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Review Article

Agronomic Assessment on Paddy Field Using Aerial Imagery and Vegetation Indices Algorithm: A Review

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Abstract: Rice is consumed by the majority of Southeast Asians, particularly in Malaysia. As years pass by, rice production has not been inclined to align with some populations in Malaysia that keep growing. Thus, the self-sufficiency level (SSL) of 100% is not achieved until today. The government intends to expand the granary areas for rice farming by concerning the SSL target to be completed. Despite that, crop management, specifically paddy farming, is tedious and requires a lot of workforces. However, as technology develops and gets more sophisticated these days, a discipline that helps in crop management has been introduced over the years called remote sensing. Remote sensing undoubtedly showed significant application in crop management. The Vegetation Indices (VIs) algorithm is a branch in remote sensing that enables researchers to evaluate vegetative covers on the ground from aerial view by using spectral measurements either qualitatively or quantitatively. The VIs are obtained from the spectral response of the ground areas from the aerial view commonly composed of vegetation areas, soil brightness, various vegetation on the ground, canopy, environmental effects, shadow, and moisture level of soil and plants. Nonetheless, the favourable of remote sensing is the spatial-temporal, which helps determine vegetation changes over a certain period. This also includes rice farming. Thus, this paper discusses and summarizes the VIs algorithm that was relevant in the application of rice planting. It proposes the popularity and relevance of the VIs algorithm in rice crop management in Malaysia.

Keywords: rice mapping, crop growth monitoring, UAV, Vegetation Index

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1. Introduction

Agriculture is one of a component that plays a vital role in many nations worldwide. It acts as a source of economy and income as well as for the activity of exporting their products to supply to other countries. Other than that, it is also undoubted that the contribution of agriculture is its product, which is compulsory for the fundamentals of human needs. Besides releasing oxygen, it provides food for humankind's consumption on a daily basis, fiber, and other products that humans will utilize in various forms (Awokuse & Xie, 2015; Gillespie & Van de Bold, 2017).

Malaysia and most Southeast Asia countries will consume rice as a staple (Firdaus *et al.*, 2020). Eventually, this has made rice the second most important or highly demanded agricultural product in the world after wheat. Also, it showed that rice is being produced on the most enormous scale in Asia as it is also the most significant consumer of it (Rajamoorthy *et al.*, 2015). Although rice is predominantly cultivated in Asia, Rice Almanac (2013) recorded only 7% of their production being exported outside their countries. In addition, Mohanty *et al.* (2013) mentioned that paddy cultivation is managed by small-scale farmer and also lack agricultural land. Even though Malaysia works on the granary areas, the position of the production of rice in Malaysia is not encouraging as the total land as of 2020 is only 0.70 million hectares. In contrast, neighbouring countries like Indonesia, Vietnam, and Thailand allocated 11.50, 7.54, and 10.83 million hectares, respectively, which is almost one time larger (USDA, 2020).

Sishodia *et al*. (2020) highlighted that the demand for rice plants and land availability have led to the inclination of agricultural intensification, like fertilizer usage, pesticides, and other external inputs. Therefore, Delgado *et al.* (2019) and Berry *et al*. (2003) suggest a sustainable agricultural system by applying and implementing the precision agriculture component during the 21st century. Boursianis *et al.* (2020) stated that agriculture should be advanced via the fourth revolution as it advances in technologies, communication technologies, and information. As years pass by, technologies keep growing and emerging technologies like remote sensing, global positing system (GIS), and geographic information system (GPS) as the tools to optimize agricultural operations targeting the improvement of agricultural production and yield as well as reduce the inputs (Delgado *et al.*, 2019; Jha *et al.*, 2019; Elijah *et al.*, 2018). The available cultural practices, including man-wise monitoring and man-eye observation, tend to not uniform assessment and cause human errors. Therefore, this paper reviews the application of remote sensing, particularly the Vegetation Indices (Vis), in determining the agronomic sense of rice plants.

2. Remote Sensing in Precision Agriculture

Khanal *et al*. (2017) defined precision agriculture as the accumulation and gathering of tools and technologies useful in the agriculture sector to determine several parameters in agricultural practices, including in-field soil and crop variability. On the other hand, this remote sensing applies a kind of technology named Variable-Rate Technology (VRT) that serves the users with a variation of soil and vegetation inputs for the site-specific application.

This technology is getting improved and cheaper in price to capture field-level data. VRT is being controlled both on the ground and remotely using sensors on satellites, aircraft, and ground-based equipment (Stavrakoudis *et al.*, 2014). Hence, this will enable the user to generate maps depicting the vegetation or land variability.

The remote sensing application in precision farming is beneficial because it reduces uncertainties in managing the variabilities for the management and allows the efficient use of the resources. Hence, several sensors are used to collect the data on the aerial view for mapping and analysis. The remotely sensed imagery captured earlier can be utilized for research and monitoring, such as soil properties, vegetation classification, crops experiencing water stress, weeds suppression on the land, diseases or pests' infection, and yield mapping and forecasting.

In the application of remote sensing in agriculture or precision farming, the main role is greatly influenced by the type of platforms the data was obtained and the sensitivity or details of the sensors used. The various platforms, including satellites, Unmanned Aerial View (UAV), drones, or ground, may vary. The sensors used are commonly the multispectral or hyper-spectral sensors, which are distinguishable, resulting in different types of spatial qualities. Besides that, remote sensing is undoubtedly tangible with the spatiotemporal, which indicates the spatial analysis over time, hourly, weekly, daily, or annually. Depending on the sensor capabilities, this will also work with the radiometric resolutions from the 8-bit to 32-bit (Khanal *et al.*, 2017).

In precision farming or agriculture, remote sensing has evolved and developed during the last half of the century. The components that are being designed are the components that play a more significant role: the instruments. Adamchuk *et al.* (2003) mentioned that the improvised devices are simple optical systems with complex digital sensors that are very helpful in scanning and capturing the Earth's surface more rapidly and with higher quality. In conjunction with the remote sensing development, the algorithms associated with remote sensing also evolved the computation of the remotely sensed data processing to generate different types of images. This can generate spatial, spectral, temporal, and radiometric resolution images that have become fundamental to the remote sensing system.

The first component of remote sensing is spatial resolution. Spatial resolution is the pixel size or the smallest area that can be differentiated in the image resolution (Adamchuk *et al.*, 2003). In remote sensing, the data is the pixel size and value as individual data. The pixel is influenced by various factors such as the platforms, sensors, distance between sensors and the target point, the viewing angle, and light intensity. The aerial image of UAVs usually gives more detailing and smaller pixel sizes compared to the satellite's image resolution. Spatial resolution images and datasets really matter when it comes to site-specific management. Usually, the resolutions range from a few centimetres to 20 meters or rarely more significant (Imam, 2018). Despite the platforms, sometimes attachable sensors also provide more excellent resolution and are being used as they are much cheaper than the smaller pixels. Plus, smaller pixel resolution usually demands more significant storage space and computation ability for processing and analysis.

Also, spectral resolution is a system that can distinguish between the levels of electromagnetic radiation that travel through the spectrum of wavelengths. For crop conditions, the best range of the spectrum that could reflect the crop condition is the visible range to the Near-Infrared Range (NIR), which has a wavelength size of 400 to 700 nanometers (Ihouma & Madramootoo, 2017). The derivation of the spectrum portions within that range has the potential to serve the user with helpful information like thermal and mid-infrared spectrums. In the spectral resolution, the spectrum bands' derivations and the wavelength's size can characterize the resolutions and indicate the physical appearances of the captured subjects. Generally, at least three types of sensors commonly used in the remote sensing field produce various colours as the final products (Adamchuk *et al.*, 2003). One of them can only have images in black and white in colours commonly found in photographic sensors or sensors that produce individual colours like specific colour sensors and infrared colour images. Other than that, the sensor with at least 10 or fewer bands is the multispectral sensor. Up to a hundred types of colour bands are called hyperspectral sensors. Despite that, the visual light bands and the NIR can be combined from the panchromatic images.

The other type of resolution is temporal resolution. Temporal resolution is the time based on the data that have been collected in a sequential manner using the same data source.

Temporal resolution is essential to compare and observe the changes between two different dates over the event's exact location (Frank, 2009). In studying crop analysis, either growth or performance, this is a beneficial tool and popular to be applied. Regarding the time frame or interval between datasets, it is flexible if the platforms used are personnel like drones, UAVs, or any manageable planned aircraft platforms. However, a few open sources provide aerial images with various flexible bands for research purposes obtained from satellite imagery that designed fixed images captured as the satellite orbiting the earth. However, the imagery may not be helpful due to the images captured during unfavourable weather conditions and the capturing time (Adamchuk *et al.*, 2003).

Lastly is the radiometric resolution (Adamchuk *et al.*, 2003). The radiometric resolution refers to the measurement of the sensitivity of the remote sensing instrument. This radiometric resolution may result in different gradations, which refer to the data values. Each gradation is produced by instrument sensitivity level – the higher the instrument sensitivity, the higher the number of gradations and the pixel created as the data values. The standard picture element of data values ranges from 0 to 255 possible data in an image. 8-bit data has 255 data values and will be tested using the 10-bit instruments capable of producing 1024 gradations and up to 65,000 gradations if the more sensitive instrument is used as the 16-bit.

3. Remote Sensing and Vegetation Algorithms Indices Application in Paddy Crop

The application of remote sensing in agriculture is rising since it is very beneficial and handy to the users, and most of the users that use this technology in their farming system are researchers and gigantic companies. The application is barely limited to the geographical factors and area for performing data acquisition (De beurs & Townsend, 2008). This advanced technology is applied in precision farming, offering users lower operational costs and time-consuming data collection over huge study areas. The remotely sensed data is mainly known to be associated with the Geographic Information System (GIS) disciplines in data acquisition. The GIS approach can be overlaid with other information to be analysed and derive another form of information like the field boundaries, subject position coordinates, and heat spotting maps (Adamchuk *et al.*, 2003).

The ultimate reason for remote sensing is applied in the agricultural sector not only on rice crops but also on other crops, including maize, ornamental plants, and oil palms, because of the capability of remote sensing to detect problems in the field in a shorter time and easier despite being a bit pricy. The power of it has been determined via the ability of remote sensing to characterize the visible components on captured images into the translation of biophysical attributes of the crop and soil attributes (Liaghat & Balasundram, 2010). Kulo (2018) also mentioned that remote sensing is much easier to attain and improved with spatial analysis in conjunction with spectral and radiometric resolution, with many options for better results. Palanisamy *et al.* (2019) agreed on the term as the narrowband and hyperspectral sensors can produce better detailing and more detailed data for analysis.

Remote sensing works with the vegetation indices algorithms application. Vegetation indices have been defined as empirically extracting quantitative data from the biophysical characteristics of the environment (Rouse *et al.*, 1974; Richardson & Wiegand, 1977). The vegetation indices and the remote sensing cooperate in obtaining the reflectance values from the wavelengths of the spectrum that are sensitive to the attribution of the vegetation, soils, and environments. In simpler terms, the vegetation indices empirically provide the qualitative information obtained remotely via aerial imagery upon the desired parameters based on the land of the surface (Gilabert *et al.*, 2011).

The soil characteristics study is one of the most favourable studies by applying the remote sensing technique in rice crops. In agriculture, specifically in rice crop farming, the soil is the most significant influencing factor for the growth yield. It features developments after temperature (De Datta, 1981). Rice plants require sandy or clayey soil for growth as they need good water-holding capacity, permeability, neutral soil pH, and fertility (Shao *et al.*, 2001). Continuous agricultural activities will eventually negatively impact the environment, such as increasing soil salinity and degradation (Kuenzer & Knauer, 2013). Hedayati *et al.* (2022) also supported the statement that the land use of planted paddy crops on less arable land has the potential to degrade the quality of the soil and erosion probability. Kong *et al.* (2008) added that this practice has the tendency to decrease the output of the rice as well as interrupt the species' habitats. The study on the soil that is still under rice cultivation could provide data and data estimation regarding the food security, social well-being and environmental health status (Hedayati *et al.*, 2022).

There are a few vegetation indices that are used in studying the soil characteristics, including the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Optimized Soil Adjusted Vegetation Index (OSAVI). The study of soil using NDVI was done by El Baroudy *et al.* (2020) by bridging a few models like the MicroLES, Storie, ALES and Root with the R-squared value above 0.8 for all of those. Other than that, Mazur *et al.* (2022) performed a study using the NDVI found a strong relationship between the NDVI and the soil's potassium content. The soil electrical conductivity and macronutrient content via the same index were associated with a similar association.

Rondeaux *et al.* (1996) have tested several indices, including the Modified Soil Adjusted Vegetation Index (MSAVI), SAVI, and OSAVI. They suggest that MSAVI and SAVI are generally better options for general vegetation classification on arid land or vegetation less than 25% as they are more sensitive to the full range of cover. Meanwhile, the OSAVI is the best option for agricultural applications in soil study.

Secondly, Palanisamy *et al.* (2019) recommend the application of remote sensing for water management. The water stress can be detected accurately and precisely in a specific place or spot. Amin (2011) mentioned that agriculture has cost up to 84% of water withdrawal, and most of the usage is for rice irrigation flooding requirements. In addition, about 70% of the available water resources for rice production in Malaysia have been used. Rice farming requires water multiple times compared to the other grain types of crops (Venkatesan *et al.*, 2005). Mishra *et al.* (1997) found that water stress directly affects rice yield production due to the higher water deficit of the soil from the continuous submergence of seedlings to the rain-fed regimes.

Hence, few studies use several indices to study the water stress level. Gao *et al.* (1996) and Babar *et al.* (2006) have summarized and classified the normalized difference water index (NDWI) and the normalized water index (NWI). However, Roll *et al*. (2019) study showed that both NDWI and NWI did not exhibit positive responses to water stress and drought even though they are both designed particularly for that. Water stress via remote sensing can be evaluated by determining the plant greenness level and the leaf area index as the water stress symptom exhibited over the leaf colour and the area of the leaf. The indices recommended by Zhang *et al.* (2021) and Saifullah *et al.* (2019) are the NDVI and the Leaf Area Index (LAI). In contrast to the Roll et al. (2019), Wang et al. (2015) found a positive relationship between the NDWI and leaf water content. Ihouma and Madramootoo (2017) also summarized that the narrow band range from 780 to 1750 nm is highly responsive and sensitive to water content.

Swamy *et al.* (2020) mentioned that the nutrient level directly affects rice production. Successfully managing nutrients for rice crops will lead to increased rice production. However, in rice crop farming, there are problems of insufficient nutrient balance of the soils and the implication towards the environmental effects as the practices like nutrient mining and various indigenous nutrient supplies at different areas during the cultivation period (Adhikari *et al.*, 1999). Singh *et al.* (2008) emphasized the importance of nutrient management because it is very helpful in reducing the potential of fertilizer losses and raising rice production and productivity.

Regarding the importance of the nutrient management crucial level in rice farming production and bridging the application of remote sensing to determine the parameter. The NDVI and Normalized Difference Red Edge (NDRE) are valuable vegetation indices to assess the level of nutrients and health of rice plants and crops. Both NDVI and NDRE have shown a positive correlation with the rice plant's nitrogen level, respectively 0.83 and 0.82, based on Li *et al.* (2021) study. Rehman *et al.* (2019) also support the application of NDVI as the most popular and valuable tool to be applied in the assessment and prediction of grain rice yield. They found that the correlation is positive for all their parameters such as N uptake, N concentration, above ground biomass, and final grain yield, with a regression value of 0.66, 0.54, 0.51 and 0.58, respectively.

Last but not least, Silleos (2006) mentioned that the Enhanced Vegetation Index (EVI) is beneficial to improve the sensitivity to a region that is higher in biomass capacity and eliminate the influential factor of the atmospheric. This explains that it enhances the vegetation observation while reducing the canopy background signal (Huete *et al.*, 2020). SAVI and MSAVI have been determined as VIs capable of reducing soil background effects and the influence of bare soil (Xue & Su, 2017). All of these have been studied by Anuar *et al.* (2022), who found that they could differentiate the road and the canopy cover also by the green colour of the canopy. The Vis can also be very helpful to reduce the atmospheric effect and undeniably enhance the interaction between the aboveground biomass and the Landsat data.

4. Conclusion

In a nutshell, it can be said that precision farming is a vital technology thing during these years to comply with the Industrial Revolution 4.0 as well as the technologies development throughout these years in the 21st century. Adaptation of remote sensing is undeniably helpful and a handy tool in agricultural sectors without denying the benefits it brings. Thus, the application of it in this sector as an alternative for the most current issues and perhaps be able to provide better innovation in the future to solve big things, including the management of agronomic needs as well as to achieve self-sufficiency level in compliance of the land availability status particularly in Malaysia.

Nonetheless, as mentioned, several studies have proven the methodologies and approaches of remote sensing in agriculture are significant work. It can be said that remote sensing is an all-rounder approach in the agriculture sector that is really helpful in monitoring, assessing, and predicting rice performances regardless of growth or yield. However, the most widespread vegetation indices used in agriculture for the same purpose is the NDVI, which requires a hyperspectral camera. Therefore, a study of the title will be done to propose the specific NDVI value from a hyperspectral camera attached to a UAV to indicate the problematic value in the agronomic assessment. A correlation also shall be studied with other vegetation indices OSAVI, LAI, and other indices via RGB camera, including the Slope Saturation Index (SI) and Green-Normalized Difference Vegetation Index (GNDVI). However, in Malaysia, the application of these vegetation indices is not being applied widely. Still, it requires a lot of exploration by the researchers.

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