDVI> 0.001	Salt pans
NDVI <-0.001	Water

RESULTS AND DISCUSSION

Temporal NDVI image interpretation

Each NDVI images allow monitoring changes in vegetation status, represented by the difference of NDVI index at a particular time, corresponding to the level of low or high values. By analyzing NDVI images in 2008, a few images where homogenous tone (light or dark) remain changes over time. The NDVI maps for the Mekong delta created from MODIS images of 12 months are shown in Fig 3. The first six months of 2008 showed that the coastal areas and the Ca Mau peninsula have very low NDVI (brightness color) and did not significantly change. In contrast, in AnGiang, DongThap, CanTho, HauGiang provinces have high NDVI values in January, February and decreased in March, April and increased in May and June. The color of difference NDVI values tends to darken over time (lowering NDVI) in the coastal area, especially in the last six months of 2008. In contrast, the NDVI value decreased in September, October and November in AnGiang, DongThap and Kien Giang provinces. The results in 2009 also showed similar variation.

Analysis of variation in NDVI values

Usually, suppose the NDVI index peaks (from 0.5 to 0.9) are the regions with well-developed. In that case, Rice is in tillering/maturing/flowering or industrial crops/fruit trees/ forests. If NDVI < 0.5, there is no poor plant growth, specialized areas such as shrimp, salt, waterlogging, or sowing rice. The NDVI values of uncultivated are often stable throughout the year-the NDVI values of objects that do not have high fluctuations over time split into separate objects. The changes in NDVI sinusoidal shape reached maximum values at 0.8-1.0, corresponds to the complete growing stage and decreased to about 0-0.4 when the crops were harvested. This value continues to increase as a rule when starting a new season. Depending number of rotations per year, there were mono, double and triple rice crops in the Mekong delta (Fig 4, 5, 6, respectively).

The progress of rice sowing

Based on the temporal variation of NDVI, the study delineates the rice sowing progress in different provinces (Fig 7 and Table 3) for the rice cropping calendar estimation for mono, double and triple rice cropping calendars (Fig 10, 11, 12, respectively). The rice cropping calendar helps the Government decide the date of rice seedling, or transplanting, depending on the freshwater supplied from the river or saline water intrusion.

Interpretation accuracy assessment

The interpreted image accuracy assessment adopts the Cohen's kappa coefficient (κ) and 479 locations. The validation results show:
Overall accuracy = 90,351%; Kappa coefficient = 0.902

Comparison with statistical data

The results compared with official data for 2009, supported by Southern Center for Crop protection, which showed very high determination coefficiency (R^2 = 0.812**; n = 481, df = 479) (Fig 8 and 9). So then, the results are pretty reliable and can be used in monitoring the status of rice cropping stages.

Main rice cropping calendars in the Mekong Delta

We determine each cropping season's starting and ending time-based on the relationship between NDVI values and the rice cropping stages over time. It can assist in developing the major rice cropping calendars for the study area.

Mono rice cropping (Traditional rice)

The Mono rice crops distribute along the coast from LongAn, BenTre, TraVinh and Soctrang, BacLieu and CaMau provinces. The transplanting period ranges from August to the middle of September (Rice sowing in June, July) (Fig 10).

Double rice crops

This rice cropping calendar is most popular in the MKD (freshwater and slightly saline areas). The image interpretation showed that the NDVI index reached its maximum twice a year at different intervals depending on sowing time (Fig 11).

Summer-autumn and autumn-winter

The cropping calendar scatters distributed in the coastal areas. The autumn-winter starting date of rice sowing around

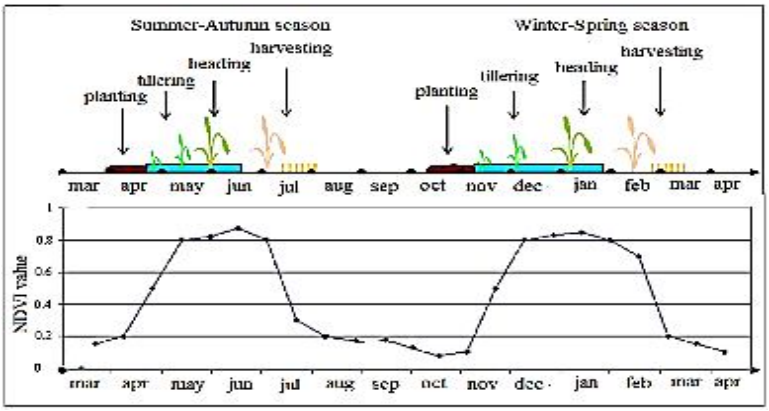

Fig 2: NDVI change at different rice growing stages in winter-spring and summer-autumn crops.

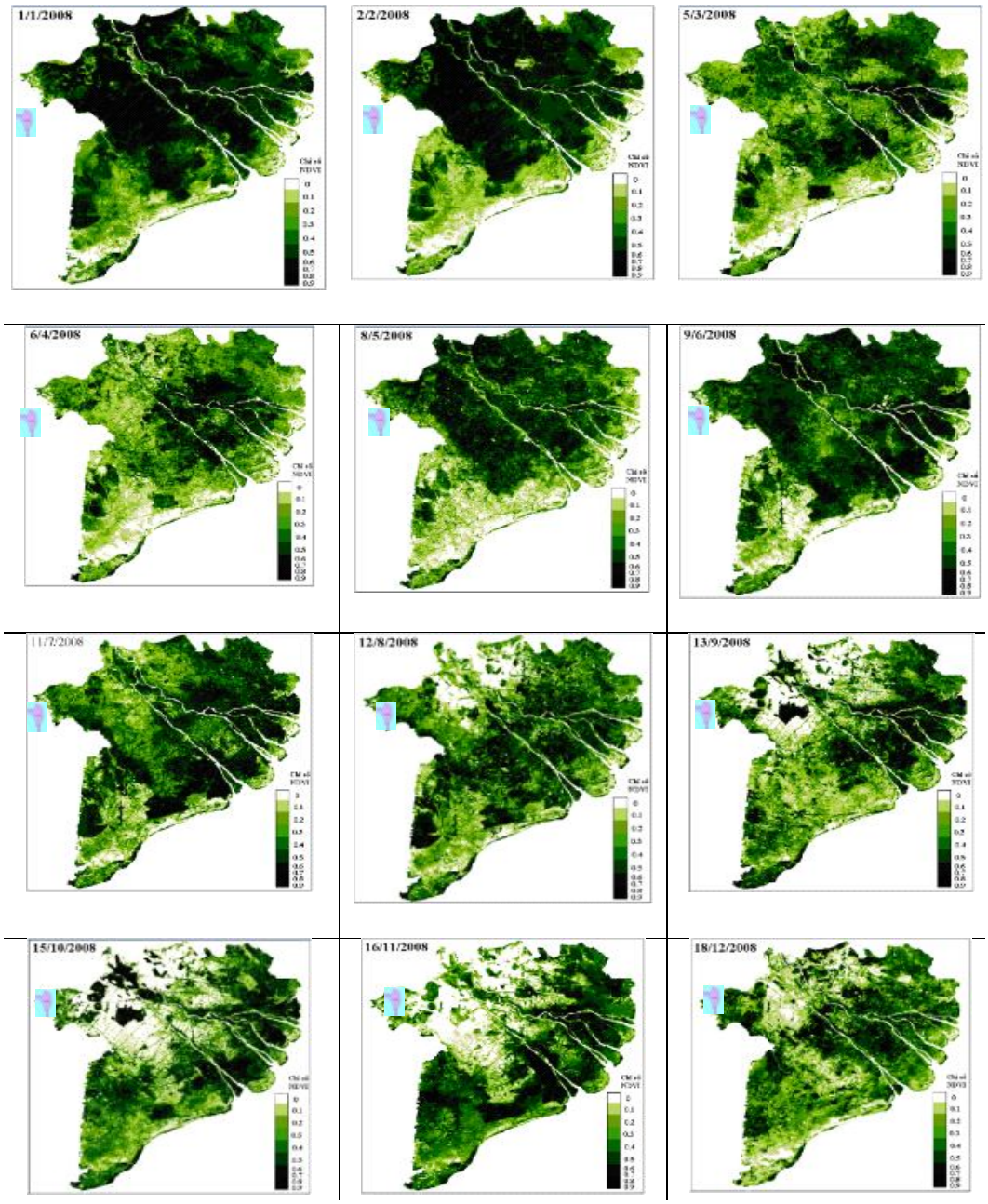

Fig 3: NDVI map for the Mekong delta created from MODIS images of 12 months of 2008

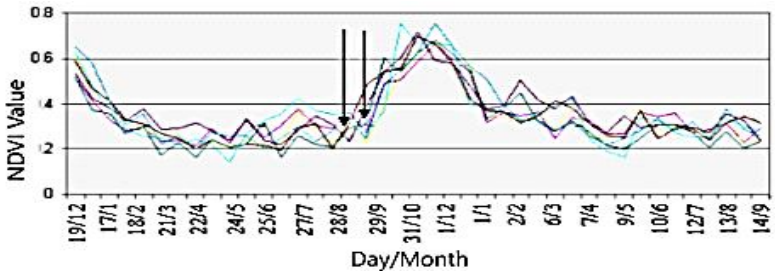

Fig 4: Example of changing of NDVI index for one crops.

the middle of September of the previous year (2007) ended at the end of January after (2008). Then, the soil will be followed for three months (due to salinity or flooding) and start sowing the summer-autumn rice crop in May. Then it creates for the next rotation.

Main winter-spring and early summer-autumn

The winter-spring cropping season started from the previous year in November. After harvesting, it starts sowing for the next cropping season from 21/3 to 6/4. Then this cropping season, the soil is left fallow from early August to the end of October and will begin the Winter-Spring cropping season for the next rotation of 2009.

Early winter-spring and late summer-autumn

The rice sowing of the first cropping season is within October. The soil will be fallowed after this cropping season for two months before starting the summer-autumn cropping season

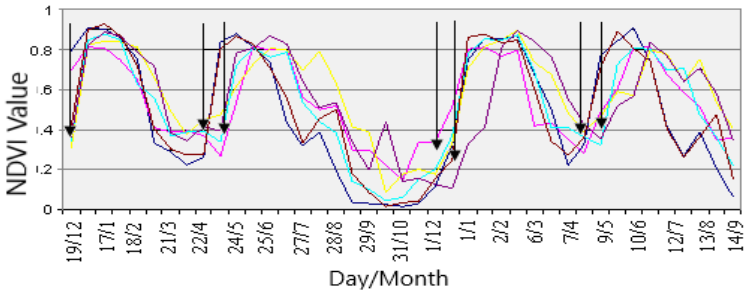

Fig 5: Example of changing of NDVI index for two crops.

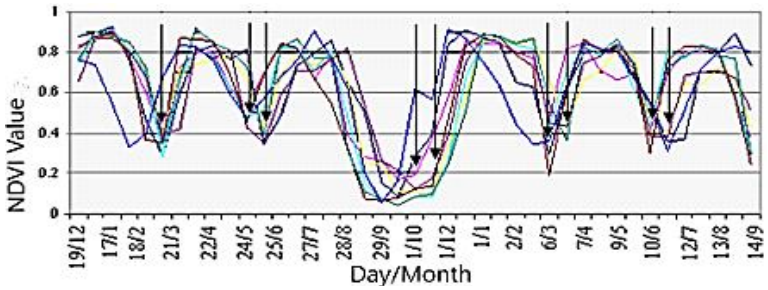

Fig 6: Example of changing of NDVI index for three crops.

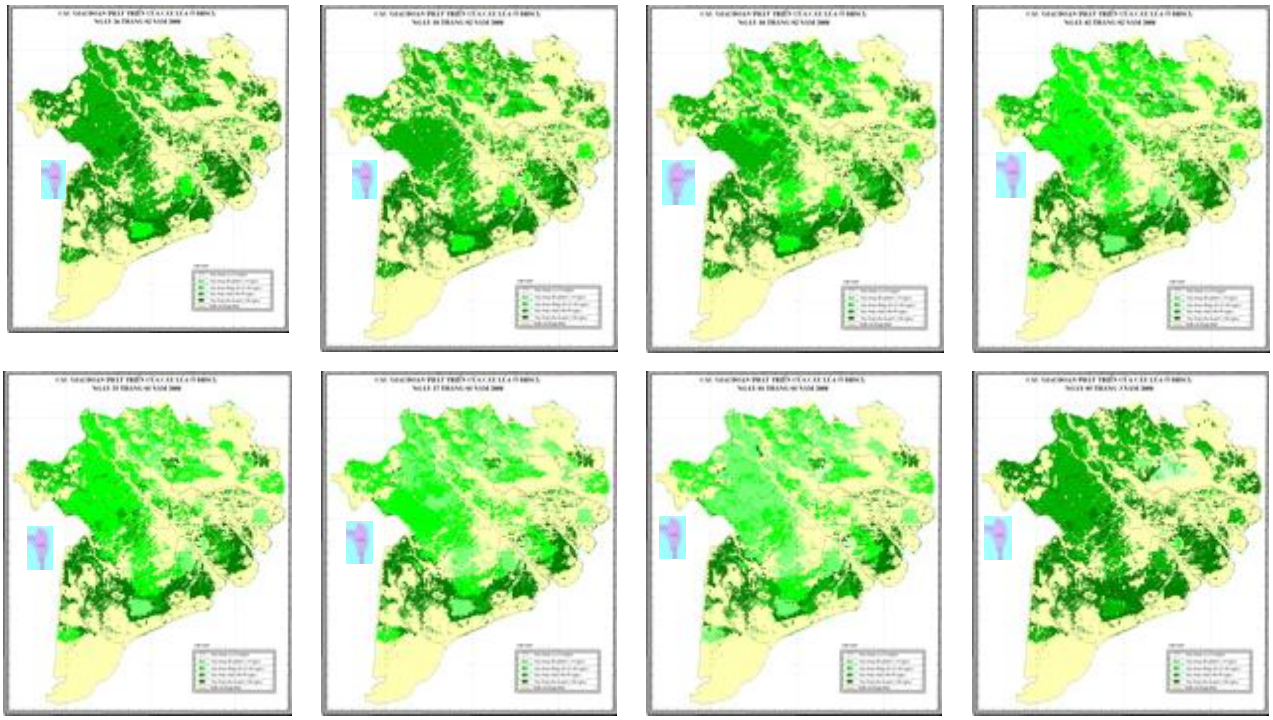

Fig 7: Time of rice sowing at different date intervals for one cropping season delineated from NDVI maps.

Table 3: Rice sowing area (ha) intepreted from MODIS images in May and June, 2009 in different districts.

From	To	AG	BL	BT	CM	CT	DT	HG	ST	TG	TV	KG	LA	V L	Total
01/05	08/05	30,712	850	87	56	21,412	67,468	26,106	7,093	2,543	1,468	77,843	20,506	10,531	14,543
09/05	16/05	78,262	12,456	618	237	7,750	29,912	14,187	20,075	5,643	3,512	15,050	26,431	50	9,206
17/05	24/05	166,600	10,600	18,156	5,518	5,050	74,500	29,343	52,768	45,418	38,337	105,862	135,131	5,543	8,930
25/05	01/06	650	3,231	1,331	550	6,250	406	1,450	6,318	1,006	11,375	1,662	23,737	31	12,412
02/06	09/06	2,356	35,856	6,550	2,537	37	37	400	17,400	6,500	4,375	9,243	17,287	6	10,881
10/06	17/06		156						868						1,024
18/06	25/06		4,131	68	9,431	400	4,012	168	39,868	1,106	943	18,625	225	175	2,225
26/06	03/07								243	206			25		206

Note: AG: Angiang; BL: Baclieu; BT: Bentre; CM: Camau; CT: Cantho; DT: Dongthap; HG: Haugiang; ST:Soctrang; TG: Tiengiang; TV: Travinh; KG: Kiengiang; LA: Longan; VL: Vinhlong.

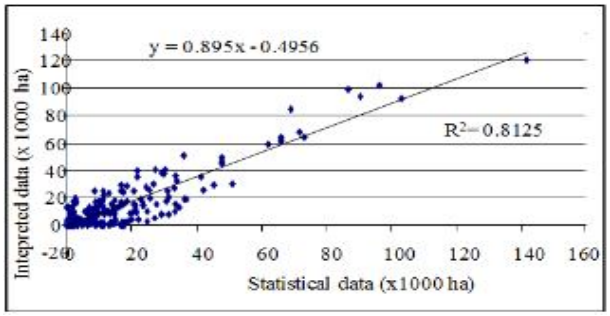

Fig 8: The correlation between the area of statistical and interpreted data.

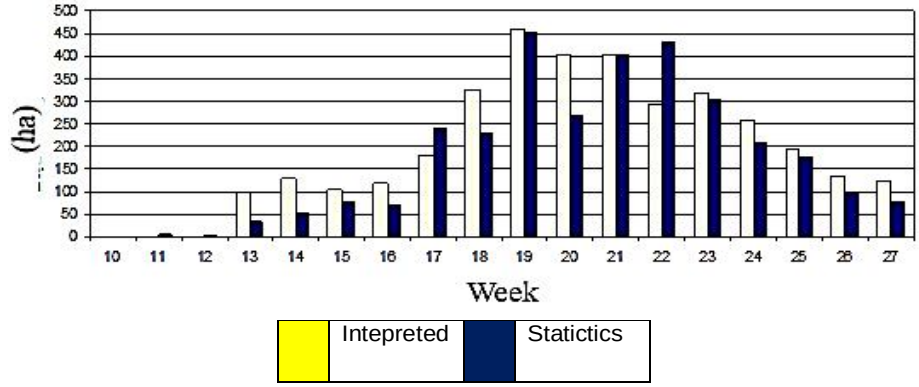

Fig 9: Comparison between interpreted and Statistical data of rice seedling area from week 10 to week 27 (1 March to 30 June 2009).

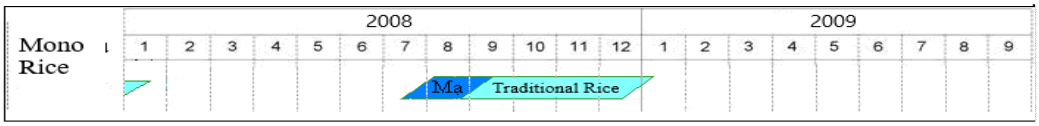

Fig 10: Typical mono rice cropping calendar.

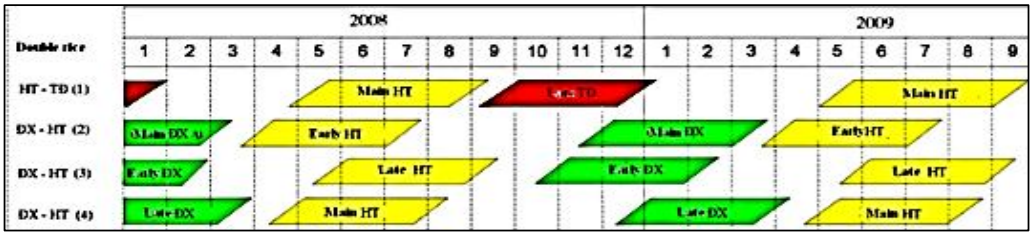

Fig 11: Some typical double rice cropping calendars.

(1) Summer-Autumn and Autumn-Winter (2) Main Winter-Spring and Early Summer-Autumn (3) Early Winter-Spring and Late Summer-Autumn (4) Late Winter Spring – Main Summer-Autumn

Table 4: The extent of rice cropping season area in the MKD 2008-2009 interpreted from MODIS images.

Cropping systems	Rice cropping season	ha	%
Mono rice crop (5.5%)	(Traditional rice)	76,100	3.1
Double eice crops	Summer-Autumn and Autumn-winter	13,830	0.6
(63%)	Main Winter-Spring and Early Summer-Autumn	624,300	25.8
	Early Winter-Spring and late Summer-Autumn	722,500	29.9
	Late Winter-Spring and Main Summer-Autumn	238,600	9.9
Tripple rice crops	Winter-Spring and Summer-autumn and Late Summer-Autumn	157,700	6.5
(30.7$	Late Main Winter-Fpring and Main Summer-Autumn	530,000	21.9
	Late Winter-Spring and Main Summer-Autumn and Late Autumn-winter	55,960	2.3
	Total	**2,418,990**	**100,0**

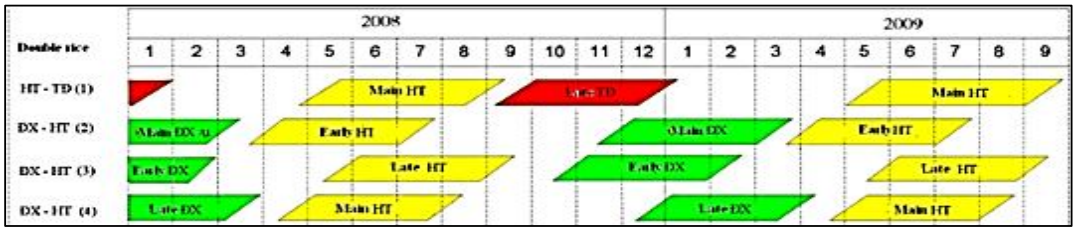

Fig 12: Some triple rice cropping calendars

Notes: (1): Summer-Autumn and Autumn-Winter (2): Main Winter-Spring and Early Summer-Autumn (3): Early Winter-Spring and late Summer-Autumn (4): late Winter-Spring andMain Summer-Autumn.

(from 8/5 to 24/5). After harvest, the farmer let the soils fallowed for one month and then it starts the Winter-Spring cropping season of 2009.

Late Winter Spring – Main Summer-Autumn

The starting time of rice sowing for Winter Spring (2008) within December and the main Summer-Autumn starting from 21 Mar-6 April. In 2009, the Sumer-Autumn rice sowing relatively later than in 2008 (middle to end of April).

Triple rice crops

The triple rice cropping season in the freshwater alluvial soil ecosystem is most popular and almost year-round. Therefore, farmers divide the rice sowing calendar into early winter-spring, primary Winter-Spring and Late Winter-Spring rice cropping (Fig 12).

Winter Spring-Spring Summer–Late Summer Autumn

At the ending of the Summer-Autumn crop, the soil is left fallow for 1 or 2 months before starting the Winter-Spring rice crop of next year. Thus, the sowing time for three cropping seasons is described as (1) Winter Spring-starting from the end of November up to the beginning of December, (2) the second rice crop starting from the middle of March, (3) the third rice crop starting from the beginning of June.

Main Winter-Spring and Summer-Autumn and Autumn-Winter

The Winter-Spring crop sowing time starts at the beginning of December, the Summer-Autumn from sixth/April to 22nd/ April, Autumn-Winter sowing from the end of July to the first half of August. When farmers harvested the Autumn Winter rice crop in 2008, they let the soil fallowed for a month before starting the Winter-Spring crop of 2009.

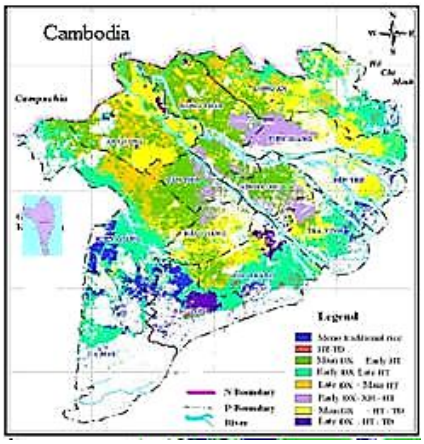

Fig 13: Distribution of rice cropping seasons and rice sowing in the MKD in 2008-2009. Note: ĐX: Đong-Xuan (Winter-Spring); XH: Xuan-He (Spring-Summer); HT: He-Thu (Summer-Autumn); TĐ: Thu-Đong (Autumn-Spring)

Late Winter-Spring and Summer-Autumn and Autumn-Winter

Winter-Spring season starts sowing from late January to early February. The Summer-Autumn crop begins to plant from the end of May. In comparison, the Autumn-Winter season starts from mid-September.

Table 4, the extent of rice cropping season area shows that the double rice crops dominated (> 63.8%) and followed by triple rice crop (30.7%) and finally mono rice crop (5.5%). In which the early Winter-Spring and Summer-Autumn cropping season populated (>27.9%), followed by the main Spring-Summer and Eearly Summer-Autumn cropping

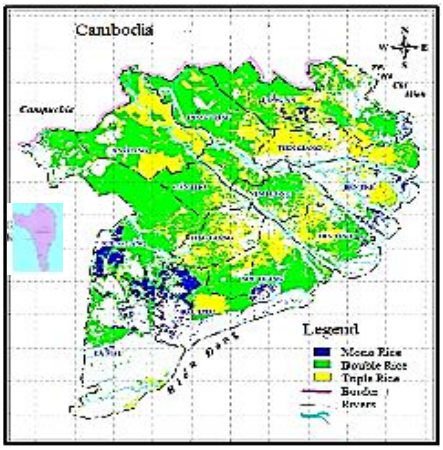

Fig 14: Map of rice cropping seasons 2008-2009 in the MKD, Vietnam. Note: ĐX: Đong-Xuan (Winter-Spring); XH: Xuan-He (Spring-Summer);HT: He-Thu (Summer-Autumn); TĐ: Thu-Đong (Autumn-Spring).

season (>25.5%). The third is main Winter-Spring and Summer-Autumn and Autumn-Winter rice cropping seasons (22.0%). The lowest is double rice crops of Summer-Autumn and Autumn-Winter cropping season (0.6%).

Within eight major rice cropping calendars represented in the Mekong Delta, the double and triple rice crops dominated, which account for about three-quarters of the total area. The remaining rice cropping calendar occupies negligible.

The extend of rice cropping seasons and major rice cropping in the Mekong delta are sown in Fig 13 and 14, respectively.

CONCLUSION

The MOD13Q1 (250-m spatial resolutions, 16-day composite) monitored and delineated rice sowing/ transplanting and then the cropping calendars using the time-series of NDVI images. As a result, the study outlined three (3) major Rice cropping systems and eight (8) rice cropping seasons. The cropping seasons of Main Winter Spring-Early Summer Autumn and Late Main Winter-Spring-Main Summer Autumn mainly dominated.

The application of temporal variation of NDVI from MODIS images is efficient and helpful for determining the current state of rice evolution for rice sowing stages and rice cropping calendar delineation. Multispectral and Temporal Remote Sensing Data, MODIS most suitable for research at the regional level. The results assist the managers in selecting appropriate and low-cost strategies for better crop management.

It needs further studies and more field validation to enhance the accuracy. The cloud occurrence and images low spatial resolution impaired the accuracy of the results,

ACKNOWLEDGEMENT

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