Spectral pattern of paddy as response to drought condition: An experimental study

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Abstract. *Every single physical object has a different response to the electromagnetic wave emitted to it. The response is in the form of how it absorbs and reflects the energy in every range of wavelength. The absorption and reflection curve is known as a spectral pattern. The spectral pattern of each object can be used to determine the object. In agriculture, the spectral pattern of plants can be used to determine the health condition of the plant. Drought is one factor that can affect the health of the plant. By identifying the spectral pattern of the plants, the effect of drought on paddy can be identified. This experimental study tried to identify the spectral pattern of some varieties of paddy and different growth stages. A spectrophotometer with a wavelength range of 350-1052 nm was used. Four varieties of paddy were planted in a greenhouse and being treated in drought conditions from the stage of vegetative, generative, and reproductive. Based on the result, the spectral response from the generative phase of all varieties gave the most different pattern compared to the control. This result was compromising the rapid detection of paddy fields affected by drought using optical remote sensing data. Especially for plants in the stage of generative.*

INTRODUCTION

Every single physical object has a different response to the electromagnetic wave emitted to it. The response is how it absorbs and reflects the energy in every range of wavelength. The absorption and reflection curve is known as the spectral pattern (Huete, 2004). The spectral pattern of each object can be used to determine the object. In agriculture, the spectral pattern of plants can be used to determine the health condition of the plant. The effect of the anomaly of photosynthesis activity can be seen physically. For instance, as resistant to drought conditions, the plant will roll its leaves (Nio and Lenak, 2014). By rolling the leaves, a plant can decrease evapotranspiration due to an increase in water absorption. This rolling is also an effect of drought, which can be monitored in the visible light spectrum. Plants tend to absorb the visible spectrum of waves mainly in the blue and red spectrum and reflect the Near Infra-Red (NIR) spectrum (Espinoza *et al.*,

2017; Maes and Steppe, 2019; Tran *et al*., 2017). However, the effect itself already occurs before the leaves started to roll. This cannot be monitored in the visible light spectrum, but it can be monitored in the invisible light spectrum such as NIR. In normal conditions, the NIR spectrum (wavelength 750-1500 nm) is absorbed by the plants due to its water content. The characteristics of the red and near infra-red channels in this vegetation are then used to calculate the vegetation index, which shows the level of the greenness of the vegetation (Congalton, 2015; Lillesand and Kiefer, 1994). Penuelas *et al*. (1993) found that the reflectance at the 950-970 nm of wavelength, which is in the range of NIR spectrum, is the indicator of water status in plants and then proposed the Water Band Index (WBI) (Penuelas *et al*., 1997). Other indexes proposed to estimate water content in plant leaves are Normalised Difference Water Index (NDWI) (Gao, 1996), Normalized Multi-band Drought Index (NMDI) (Wang and Qu, 2007), Normalized Difference Infrared Index (NDII), and Moisture Stress Index (MSI) (Hunt and Rock, 1989).

Drought is one factor that can affect the health of paddy plants. For example, as a form of drought resistance, paddy plants will show rolling leaves symptoms (Anusha and Bharathi, 2020). By rolling the leaves, paddy plants can reduce evapotranspiration rate due to increased water absorption in dry soil. This rolling of the leaves is an example of the effects of drought on paddy plants which can be observed in the visible light spectrum. Paddy has different spectral responses depends on plant age, varieties, and physiological conditions. Paddy and other plants, in general, absorb more light in the spectrum of red and blue for photosynthesis purposes. It is because red and blue lights are effective for photosynthesis (Reece and Campbell, 2012). But basically, the impact of drought on paddy plants has occurred before leaf rolling. This impact cannot be observed in the visible light spectrum but is observed in the invisible light spectrum such as near-infrared (NIR). The reflectance value increases in the near-infrared (NIR) spectrum (wavelength 750-1500 nm). This is following the characteristics of the NIR spectrum which tends to be completely absorbed by water, resulting in a low reflectance value. In drought conditions, with a low water content, it will result in a high NIR reflectance spectrum (Orych *et al*., 2014; Jacquemoud and Ustin, 2019).

By identifying the spectral pattern of the plants, the effect of drought on paddy can be identified. This experimental study tried to identify the spectral pattern of some varieties of paddy in different growth stages.

METHODOLOGY

Study Location and Experiment Design

The experiment was done in a greenhouse located in Bogor, West Java, Indonesia. There were four varieties of paddy observed in the experiment: IPB 9G, Hipa 19, Jatiluhur, and IPB 3S treated in three repetitions each for treatment and control. For each plant, data acquisition was repeated three times. Hence, there would be nine data for each paddy variety, both for treatment and control. The plants were in three different growth stages: vegetative (P1), reproductive (P2), and generative (P3). Data acquisition was done before the drought treatment on September 11th, 2019, and on October 14th, 2019, or one week after the treatment.

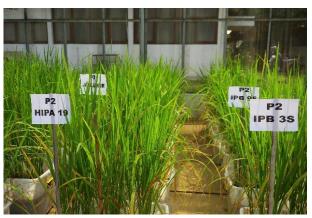| P3 TREATMENT | Jatiluhur | Hipa 19 | Jatiluhur | IPB 9G | Jatiluhur | IPB 9G |
	IPB 9G	IPB 3S	Hipa 19	IPB 3S	IPB 3S	Hipa 19
P3 CONTROL	IPB 3S	IPB 9G	IPB 9G	Jatiluhur	Hipa 19	IPB 9G
	Hipa 19	Jatiluhur	IPB 3S	Hipa 19	Jatiluhur	IPB 3S
P2 TREATMENT	IPB 3S	IPB 9G	Jatiluhur	Hipa 19	IPB 9G	IPB 3S
	Jatiluhur	Hipa 19	IPB 3S	IPB 9G	Jatiluhur	Hipa 19
P2 CONTROL	IPB 3S	Hipa 19	Jatiluhur	IPB 9G	IPB 3S	Jatiluhur
	IPB 9G	Jatiluhur	IPB 3S	Hipa 19	Hipa 19	IPB 9G
P1 TREATMENT	IPB 9G	Jatiluhur	IPB 3S	IPB 9G	IPB 3S	Hipa 19
	IPB 3S	Hipa 19	Jatiluhur	Hipa 19	Jatiluhur	IPB 9G
P1 CONTROL	IPB 9G	IPB 3S	IPB 9G	Hipa 19	Jatiluhur	IPB 9G
	Hipa 19	Jatiluhur	IPB 3S	Jatiluhur	Hipa 19	IPB 3S

Figure 1 Experiment design

Figure 2 Experimental plants in the greenhouse

Measurement Instrument

The tool used in the experiment was a spectroradiometer EKO Instruments, namely MS-720. The MS-720 portable spectroradiometer is designed to measure the spectral irradiance in the range from visible (red, green, and blue) to Near-Infrared (NIR). It is mainly used for geological data acquisition, vegetation, oceanography, remote sensing, and other applications. It has a wavelength range from 350 to 1050 nm, optical resolution of less than 10 nm, wavelength accuracy of less than 0.3 nm, and has three different aperture options: 45, 25, and 10 degrees. The aperture of 45 degrees was used in this experiment. To avoid the shadow of the operator, an approximately 2 meters monopod was used. The instrument should be at the height of 1.2 m above the plants. By using 45 degrees of aperture, the Field of View (FOV) would be approximately 0.5 m. This range completely covered the area of plants. The illustration of data acquisition is shown in Figure 3. A piece of black fabric was also used to avoid reflectance from non-plant objects, as shown in Figure 4.
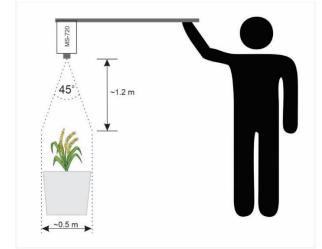

Figure 3 Illustration of data acquisition using MS-720 spectroradiometer

Figure 4 Application of black fabric to avoid reflectance from the non-plant object

Data Processing

The output of the MS-720 spectroradiometer is not in the form of reflectance but the form of irradiance. Hence, by assuming the Lambertian surface, reflection from paddy (ρ) can be estimated by using the following formula:

$$\rho = \pi l_d \ / \ l_u \Omega$$

Information: l_d = lights reflected from plants, l_u= lights hit the plants, Ω= solid View Port viewing angle

Data processing was carried out in R software. The reflectance of each sample with the same varieties and wavelength was averaged. To get the reflectance of each spectrum of light, the wavelengths were divided into four groups based on several wavelength ranges, as shown in Table 1. The reflectance of each spectrum was obtained by averaging the reflectance data in the wavelength range. The reflectance difference of post and pre-treatment in each growth stage was calculated to identify the most determining spectrum to drought. Figure 5 shows the overall flow of data processing in this study.

Table 1 Division of data based on wavelength

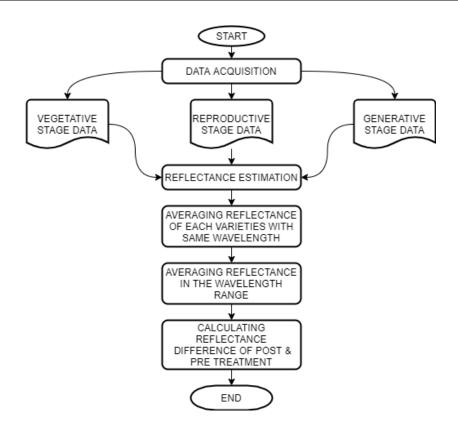| Spectrum	Wavelength (nm)
Blue	450-510
Green	530-590
Red	640-670
NIR	850-880

Figure 4 Data processing flowchart

RESULTS AND DISCUSSION

Spectral Pattern

Experiment on a laboratory scale has been carried out to see several paddy varieties' spectral response to drought treatment. The result which was obtained is a distinctive pattern as a response to paddy plants due to drought stress.
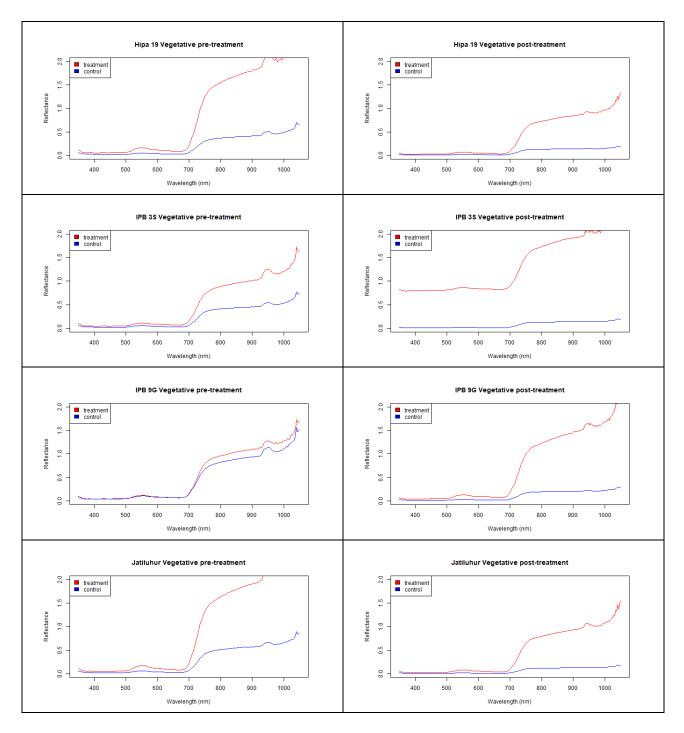
Figure 6 The spectral response of several paddy varieties in the vegetative phase to drought stress

Based on this study, the most different spectral responses were found in the generative growth phase. In this phase, plants give a uniform response, namely an increase in reflectance in the red-light spectrum (wavelength 620-750 nm). The increase in red-light spectrum reflectance is followed by a decrease in the near-infrared (NIR) spectrum with a wavelength of 700-1 100 nm. In the blue wavelength range (600-608 nm) there was also an increase in reflectance. This indicates a change in photosynthesis activity that occurs in plants. Changes in photosynthesis activity are caused by leaf structure changes (Jacquemoud and Ustin, 2019) and biochemical content in plant leaves.
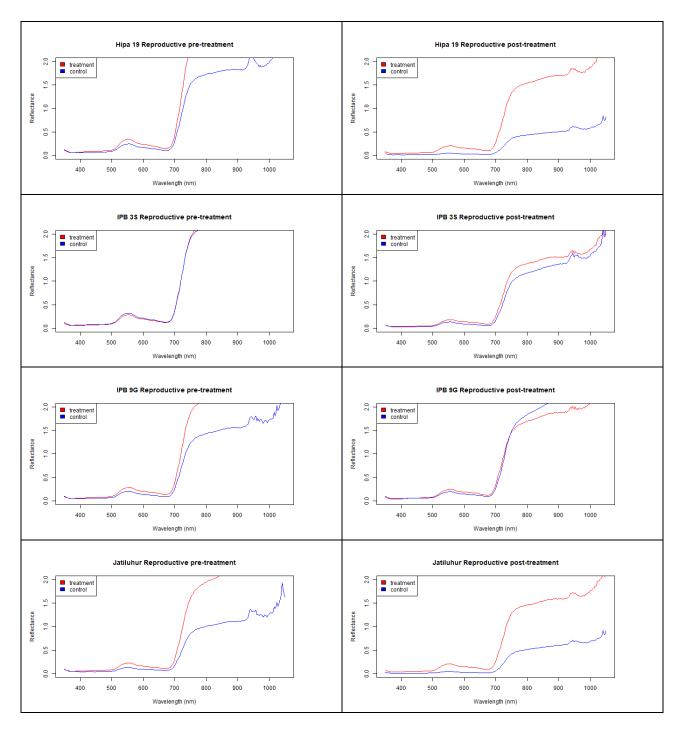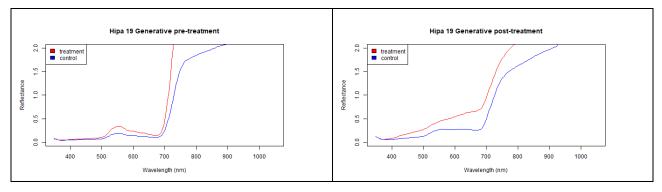
Figure 7 The spectral response of several paddy varieties in the reproductive phase to drought stress
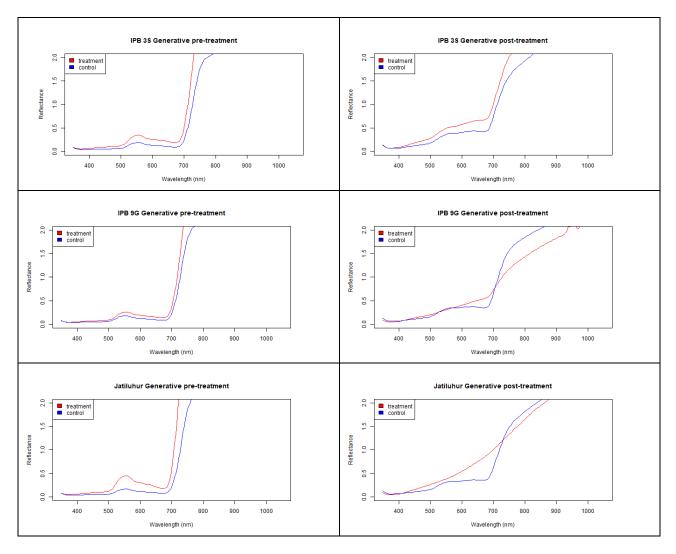
Figure 8 The spectral response of several paddy varieties in the generative phase to drought stress

Reflectance Difference of Post and Pre-treatment

In this study, the reflectance difference of post and pre-treatment in each growth stage was calculated by grouping the wavelength into four groups of the spectrum to identify the most determining spectrum to drought. A positive difference indicates decreasing in reflectance before and after the drought treatment. Otherwise, a negative difference indicates the increment of reflectance after treatment.
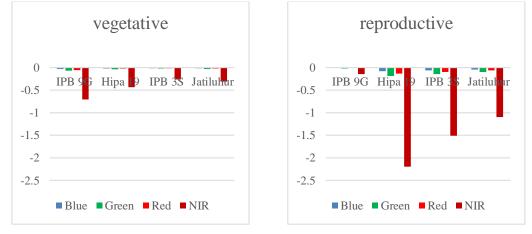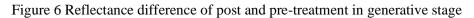
Figure 5 Reflectance difference of post and pre-treatment in the vegetative and reproductive stage

Figure 6 Reflectance difference of post and pre-treatment in generative stage

The negative difference is found in the vegetative and reproductive growth stages. The reflectance from all spectrum range was decreased after the treatment. A different result was obtained from the generative stage. All of the wavelength spectrum reflectances increased, except the NIR spectrum. The largest drop was from the red-light spectrum, for all varieties. This result fits the theory that unhealthy plants absorb the less visible light spectrum and reflect it more than healthy plants. The red-light spectrum was the highest increase compared to the other light spectrum. This pattern was the same for all of the paddy varieties.

WBI Calculation

The simple Water Band Index (WBI) proposed by Penuelas *et al.* (1997) was also calculated in this study. The WBI or Water Index (WI) was presented to estimate Plant Water Content (PWC) in ground-based. It is calculated by comparing the reflectance of 900 nm to 970 nm wavelength. Other water indexes such as Normalized Difference Water Index (NDWI), Moisture Stress Index (MSI), Normalized Difference Infrared Index (NDII), and Normalized Multi-band Drought Index (NMDI) were not calculated in this study due to the limitation of the spectroradiometer instrument.

Table 2 Water Index from all varieties and growth stage

Stage		IPB 9G	Jatiluhur	Hipa 19	IPB 3S
Vegetative	Pre	0.906	0.903	0.900	0.883
	Post	0.932*	0.941*	0.948*	0.958*
Reproductive	Pre	0.929	0.935	0.936	0.930
	Post	0.965*	0.967*	0.966*	0.968*
Generative	Pre	0.984*	0.995*	0.982*	0.965*
	Post	0.899	0.894	0.901	0.897

Note: asterisk indicates a larger value

From Table 2, the WI value varies in the range of 0.8 to 1.0, which is indicated as a normal condition based on WI value interpretation. Similar patterns were found from the vegetative and reproductive stage and all paddy varieties, which give more significant value from post-treatment, indicating the WI increase after treatment. Different results come from the generative stage, where decreasing WI is provided by all varieties of paddy. This result is similar to the result of the spectral pattern, which offered different results from the

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generative growth stage. However, the increasing or decreasing value of WI in this study was not significant. The largest difference was found from Jatiluhur in the generative stage, which decreased by 0.101, followed by Hipa 19, which decreased by 0.081. The largest increment was found from IPB 3S, which increased by 0.075 followed by Hipa 19, which increased by 0.048. Champagne *et al.* (2001) stated that at the canopy scale, WI has low sensitivity to a low water content of the individual leaf because it is strongly influenced by canopy structure.

CONCLUSION

Four varieties of paddy in this study gave a typical response to drought treatment. The most typical spectral responses were found in the generative growth stage. In the generative stage, four varieties' spectral response increased in the visible light spectrum (red, green, blue) as a response of the plants after treated by drought conditions. The highest increase was found from the red-light spectrum. It indicates the red-light spectrum is the most determining spectrum in the detection of drought that affects paddy in the generative growth stage. This result was compromising the rapid detection of paddy fields affected by drought using optical remote sensing data. Especially for paddy plants in the stage of generative.

WI provided low sensitivity to indicate water stress in paddy in this study. However, WI promises the detection of the growth stage of paddy under drought stress. WI can be used to distinguish the vegetative/reproductive and generative stages of four varieties of paddy in this study.

ACKNOWLEDGMENT

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