

Early detection of plant disease using close range sensing system for input into digital earth environment

W C Chew¹, M Hashim², A M S Lau^{1,4}, A E Battay³ and C S Kang¹

¹Department of Geoinformation, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

²Institute of Geospatial Science and Technology (INSTEK), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

³GIS and Remote Sensing Laboratory, Arabian Gulf University, Bahrain

Email: alvinlau@utm.my

Abstract. A case study on pre-symptom stage of plant disease infection using ground based hyperspectral remote sensing was conducted. The objectives of the study are: (1) to validate the existence of pre-symptom stage of *Ralstonia Solanacearum* infection in *Solanum Melongena L.* (eggplant), and (2) to determine the induced electromagnetic spectral response for infected eggplant. From the experiment, the pre-symptom duration of *Ralstonia Solanacearum* infection in the case of eggplant was estimated (with the artificial photosynthetic stress conditions were adopted in the experiment to induce measurable changes in daily hyperspectral measurement of disease infected eggplant samples during the pre-symptom stage) as four days which is the critical period for practicing effective treatments. Vegetation indices namely, (1) Chlorophyll Absorption Integral (CAI), (2) Photochemical Radiation Index (PRI), and (3) Normalized Difference Vegetation Index (NDVI) have successfully shown noticeable progress of index value from the infected sample plant (with 100% light stress condition) throughout the study. Yet, other infected sample plants with moderate light stress conditions (50% or 75%) did not result any similar progress of index value from the daily leaf scale hyperspectral measurements. Apparently, extreme light stress can induce significant changes at visible portion in hyperspectral measurements for a disease infected eggplant during the pre-symptom stage.

1. Introduction

An early detection and accurate diagnoses on infection of bacterial is helpful in managing large farms, which includes alerting to prevent outbreak of diseases or mitigate massive crop losses, and applying of early and effective treatments with sufficient amount of chemical applications [1]. Annually, global crop lost due to plant diseases are identified to be not less than 10 % from the total yield [2], and this loss has not taken into account other incidences of natural disasters. *Ralstonia Solanacearum*, a famous soil-borne bacterium which most likely to cause bacterial wilt disease on host plants in large scale of damage like crop losses up to 50 % or even 100 % of total yield in eggplant farming [3, 4].

In conventional farming, visual approach or field scouting is the one common method that has been used in early detection and assessing the damage of crops due to particular plant pathogen infection. However, the effectiveness of this method is highly dependent on the frequency of field scouting and the experiences of farmers in detecting the particular pathogen infection [1]. Besides, field scouting is not an economical method and having low efficiency for large farming area as it is very time consuming [5, 6].

Alternatively, remote sensing technology has been widely applied in agricultural sector especially precision farming since 21st century with the advancement of satellite imaging technology [7];

⁴ To whom any correspondence should be addressed.



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however, this technology is not yet well established for the early detection of plant pathogen infection and its related study. Recently, several studies of early detection of plant pathogen infection during the pre-symptom stage were conducted with remote sensing methods, which including the detection of pathogen infection with thermal infrared imageries and the hyperspectral measurements with different vegetation indices. Thermal infrared imageries have been proven effective in early detection of *Ralstonia Solanacearum* infection within five days before the appearance of physical symptom which the daily mean and minimum leaf temperature of infected tomato plants was relatively higher than that non-infected tomato plants [3]. In recent years, hyperspectral remote sensing have been widely studied by researchers in plant pathology and their results have proven the potentials use of hyperspectral remote sensing analysis in this field [8-11]. A research group has attempted to detect and distinguished different pathogen infections in sugar beet plants via classification methods and hyperspectral data with vegetation indices and found that Support Vector Machines (SVM) was the best classifier to achieve the objectives as compared to Decision Trees and Artificial Neural Networks (ANN) [5]. In another *Ralstonia Solanacearum* infection study, physiological stress in light has successfully induced measurable changes of daily electromagnetic spectral responses of infected cucumber plants in the pre-symptom stage [12].

This paper presents an experimental early detection study on a soil-borne bacterium using hyperspectral remote sensing technique in eggplant (*Solanum Melongena L.*). The objectives of the study are: (1) to validate the existence of pre-symptom stage of *Ralstonia Solanacearum* infection in *Solanum Melongena L.* (eggplant), and (2) to determine the induced electromagnetic spectral response for infected eggplant. Photosynthetic stress was found as an inducing factor during pre-symptom stage to highlight measurable changes in electromagnetic spectral responses of infected crop. Thus, the experiment was designed to determine the impacts on infected eggplant plants due to different levels (50%, 75%, and 100%) of photosynthetic stress.

2. Methodology

2.1. Experiment setup

After 50 days of cultivation in a greenhouse facility conducted in University Putra Malaysia (UPM), twelve young eggplant plants were selected to form two samples groups in equal number as shown in figure 1. In order to cause infection of plant disease in either one of the eggplant groups, cultivated *Ralstonia Solanacearum* bacterial cells were injected into soil layer that was near to plant root system. Meanwhile, artificial light stress conditions (50%, 75%, and 100%) were implemented onto sample plants by using opaque black materials to block incoming sunlight throughout the experiment. Artificial photosynthetic stress was also expected to speed up the disease infection inside infected sample plants as compared to the control sample (infected without photosynthetic stress) throughout the experiment.

2.2. Daily hyperspectral data collection

After bacterial inoculation, sample plants were observed in the following days to ensure the presence of pre-symptom stage (without appearance of wilting leaf or stem). Leaves were also collected from all sample plants daily and kept in plastic bags with labeling and then stored in a cooling case to retain freshness of leaves before sending to laboratory (within an hour) for spectral measurement at leaf scale.

Spectral measurement setup and configuration prior to sampling is an important step to obtain accurate data. In order to perform good sampling, leaves samples were placed on a black cloth with low reflectivity to minimise the background effect in spectral measuring and a fixed geometry for sensor, light illumination and leaf sample was set up. An Analytical Spectral Devices (ASD) Spectroradiometer (full spectral range of 350nm to 2500nm and output spectral interval in 1 nm) was used to collect *in-situ* hyperspectral data of eggplant leaves samples. The spectroradiometer was placed 1 meter vertically above sample and an 8° fore optics was used to result a field of view in 14 cm diameters. Tungsten lamp was used to produce a constant light source in order to minimise potential spectral variation between samples due to illumination condition. Ten spectral measurements were taken for each leaf sample to obtain a mean and white panel reflectance was frequently checked to maintain the accuracy of data. During spectral data collection, chlorophyll level of eggplant leaves

samples were measured using SPAD-502 chlorophyll meter. This data collection procedure has been repeated on a daily basis in the study.

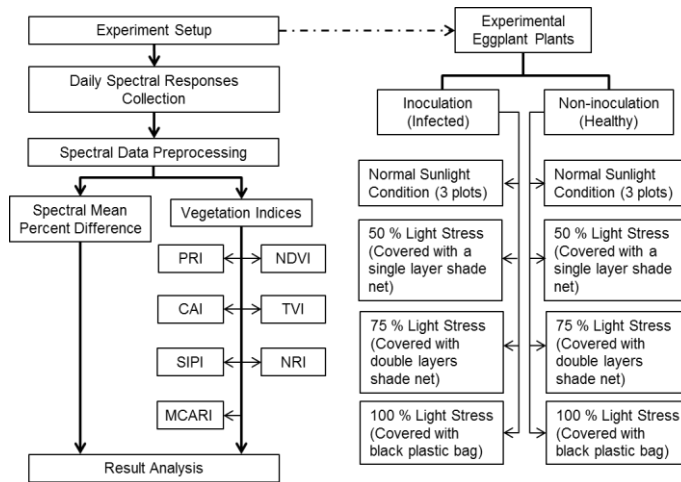


Figure 1. This is the work flow of the study. The sample eggplant plants were equally divided into two groups namely infected and healthy groups respectively, both groups were experienced different degrees of light stress.

2.3. Spectral data processing

2.3.1. Validation of pre-symptom stage. In order to validate the existence of pre-symptom stage of *Ralstonia Solanacearum* infection in eggplant, the Mean Percent Difference method was applied. The Mean Percent Difference of spectral responses between infected and healthy sample plants (normal sunlight condition) was calculated using equation 1.

$$\text{Mean Percent Difference} = \sum \left(\frac{|R_{Hi} - R_{Ii}|}{R_{Hi}} \right) \times \frac{100}{N} \quad (1)$$

where R_{Hi} and R_{Ii} are spectral reflectance in narrow spectral band i for the healthy and infected eggplant plants respectively, the spectral bands were ranged from 500 nm to 2000 nm and N is the number of spectral bands which was 1501.

Vegetation indices testing. In data analysis, seven vegetation indices, namely (i) Chlorophyll Absorption Integral (CAI), (ii) Photochemical Reflectance Index (PRI), (iii) Normalized Difference Vegetation Index (NDVI), (iv) Structure Insensitive Pigment Index (SIPI), (v) Triangular Vegetation Index (TVI), (vi) Nitrogen Reflectance Index (NRI) and (vii) Modified Chlorophyll Absorption and Reflectance Index (MCARI) were applied to assess the impact of physiological stress toward infected eggplant plants at different levels. Any measurable changes in spectral responses could be detected by implementation of these vegetation indices for all eggplant samples. The formulae of these indices are shown in table 1 as follow.

Table 1. Seven vegetation indices were used in this study to estimate daily index value of eggplant plants which induced with light stress.

Suggested Vegetation Indices	References
$CAI = \int_{R_{556}}^{R_{755}} r$, $r^a = R_s/R_e$	[13]
$PRI = (R_{550} - R_{531}) / (R_{550} + R_{531})$	[14]
$NDVI = (R_{850} - R_{680}) / (R_{850} + R_{680})$	[15]
$NRI = (R_{570} - R_{670}) / (R_{570} + R_{670})$	[16]
$SIPI = (R_{800} - R_{445}) / (R_{800} + R_{680})$	[17]
$TVI = 0.5[120(R_{750} - R_{550}) - 200(R_{670} - R_{550})]$	[18]
$MCARI = [(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})](R_{700}/R_{670})$	[19]

^a r is envelope quotient, R_s is the measured reflectance and R_e is the reflectance of envelope at particular narrow spectral band i .

^b R_i is the reflectance of measured spectra at particular narrow spectral band i .

3. Results and discussions

3.1. Pre-symptom stage of *Ralstonia Solanacearum* in eggplant

An assumption was made whereby daily Mean Percent Difference of spectral reflectance between infected and healthy eggplant plants should be less than 20% during pre-symptom stage. The result in figure 2 has shown that ~20% difference in the spectral analysis with the existence of pre-symptom stage for the plant disease infection on Day 4 of the experiment. It indicates within this critical duration, effective actions should be taken to terminate the disease in infected host plant as this would effectively prevent the disease to spread. This result is supported by a previous study carried out by Chiwaki *et al.* which the pre-symptom stage for *Ralstonia Solanacearum* infection in tomato was recorded to be five days [3]. This finding somehow serves as a reference for precision farming in implementing early detection of *Ralstonia Solanacearum* infection in crop.

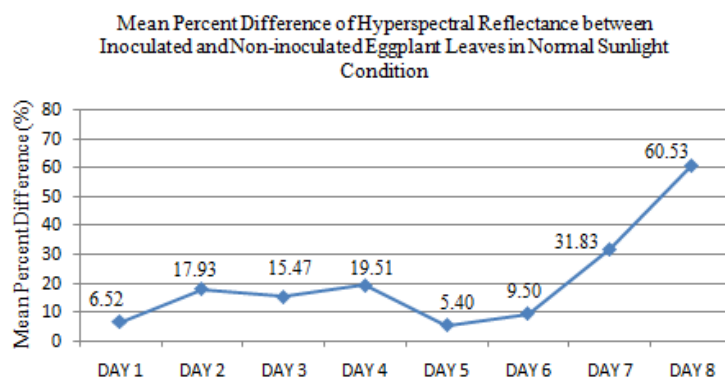
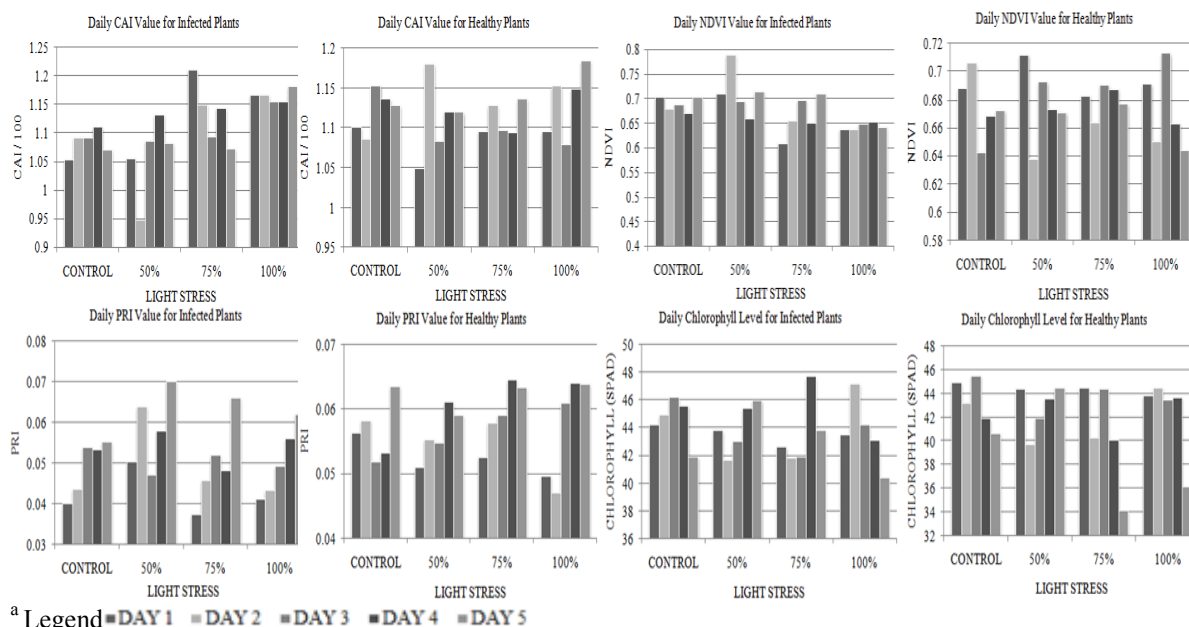


Figure 2. The changes of spectral difference in hyperspectral responses between the infected and healthy eggplant plants for eight days duration.

3.2. Vegetation indices

Comparison in results between the two samples groups (healthy vs. infected eggplants) were done based on calculated index values. From the comparison done, CAI, NDVI and PRI are the indexes which are able to detect the changes in vegetation index value for infected plants at early stage. This can be further explained as Chlorophyll Absorption Integral (CAI) is an index that sensitive towards chlorophyll absorption changes within red and red edge spectral regions. In this study, the infected eggplant plant (with 100% light stress) shows a distinctive pattern as plotted in figure 3 which its daily CAI value is stable at high value around 1.15. The results from this study indicate that the

infected plant had experienced low chlorophyll absorption relative to other experimental plants since first day of bacterial cells inoculation towards eggplants. NDVI was found to have the daily index value of less than 0.65 in the infected eggplant at all dates, which was also the lowest in average among all other plants. Furthermore, a stable index pattern is only found in this infected eggplant plant whereas other plants experienced fluctuation on daily NDVI.



^a Legend ■ DAY 1 ■ DAY 2 ■ DAY 3 ■ DAY 4 ■ DAY 5
^b CONTROL refers to eggplant plant in normal sunlight condition

Figure 3. The plots of daily CAI, NDVI, PRI, and SPAD values of all eggplant plants.

Based on result calculated from CAI and NDVI, injection of bacterial cells inside the infected eggplant plant (100% light stress) is suspected to cause malfunction of chlorophyll in leaves started from the first day (although no physical symptom was visible during this pre-symptom stage). Somehow, the extreme light stress really speeds up the infection process in this plant with a significant rate. As supporting fact, the chlorophyll level in figure 3 shows a rapid decreasing trend from the second spectral collection date for this infected eggplant plant.

PRI has shown its potential as a good indicator to be used with remote sensing data in early detection of plant disease infection in the case of eggplant. In this study, the 100% light stressed infected plant has a steady increasing of daily PRI index value which the same pattern was not found in the healthy eggplant plant (100% light stress). Literature stated that high PRI value was associated with low photosynthesis process and thus low chlorophyll absorption occurred at blue spectral region [20]. As impact from the extreme light stress in development of bacterial cells, the infected plant (100% light stress) has experienced a rapid dropping in photosynthetic rate throughout the study.

4. Conclusions and recommendations

The intentions of this study are to validate the existence of pre-symptom stage of *Ralstonia Solanacearum* infection in eggplant and to study the spectral responses of eggplant plants toward infection under different light stress conditions. Hereby, the pre-symptom stage of *Ralstonia Solanacearum* infection in eggplant is estimated as four days. Vegetation indices, namely CAI and NDVI have shown distinctive index patterns from daily spectral responses of the full light stress infected eggplant plant where significant low chlorophyll absorption was recorded in this study. The PRI index has also indicated steady dropping of photosynthetic rate of this infected plant throughout the experiment. The study has proven that invasive of *Ralstonia Solanacearum* gives negative impact on leaves chlorophyll while extreme light stress is likely to speed up the infection and further impacts on chlorophyll concentration of infected host plant.

From this pilot *in-situ* hyperspectral remote sensing study done on eggplant disease infection, more works should be carried out to enhance the research procedure and validation of findings in current

study respectively. Constraints in spatial resolution and atmospheric effects should be taken into considerations when performing sensitive hyperspectral study especially in pre-symptom stage of vegetation disease study. Good spatial resolution is also an essential option to locate the potential host plants precisely while minimum atmospheric effects during data collection is an ideal case for accurate and reliable spectral measurements in remote sensing study. It is highly recommend to test the implementation of airborne or spaceborne remote sensing data whether is it possible for early detection of plant pathogens infection and to identify more spectral range for this purpose.

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