บทความวิจัย

# Prediction of GHG Emissions in Paddy Fields by Application of Vegetation Indices

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## Abstract

The main aim of this research is to inconsistent study methane emissions occurring in the paddy fields starting from cultivation to harvesting and to use vegetation indices to predict the methane emissions. The results showed that the vegetation indices: the Normalized Difference Vegetation Index (NDVI), the Soil Adjusted Vegetation Index (SAVI), the Green Normalized Difference Vegetation Index (GNDVI), and the Infrared Percentage Vegetation Index (IPVI) were in correlation with methane emissions in the same direction as in the paddy fields. The correlations coefficients of Pearson between methane emissions and vegetation Indices (NDVI, GNDVI, SAVI, and IPVI) are at high values of 0.777, 0.835, 0.756, and 0.756, respectively. Therefore, these vegetation indices are suitable to be applied in the quadratic predicted equation. The most suitable predicted equation is from the GNDVI index which the predicted equation is $Y = -83.671X^2 + 80.359X -16.993$. This predicted equation showed the highest accuracy in predicting methane emissions with $R^2$ of 0.857.

## Keywords

methane emissions; organic paddy fields; vegetation index; remote sensing

## 1. Introduction

At present, global climate change has effects on the environment caused by greenhouse gas (GHG) emissions. The agricultural sector in Thailand is considered one of the main sources of GHG emissions; it is only second to the energy sector with 51.88 million tons of $CO_2$eq. GHG emissions in paddy fields are 29.94 million tons of $CO_2$eq, or 57.7% of the agricultural sector [1]. Methane is the major GHG emission from the paddy fields [2]. Thailand has 60 million rai of rice cultivation fields (25% of Thai agricultural area) and most of the rice fields are in the Northeast of Thailand [3].

Tung Kula Ronghai is the largest jasmine paddy field in the Northeast region. Organic jasmine paddy fields are popular with consumers because of food

safety awareness.  Therefore, many sectors, including the general public and communities, are placing more focus on activities which are likely to affect health and the environment.  The amount of methane emissions from paddy fields is thus an issue of interest worldwide, because of its effect on the environment.

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area [4]. Moreover, the vegetation indices are the mathematical values that can be used to monitor the vegetation with satellite observations [5] which can be applied along with other geographic information and can offer another way to examine and to classify areas, as well as to provide suitable methods to gain accurate data [6]. The vegetation indices are used to create the predicted equation. The use of vegetation indices is one of the techniques that can also help to evaluate the methane emissions in the paddy fields [7].

Hence, this research is aimed at examining and predicting the amount of methane emissions in paddy fields by applying the vegetation indices to create the equation that can be used to predict methane emissions accurately.

## 2.  Experimental

### 2.1 Site description and Scope

Data collection for methane emissions from paddy fields was carried out at the organic Hom Mali paddy fields (wet-season rice) of Nongkhaen Sub-District, Pathumrat District, Roi-et Province. (Figure 1)
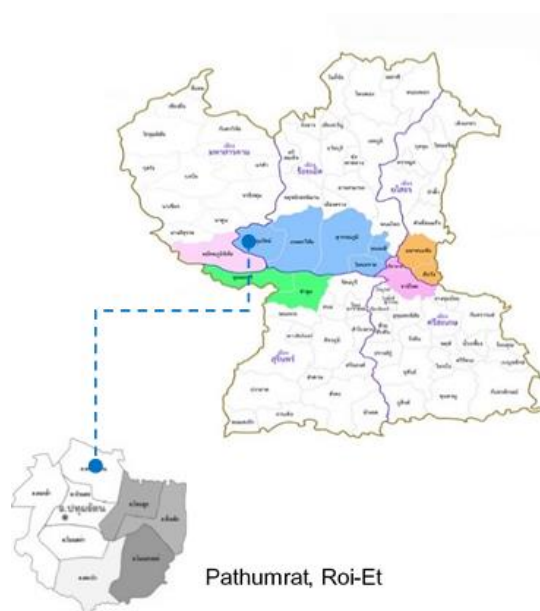


**Fig. 1**    The study areas in Tungkula Ronghai

The study followed the stages of rice growth as follows:

Stage 1 Seeding to tillering (0 – 60 days)

Stage 2 Tillering to ripening (60 – 90 days)

Stage 3 Ripening to harvesting (90–120 days)

### 2.2 Analysis of the methane emissions

The Methane emissions were measured by using the static chamber method. The chamber was made of acrylic plastic. The chamber size was 30 x 30 x 50 cm. (Figure 2). The gas samples were fed into gas sampling bags (Tedlar® bag) by using an air sampling pump 5 times at 0, 5, 10, 15, 20, and 25 minutes. Gas samples were taken by using a 10 ml syringe and immediately transferring the samples into a vacutainer tube and then wrapping it with parafilm. The gas samples in the vacutainer tube were analyzed with Gas Chromatography with a Flame Ionization Detector (GC-FID) [8].
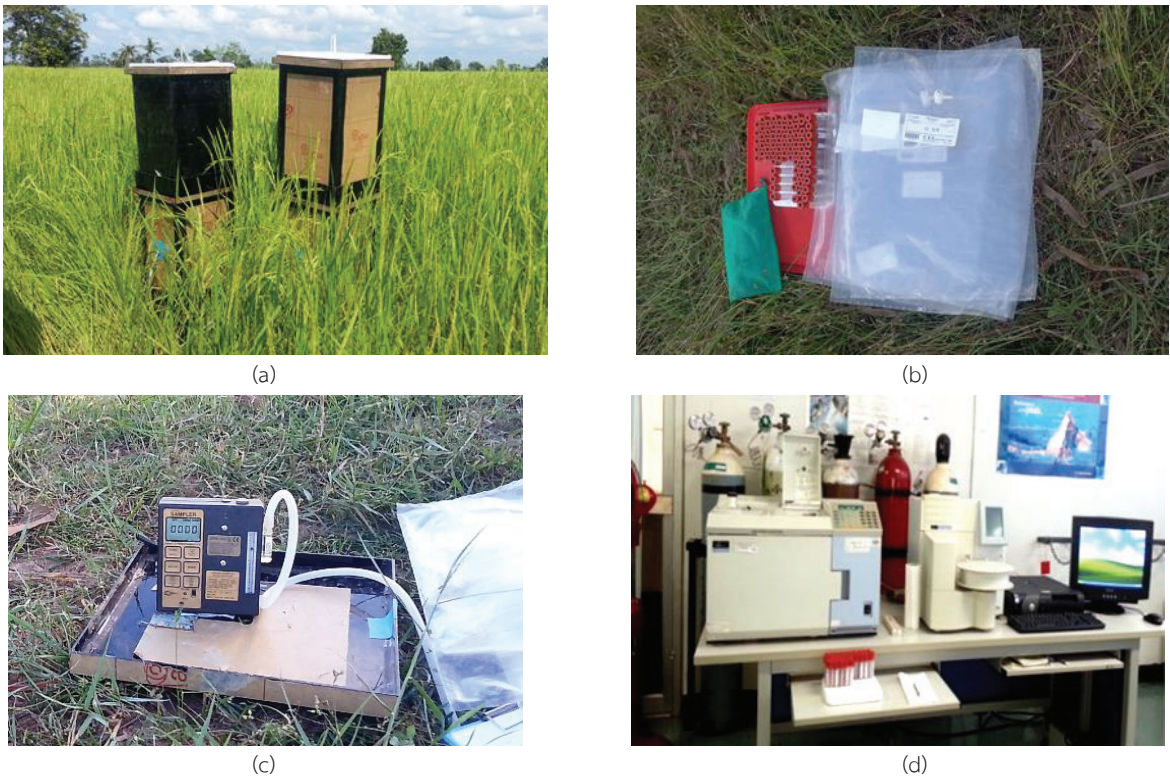
**Fig. 2**   The chamber and the equipment for gas collection, (a) Chamber, (b) Vacutainer tube and Tedlar bag air sampling, (c) Low flow pump, and (d) GC-FID.

The Methane flux was calculated from the following equation:

$$Flux_{CH4} = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \rho \times \frac{273}{273 + T} \qquad (1)$$

where $Flux_{CH4}$ is the hourly gas fluxes and cumulative emission ($mgCH_4m^{-2}h^{-1}$), $\Delta C/\Delta t$ is the concentration change over time (ppm- $CH_4$), V is the chamber volume ($m^3$), A is the chamber area ($m^2$), $\rho$ is gas density (0.717 $kgm^3$), and T is the mean air temperature inside the chamber (°C).

## 2.3 Analysis of vegetation indices and principal component analysis (PCA)

From the study, spectral reflectance of vegetation, Sentinel 2 satellite imagery were used in data analysis and transformed by ArcGIS and PCI Geomatics software. In addition the PCA technique was used to extract data with many variables and create visualizations to display that data. The various vegetation indices for estimation of methane emissions were; Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Soil Adjusted Vegetation Index (SAVI), and Infrared Percentage Vegetation Index (IPVI)

Thus, the vegetation index equations are shown as below:

1)   Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad (2)$$

2) Green Normalized Difference Vegetation Index (GNDVI)

$$GNDVI = \frac{(NIR - GREEN)}{(NIR + GREEN)} \qquad (3)$$

3) Soil Adjusted Vegetation Index (SAVI)

$$SAVI = (\frac{NIR - RED}{NIR - RED + L}) \times (1+L) \qquad (4)$$

4) Infrared Percentage Vegetation Index (IPVI)

$$IPVI = \frac{NIR}{NIR + RED} \qquad (5)$$

where NIR is near-infrared wavelengths, Red is red wavelengths, Green is green wavelengths, and L is a canopy background adjustment factor.

**2.4 Statistic for data analysis**

The correlation coefficients of Pearson were used to find the correlation of 2 data sets which are the correlation level of methane emissions from the paddy field and vegetation indices (NDVI, GNDVI, SAVI, and IPVI).

The equation to find the correlation coefficients of Pearson is as shown in Equation 6.

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\left[n\sum X^2 - (\sum X)^2\right]\left[n\sum Y^2 - (\sum Y)^2\right]}} \qquad (6)$$

where $r$ is correlation coefficients, n is number, $X$ is independent variables, and $Y$ is dependent variables.

The correlation of the quadratic equation from each vegetation indices and methane emission were used for the analysis of variance (ANOVA) to find the best correlation value. The best correlation was used to create the equation to predict methane emission.

The general quadratic equation that was used to create the relationship between vegetation indices and methane emission is shown in Equation 7.

$$ax^2 + bx + c = 0 \qquad (7)$$

**3. Results and Discussion**

**3.1 Methane emissions from the organic paddy fields**

From Table 1 and Figure 2, in the seeding to tillering stage, the average methane emission from rice in the first stage was at 0. 431 ±0. 096
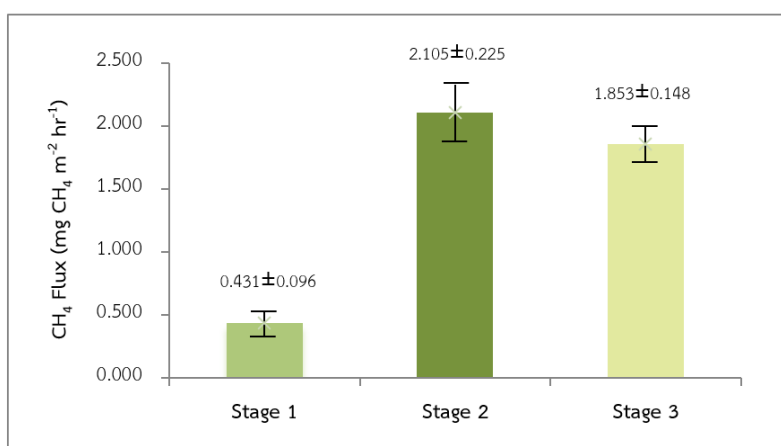


**Fig. 3**   The average of the amount of methane emissions from rice cultivation at each stage of growth.

**Table 1** The average of methane emission at each stages of rice growth.

Unit : $mgCH_4m^{-2}hr^{-1}$

| Crop | Stage 1 | Stage 2 | Stage 3 |
|------|---------|---------|---------|
| 1 | 0.368±0.026 | 2.363±0.045 | 1.820±0.099 |
| 2 | 0.302±0.082 | 2.396±0.048 | 1.890±0.195 |
| 3 | 0.577±0.190 | 2.011±0.179 | 1.433±0.398 |
| 4 | 0.414±0.093 | 1.968±0.133 | 1.773±0.381 |
| 5 | 0.493±0.032 | 1.953±0.076 | 1.618±0.400 |
| Avg. | **0.431±0.096** | **2.105±0.225** | **1.853±0.148** |

**Table 2** The average of vegetation indices: NDVI, GNDVI, SAVI and IPVI.

Unit : none

| Index | Stage 1 | Stage 2 | Stage 3 |
|-------|---------|---------|---------|
| NDVI | 0.394±0.026 | 0.616±0.040 | 0.422±0.056 |
| GNDVI | 340.0±018.0 | 489.0±027.0 | 0.374±0.029 |
| SAVI | 0.587±0.030 | 0.965±0.051 | 0.438±0.028 |
| IPVI | 0.690±0.018 | 0.832±0.024 | 0.709±0.023 |

$mgCH_4m^{-2}hr^{-1}$. The second stage, tillering to ripening was at 2.105 ± 0.225 $mgCH_4m^{-2}$ $hr^{-1}$. The third stage, ripening to harvesting was at 1.853 ±0.148 $mgCH_4m^{-2}hr^{-1}$. (Figure 3)

When comparing the variation of methane emissions with the growth period of rice, it was found that rice age and the growth period affected the amount of methane emissions. From Stage 1 to Stage 2, the amount of methane emissions increased because the rice was growing older in terms of height, size and the length of roots. These caused higher methane emissions. In Stage 3, methane emissions decreased due to the co-factors of the water level

from the drainage of the paddy field for the upcoming harvest. The methane emissions reached their highest level during the waterlogged period, especially at the tillering to ripening stage [9], whereas drainage of water from the paddy fields before harvesting leads to a decrease in methane emissions [10].

## 3.2 Spectral reflectance of vegetation and Principal component analysis (PCA)

The PCA technique was used to reduce the effects from the geographical components and the complication of the data for each wavelength range. The Sentinel 2 satellite imagery was applied to retrieve the data about the vegetation and find the vegetation indices: NDVI, GNDVI, SAVI, and IPVI. Using PCA mapping in finding the vegetation indices from spectral reflectance of rice in each growth stage are shown in Table 2 and Figure 4 to 7

It could be summarized that the average values of vegetation indices from the first stage to the third stage of growth are as follows; NDVI were 0.394 ±0.026, 0.616 ±0.040 and 0.422 ±0.056, respectively. GNDVI were at 0.340 ±0.018, 0.489 ±0.027 and 0.374 ±0.029, respectively. SAVI were 0.587 ±0.030, 0.965 ±0.051 and 0.438 ±0.028, respectively. And IPVI were 0.690 ±0.018, 0.832 ±0.024 and 0.709 ±0.023, respectively.

The results revealed that the growth of plants with fewer leaves (less chlorophyll), present less energy reflectance at the near-infrared wavelength than at the red wavelength, causing low vegetation indices. On the other hand, at the tillering stage (stage
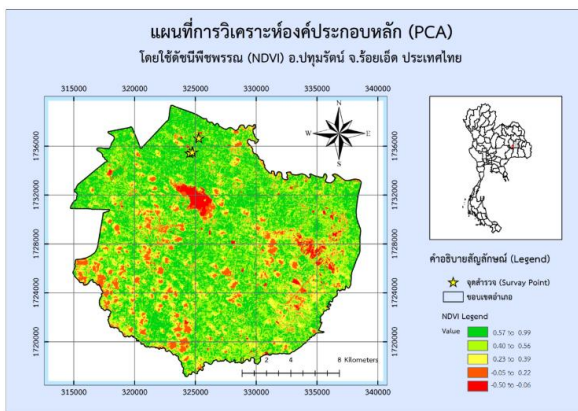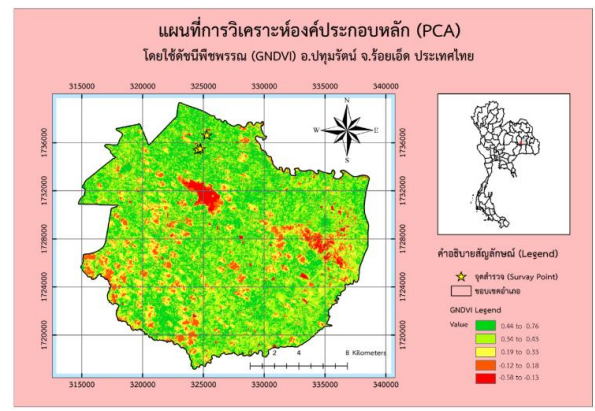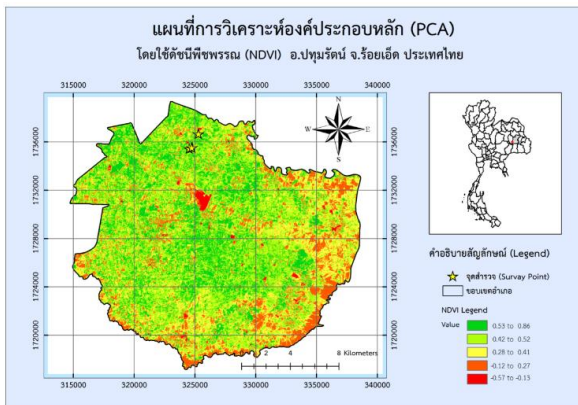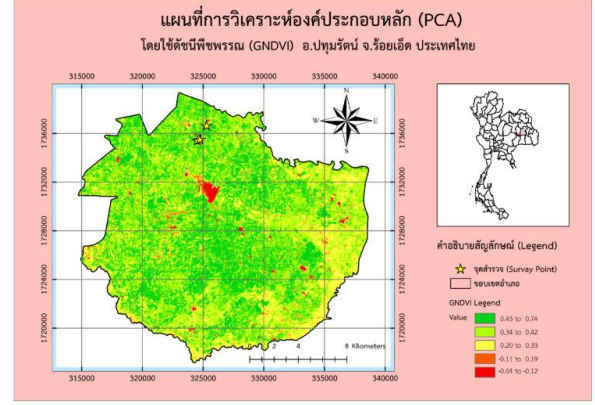
(a)



(b)
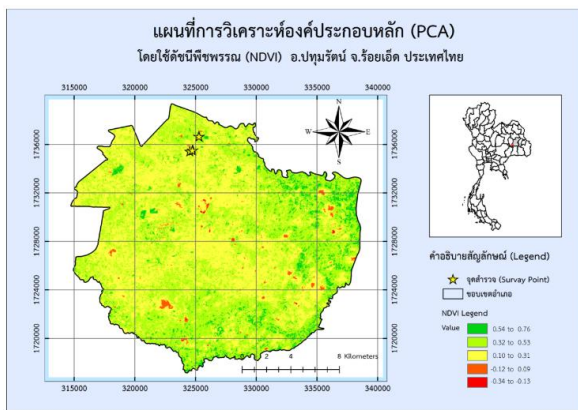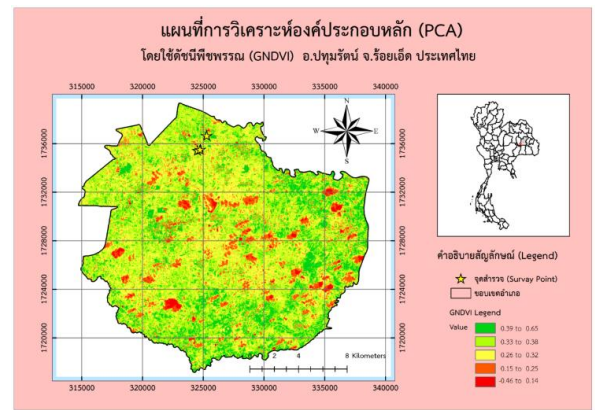


(c)

**Fig. 4** The maps of PCA (NDVI) from Sentinel 2, (a) Stage 1, (b) Stage 2, and (c) Stage 3.



(a)



(b)



(c)

**Fig. 5** The maps of PCA (GNDVI) from Sentinel 2, (a) Stage 1, (b) Stage 2, and (c) Stage 3.
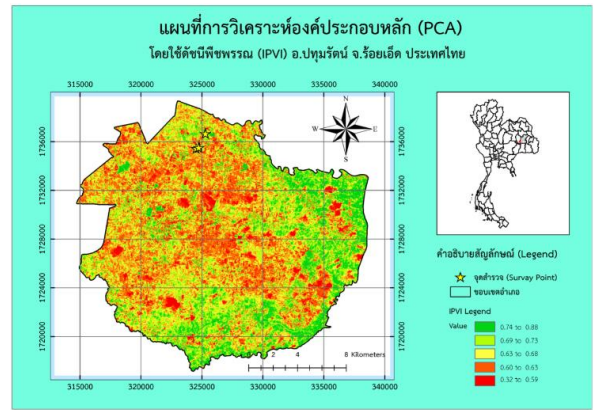
2), rice plants and leaves also grow with increases in chlorophyll during this stage. The energy reflectance at the near-infrared wavelength becomes higher than
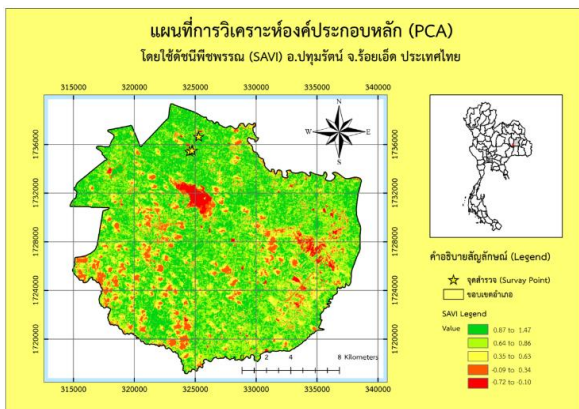
at the red wavelength, leading to higher vegetation indices. When all the leaves turn yellow in the last stage, the amount of chlorophyll is reduced and
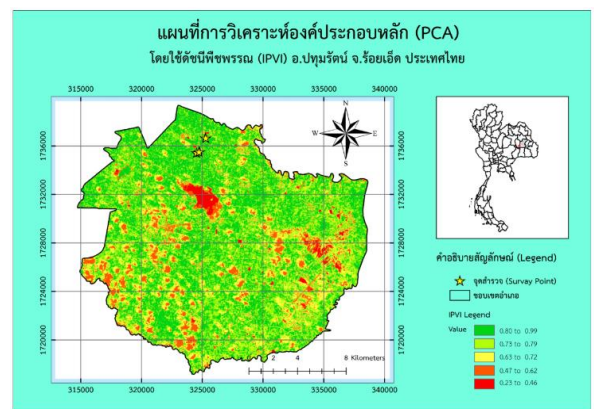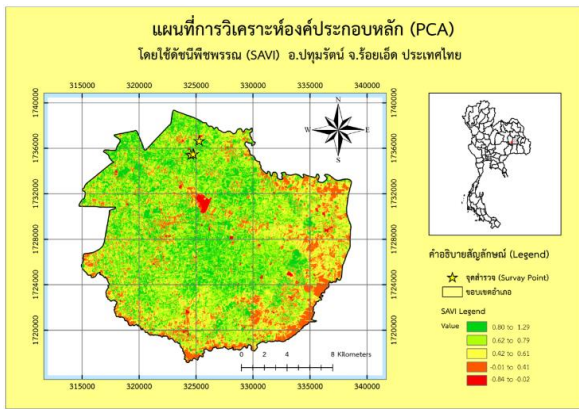
(a)



(b)
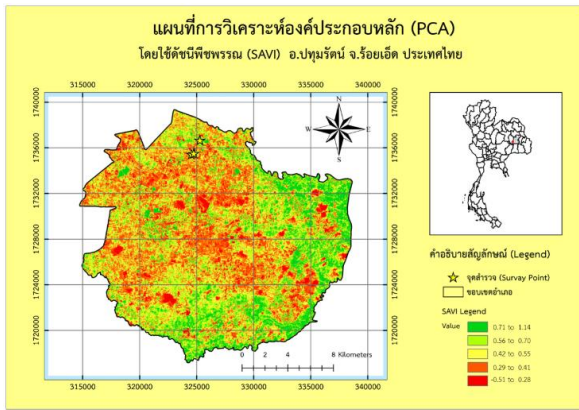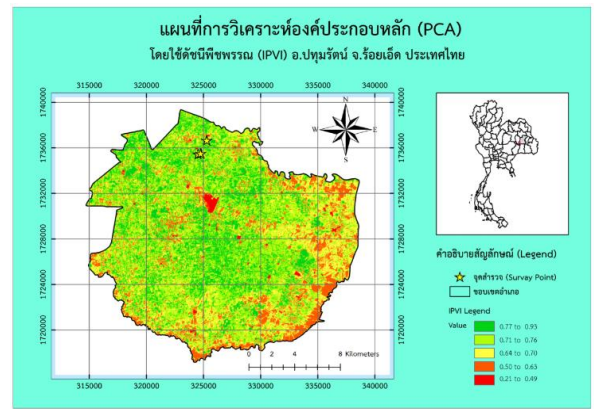


(c)

**Fig. 6**  The maps of PCA (SAVI) from Sentinel 2, (a) Stage 1, (b) Stage 2, and (c) Stage 3.

hence the energy reflectance at the red wavelength increases, which in turn results in a slightly reduced vegetation index [11].



(a)



(b)



(c)

**Fig. 7**  The maps of PCA (IPVI) from Sentinel 2, (a) Stage 1, (b) Stage 2, and (c) Stage 3.

Moreover, it was found that all vegetation indices (NDVI, GNDVI, SAVI, and IPVI) positively correlated with the methane emissions. When the growth of rice

plants increases, vegetation indices will also increase and decrease when the rice is mature at the ripening to harvesting stage. Therefore, the values of vegetation indices are suitable to be used to predict the amount of methane emissions in the organic paddy fields (Table 3).

## 3.3 Correlation of vegetation indices and methane emissions

It was found that the vegetation indices, by using PCA mapping, showed better correlation with methane emissions than without using PCA mapping, especially the NDVI index (Table 3). This is because of the reduction in variations in the data when using PCA. This helps to give a more accurate interpretation of the data. However, all of the vegetation indices (NDVI, GNDVI, SAVI, and IPVI) after using PCA gave high correlations with methane emission values. The correlation of NDVI, GNDVI, SAVI, and IPVI are at 0.777, 0. 835, 0. 756, and 0. 756, respectively ( Table 3) . Therefore, all of the vegetation indices can be used to create quadratic predicted equations.

## 3.4 The created equations for prediction of methane emission

The vegetation indices with PCA were used to create the predicted equations via quadratic equation. The predicted equations for methane emissions are shown in table 4. The equation from NDVI was $Y = -25.765X^2 + 31.419X - 7.312$ ( R$^2$ = 0. 734) at the significance of 0. 000. GNDVI equation was $Y = -83.671X^2 + 80.359X - 16.993$ (R$^2$ = 0.857) at the significance of 0. 000. SAVI equation was

**Table 3** The correlation coefficients of Pearson of the vegetation indices and methane emission.

Unit : none

| Index | Correlation | | Relation level |
|-------|-------------|-------------|----------------|
|       | Before using PCA | After using PCA | |
| NDVI  | 0.591 | 0.777 | Medium/High |
| GNDVI | 0.776 | 0.835 | High/High |
| SAVI  | 0.746 | 0.756 | High/High |
| IPVI  | 0.754 | 0.756 | High/High |

**Table 4** The quadratic equations from the Vegetation Indices.

| Index | R$^2$ | Prediction Equation |
|-------|-------|---------------------|
| NDVI  | 0.734 | $Y = -25.765X^2 + 31.419X - 7.312$ |
| GNDVI | 0.857 | $Y = -83.671X^2 + 80.359X - 16.993$ |
| SAVI  | 0.655 | $Y = -8.779X^2 + 16.968X - 5.957$ |
| IPVI  | 0.657 | $Y = -83.486X^2 + 136.626X - 53.663$ |

$Y = -8.779X^2 + 16.968X - 5.957$ ( R$^2$ = 0. 655) at significance of 0. 002. IPVI equation was $Y = -83.486X^2 + 136.626X - 53.663$ (R$^2$ = 0.657) at significance of 0.002. Therefore, the most suitable predicted equations for methane emissions by vegetation indices is the GNDVI equation which has the high accuracy of R2 = 0.857 while the NDVI, SAVI and IPVI equations have medium accuracy.

## 4. Conclusions

The results from the study found that the vegetation indices (NDVI, GNDVI, SAVI, and IPVI) were in correlation with methane emissions measured in the field after using PCA mapping. The vegetation

indices showed the increasing trend when the rice starts growing from seeding to the ripening stage and then decreasing at the stage of ripening to harvesting.

The correlations coefficients of Pearson of vegetation indices (NDVI, GNDVI, SAVI, and IPVI) and methane emissions are at high values. Therefore, the vegetation indices are suitable to be used to predict the amount of methane emissions in the organic paddy fields. The most suitable predicted equation of methane emission from the GNDVI index ($Y = -83.671X2 + 80.359X - 16.993$) gave the highest accuracy value with $R^2$ of 0.857.

In conclusion, the predicted equation with GNDVI can be used to predict the amount of methane emissions in the Tung Kula Ronghai area. The government can utilize the remote sensing data (vegetation indices) to predict methane emissions and this data can be used to manage GHG developed in organic rice farming.

## Acknowledgments

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