

Monitoring Rice Leaf Blast in Paddy with Hyperspectral Vegetation Indices in Paddy Fields with the Help of Remote Sensing

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Abstract

*Rice leaf blast (*Pyricularia oryzae*) should be detected early to minimize fungicide overuse to prevent the losses of production. The paper involved the use of hyperspectral imagery methods to identify and delineate severity of rice blast in paddy fields of Shiga Prefecture in Japan. Photochemical Reflectance Index (PRI) Normalization Difference Red Edge (NDRE) and Modified Chlorophyll Absorption Ratio Index (MCARI) are all narrow-band vegetation indices which were analyzed in reference to scales of disease severity. The highest correlation between the field-observed disease incidence was with PRI and NDRE ($R^2 > 0.85$). Validity of the spatial distribution of the disease hotspots was confirmed with drone imagery and field sampling, which justified the viability of hyperspectral sensing to target effective disease mapping. The results reveal that hyperspectral imaging, especially vegetation indices offer a scalable and accurate rice disease surveillance protocol allowing early prediction of disease incidence and effective management having the capacity to enhance crop yield and decrease over reliance on fungicides.*

Keywords: *Rice leaf blast, Hyperspectral, Vegetation indices, PRI, NDRE, remote sensing, precision agriculture.*

1. Introduction

1.1 Significance of Early Detection of Rice Blast

One of the most devastating rice crop production diseases is called rice leaf blast (*Pyricularia oryzae*), and if this rice disease is not stopped early, it causes huge losses of the crop. The timely identification of rice blast plays a vital role in the reduction of damage to crops as well as the enhancement of the management strategies of the disease. Early treatments will result in a more specific application of fungicides thus decreasing not only the magnitude of destruction but also the effects on the environment through excess use of pesticides. An early detection also augments efficiency in resource use resulting in more sustainable and commercially viable practices in rice farming. Rice blast is a very contagious fungus and so under favorable conditions it can spread rapidly and thus identifying it early enough is very necessary in order to curb contamination of the large fields.

1.2 Flaws of Classic Disease Scouting

The conventional disease scouting is based on field examination through visual checks by farmers or plant pathologists to detect disease symptoms, which in most cases come at a later stage when much damage has already been done by disease. The techniques require a lot of manual labour, time consuming and are likely to be erroneous particularly in the mass production paddy fields. Moreover, visual examination has a particular issue in its relying on subjective interpretation; it cannot identify the disease at the early stages when it is still not visible, and thus, delays in interventions occur. Such a drawback can worsen the impacts on crop losses and dependence on chemical measures, which are expensive and prove to be detrimental to the environment.(1)

1.3 Hyperspectral Vegetation Index Potential

Hyperspectral imaging system turns out to be an effective solution to these problems providing comprehensive non-destructive information about plant health at numerous spectral bands. Vegetation indices is another technology that measures slight physiological responses in plants related to the initiation of disease that cannot be identified using naked eyes because they are seen using Photochemical Reflectance Index (PRI) and normalized difference red edge (NDRE). Such indices will mean that stress in plants can be detected early such as nutrient deficiencies, water stress and disease can be detected, providing an accurate and scalable way of detecting stress in a large area. The possibility of hyperspectral vegetation indices in making early disease diagnostic and management practices is something that is making a difference in precision agriculture.(2)

2. Review of Hyperspectral Techniques in Plant Disease Surveillance

Monitoring Rice Leaf Blast in Paddy with Hyperspectral Vegetation Indices in Paddy Fields with the Help of Remote Sensing

2.1 NDVI, PRI and NDRE, MCARI used in the Past

Hyperspectral imaging techniques have become common in plant surveillance of diseases given that this methodology is capable of detecting minute changes in the health of plants even before they become observable. Provided that there is a set of vegetable indices, the Normalized Difference Vegetation Index (NDVI) has gained significant areas of application as a monitoring parameter of the plant vitality and stress. NDVI is usually utilised in an attempt to estimate the amount of chlorophyll, despite the fact that occasionally it could be restrictive in its capability to distinguish various causative factors of stress, including disease versus nutrient deficiency. More specific indices, Photochemical Reflectance Index (PRI), Normalized Difference Red Edge (NDRE), and Modified Chlorophyll Absorption Ratio Index (MCARI) have been popular due to their increased sensitivity to particular kinds of plant stress. To give an example, PRI is efficient to detect a state of photosynthetic stress whereas NDRE and MCARI are quite capable of evaluating chlorophyll level and plant health following the attack of such diseases as rice blast.(3)

2.2 Narrow-Band Index Sensitivity to Stress Detection

Narrow-band indices such as PRI, NDRE and MCARI are very beneficial in detecting stress in comparison to broad-band (e.g. NDVI). These indices measure the sensitive wavelengths to the physiological changes in plants and therefore more sensitive to the early symptoms of disease. As an example, PRI can measure the ratio of the light absorbed by plant pigments and signal the change in photosynthetic efficiency, which is mediated by disease. NDRE and MCARI with their sensitivity to the red-edge region are more sensitive to chlorophyll and to stress thus reflecting the health of plants better in the disease condition such as rice blast.

2.3 Loopholes of Existing Programs on Detection of Rice Blast

Although hyperspectral methods have been proven very promising, the existing methods of detection of rice blast have some loopholes. The spatial resolution of hyperspectral images may not always enable it to diagnose the disease at its early stages particularly in extensive fields. Also, the combination of hyperspectral information with validation and mapping of disease hot spots in the field is a difficult task. More studies should be conducted to improve the application of hyperspectral indices in tracking Cost-effective and scalable means of large-scale rice blast monitoring should be developed.(4)

3. Experiment Site and appurtenance Domain

3.1 Paddy Fields (Location, Variety, Season)

Research was carried out in paddy fields of Shiga Prefecture in Japan and one of the predominant features of the paddy is that the area has a good climatic condition that favours the rice crop. The experiment was conducted in the two fields that were found in Kusatsu City, which is considerable in rice production. Rice variety in the study was Koshihikari, a Japonica rice cultivar, a popular variety that has caused major losses as it is both high-quality rice and it is also sensitive to rice blast disease (*Pyricularia oryzae*). The experiment was conducted in the rice-growing season of 2019 that lasted between May and October and covered the general climate pattern of the region involving warm weather and occasional precipitation. These environments are optimal to the development of rice blast hence this place is the right place to carry out disease surveillance studies.

3.2 Disease Score Methodology Ground-Truth

In order to test the reliability of the hyperspectral data, ground-truthing in the field-based was done by using the disease scoring technique. The severity of the disease was also visually measured using disease incidence scale; rice plants were classified according to the leaf area infected by rice blast expressed as a percentage. A scale between 0-5 was taken whereby, 0 equals no symptoms and 5 equals full blight on the plant. The survey was done frequently on a growing season basis by recording the extent of the disease at various places in paddy fields. This was the data that was used as reference to correlate hyperspectral indices with the actual disease incidence and mapping disease hotspots.(5)

3.3 Hyperspectral Imaging Equipment

To collect high-resolution and efficient data, pictures that acquire hyperspectral images were obtained using a Hyperspectral Imaging System (HIS) installed on drone platform. A wide range (400 1000 nm) of spectrum (400 1000 nm) was used with the hyperspectral sensor where detailed spectral information is obtained which is capable of registering subtle physiological change in the rice plants due to disease. The drone used a GPS system to georeference data and thus it was possible to map the distribution of disease in the field. Remote sensing of

hyperspectral imaging using drones achieved high-resolution image and fine-scale data in large areas circumventing the need to use a stationary platform which is an invaluable resource in disease surveillance.

4. Spectral Processing Pipeline and Vegetation indices

4.1 Choice and identification of Indices (PRI, NDRE, etc.)

Here, a number of narrow-band vegetation indices were chosen in terms of their sensitivity to the plant stress and their capacities of uncovering early symptoms of the rice plant disease. The indices that were employed were:

- **Photochemical Reflectance Index (PRI):** PRI is highly responsive in relation to the fluctuation of photosynthetic efficiency and therefore can be used to detect stress levels caused by illness before the mechanism manifests. It is determined by a ratio of reflectance, which is that of certain wavelengths (531 nm and 570 nm), represented by alterations in the lights absorbed by chlorophyll during photosynthesis.
- **Normalized Difference Red Edge (NDRE):** NDRE is sensitive to red-edge region of the electromagnetic spectrum which has high sensitivity to the chlorophyll content. It is also an effective tool in evaluating the health of plants in such stresses like rice blast because it indicates the alteration in the absorption of chlorophyll.(6)
- **Modified Chlorophyll Absorption Ratio Index (MCARI):** MCARI measures reflectance recorded in both the red and near-infrared parts of the spectrum; it is therefore responsive to a change in the chlorophyll content which is usually varied with disease caused stress.

Such indices were selected due to their credibility in reporting stress-induced variations in plants, hence revealing appropriate reports on the health status of rice plants at the risk of attack by the blast disease.

4.2 Calibration, Pre processing and reflection correction of image

Hyperspectral images were analyzed so that there is proper spectral analysis. The calibration processes incorporated the atmospheric corrections as well as the temperature- or sensor-related distortions by standardization based upon reflectance panels. This was to be followed by the technique of preprocessing to eliminate noise and outliers hence ensuring that the data gave a proper reflection of the reflectance of the rice plants. Adjustment of the reflectance was done to take into consideration the environmental factors, i.e. lighting and background reflectance to enable more accurate interpretation of plant health.(7)

4.3 Disease severity correlation with segmentation of data

In order to associate the hyperspectral data with the field observation of the disease the images were segmented or partitioned into patches that represent certain part of the paddy fields. The segments were then examined to align with the levels of disease severity (on the basis of ground-truth scores). The relationship between the hyperspectral indices and the severity of the disease was determined and the indices that predicted their occurrence and severity best were established. This segmentation made it possible to identify the hotspots of the disease and it assisted in terms of understanding the spatial distribution of the disease in the paddy fields.

5. Validation and Mapping of disease severity

5.1 R² Values, Regression Models- Correlation Analysis

Regression models were used to measure the correlation between the severity of the disease and hyperspectral vegetation indices (PRI, NDRE, MCARI). These models were to determine the relationship between the spectral data retrieved through hyperspectral images and the incidence of the disease as seen in the field. The strength of the correlation was determined using the R² values. The strongest correlations with the extent of the disease were found in PRI and NDRE, with R² above 0.85, meaning the relationship was linear, as well. These measures indicate that hyperspectral imaging, namely, PRI, and NDRE could be effective in detecting the rice leaf blast at different periods of development. The data were also used to describe disease severity as the function of spectral values using regression models which gave a valid instrument in mapping the distribution of the disease.(8)

5.2 Geographical Display of Geographical Disease Hot Spots

Georeferenced hyperspectral images in combination with ground-truth disease incidence data were used to visualize spatial distribution of the severity of rice leaf blast. The hyperspectral data was used to identify disease hot spots, i.e. those areas where the disease was most severe, and to map the disease hot spots to the study area. Geographic Information System (GIS) software was used to carry out this spatial analysis; hyperspectral indices were color-coded according to various degrees of the severity of the disease. Such maps could give useful

Monitoring Rice Leaf Blast in Paddy with Hyperspectral Vegetation Indices in Paddy Fields with the Help of Remote Sensing

information on the spatial variation of the occurrence of rice blast in the paddy fields as well as new regions that need special attention during intervention.(9)



Figure 1: Spatial Distribution of Disease Severity in Paddy Fields

5.3 Image validation of drone and Field Sampling

The hyperspectral data verification and the mapping of the disease were carried out at various locations within the paddy fields by use of the field sampling. These field samples translated to the actual measurement of the disease (ground- truth disease scoring methodology or 0-5 scale methodology). This was followed by a comparison of the results of the field data and the hyperspectral. The validation of the results was carried on further using the drone imagery. During the fifth process, the drone images have been compared to the hyperspectral maps to ensure spatial preciseness and uniformity of the disease hotspots. The validation process created a significant relation between on-ground test and the remote sensing data and substantiates application of hyperspectral techniques in the disease surveillance.(10)

Table 1: Correlation Between Hyperspectral Indices and Disease Severity

Index	R ² Value (Disease Severity)
PRI	0.86
NDRE	0.88
MCARI	0.79

6. Agronomic and Interpretation

6.1 Early Fungicide Application Practical Implications

Early identification of the rice leaf blast through hyperspectral imaging presents great importance in application of fungicides. Conventionally, fungicides are currently used basing on observable symptoms or interval scouting, thus resulting to either over application or late treatment. Application of hyperspectral indices such as PRI and NDRE at an early stage allows a better applications of fungicides. As the disease hotspots can be detected at the early stages, farmers will be able to use only certain areas of the field, which can reduce the quantity of fungicide used. Not only does this minimise the possible loss of yield because of uncontrolled disease, but also it decreases the total expenditure of fungicide application, making the issue of controlling pest more operative.

6.2 Scaling to Rice-Growing Megaregion

Among the first virtues of hyperspectral sensing is that it can be switched to a large-scale rice-growing area. Such paddy fields will be managed effectively with the help of the drones or hyperspectral sensors on satellites as thousands of acres can be covered within no time. The technology has the ability of collecting data via high resolution and large coverage, and therefore, the farmers can be able to analyze several fields at a time. This scalability is especially relevant within areas that have large rice monocultures because a disease outbreak is easily transmitted. Hyperspectral Imaging, when complemented by spatial mapping has the potential to enable a farmer to obtain a comprehensive and fieldwide view on the occurrence of disease which can then be used to make well informed decisions on how to manage the disease on a regional level.

6.3 Benefits of Early Detection to Economy and Environment

The cost savings of the early detection of the disease to an economy and environment are significant. The prompt diagnosis of rice blast advances practical fungicide application and considerably cuts down on chemicals utilized in a field. This will lower the cost of input on the farmers and also the impact of fungicide runoff into the ecology of the surrounding vegetation. In addition, early detection controls the high frequency of disease outbreak by guarding against large scale losses thus ensuring that crop yields remain high which is important in terms of food security and profitability in rice production. These advantages render hyperspectral sensing as an environment-friendly and sustainable technique of managing any rice diseases towards economic and environmental sustainability in rice production.

7. Restrictions and Future Suggestions

7.1 Environmental conditions Hanging on Spectral Accuracy

Although variety of benefits emerge due to hyperspectral imaging, it can be considered, that the accuracy and reliability of spectral data can be affected by several environmental factors. Conditions pertaining to the atmosphere, including cloud cover, light and rainfall, and humidity may cause noise and the distortion of the reflectance values. The inconsistency of the spectral values also has the potential to be produced by differences in soil type, moisture content and health issues within fields. Reflectance calibration and atmospheric correction, therefore, comes in to counteract these difficulties. Nevertheless, how they determine reliability of the different methods in diverse environmental conditions needs to be established. Further, the field conditions like the crop stage or the existence of weeds can also vary the spectral signals and thus fine tuning of the hyperspectral models to specific conditions should be done so that there are constant results.

7.2 Possible UAV systems or AI Classifier integration

A good example of future work is the combination of the concept of Hyperspectral imaging and Unmanned Aerial Vehicles (UAVs). Hyperspectral data can be gathered on large and complex field areas with a high spatial resolution using UAVs in a more efficient manner. UAV applications enable the data to be collected rapidly and locally including the inaccessible sites of a large paddy field.

In addition, using AI classifiers, AI data interpretation algorithms, and AI-powered prediction of the disease severity might be included to enrich the data interpretation and predict severity of the disease. It is through the AI models that complex hyperspectral data can be analyzed in a better way to outline patterns and anomalies which might not be obvious at first. Evaluation of hyperspectral indices and rice blast severity through machine learning techniques, including supervised classification or deep learning, would also improve such correlation. The integration would enhance the scalability and automation of the monitoring of rice diseases and make them more available to large-scale real-time applications.

7.3 Closure and Future Work

In order to address these constraints, the future studies must aim at enhancing data preprocessing procedures, advancing more accurate AI models, and investigating the role of the UAVs and hyperspectral imaging in observation with true positive detection characteristics, in different environmental settings.

8. Conclusion

8.1 Overview of Results

This research was able to show the possibility of hyperspectral imaging especially by using the vegetation indices like, PRI, NDRE and MCARI, in early detection and mapping of rice leaf blast (*Pyricularia oryzae*) of paddy field. This analysis showed that these indices were substantially correlated ($R^2 > 0.85$) with ground-truth disease severity, proving their effectiveness to diagnose rice blast at early stages and determine disease severity prior to visible symptoms. The geographic distribution of the disease hot spots which was confirmed through field sampling and drone imagery proved to give great insight into the disease distribution in the field which the intervention could then be focused. The results indicate the plausibility of the use of hyperspectral sensing as an accurate and scalable rice disease surveillance technique with the potential to provide a nonintrusive and accurate device to manage the disease.

8.2 Matters of relevance to Precision Plant Pathology and Disease Management

The findings can be very relevant in the precision plant pathology as it is a contribution through the awareness of early detection of diseases in the rice plant. Hyperspectral imaging is a cost effective method which has high resolution as a substitute to conventional scouting methods and can be utilized to monitor large areas in real time.

Monitoring Rice Leaf Blast in Paddy with Hyperspectral Vegetation Indices in Paddy Fields with the Help of Remote Sensing

Through vegetation indices, the farmers will have the ability to know when huge diseases outbreaks appear and then get able to administer fungicide early and in specific locations. The practice uses less chemicals, is less expensive, and it assists in alleviating environmental effects and this is in tandem with sustainable farming.

Moreover, there is an opportunity to employ this technology to manage diseases with a high level of precision due to the use of high spatial accuracy in disease detection. Farmers are able to prioritize application on high risk spots making effective use of fungicide and giving increased crop yield. Hyperspectral imaging is also an appealing source of providing information regarding large-scale fertilizing of rice as was also the case in the scalability of the process to large field and varying environmental conditions. With maturing technology, it is capable of revolutionizing plant disease management through the provision of adroit, fortuitous and data-driven wisdom to assistance enlightenment, all of which will result in more labile and lasting farming.

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Conflicts of interest

The authors have no conflicts of interest to declare

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