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Temporal Changes In NDVI And Nitrogen Content: A Study On Paddy Vegetation Reflectance Under Daily Light Variation

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Abstract. Remote sensing tools such as the Normalized Difference Vegetation Index (NDVI) are widely used to assess crop nitrogen status. However, variability in light intensity across the day can affect the reliability of NDVI readings. This study aimed to (1) examine the diurnal variation of lux intensity, (2) evaluate NDVI changes at different times of day, and (3) compare NDVI values between greenhouse and field trials. The experiment was conducted using MR303 rice grown under two conditions: a greenhouse and a field in Melaka, Malaysia. A randomized complete block design (RCBD) with five nitrogen treatments (T0–T4) was applied. Measurements of lux, NDVI, SPAD, and nitrogen content score (NCS) were taken during the reproductive stage in the morning, noon, and evening. Findings showed that lux intensity was significantly higher at noon (47,304 ± 20,422 lux) than in the morning (6,615 ± 2,568) or evening (4,829 ± 1,935) ($p < 0.05$). NDVI values were significantly lower at noon in both environments ($p < 0.05$), while morning and evening values were statistically similar. No significant differences were found in NDVI values between greenhouse and field conditions. Although no statistically significant differences were found in NDVI values between greenhouse and field conditions, readings within the greenhouse were consistently slightly higher than those in the field. To ensure accurate nitrogen estimation, measurements should be taken under consistent timing and light intensity conditions for reliable comparison. These results support the development of standardized NDVI protocols to improve nitrogen monitoring accuracy in rice production systems.

1. Introduction

Remote sensing technologies have become indispensable tools in modern agricultural monitoring, enabling non-destructive, rapid, and spatially extensive assessment of vegetation health, canopy structure, and physiological status [1]. Among various spectral indicators, the Normalized Difference Vegetation Index (NDVI) remains one of the most widely applied indices due to its simplicity, robustness, and strong correlation with leaf area

Given these challenges, there is a pressing need to investigate how temporal factors influence lux and NDVI readings and to evaluate whether controlled-environment data can reliably represent field conditions. Understanding the temporal behavior of these variables is essential for optimizing the timing of data collection and improving the accuracy of spectral indices in plant health monitoring systems.

The objectives of this study are threefold: (1) to examine the temporal variation in lux intensity at different times of day, (2) to analyze the diurnal pattern of NDVI under both greenhouse and field trial conditions, and (3) to assess whether NDVI values differ significantly between greenhouse and field environments at similar time points. These analyses aim to support the development of more reliable and standardized remote sensing protocols for agricultural monitoring and management.

2. Materials and Methods

2.1 Experimental setup, plant material, soil properties and rice establishment

The experiment was conducted in the Greenhouse at UiTM Jasin Melaka Campus and a paddy field at Sawah Pengkalan Samak in Merlimau, Melaka, during the main season across two planting cycles. The objective was to compare growth performance and NDVI responses under controlled and open-field conditions. MR303 rice variety was used in the experiment, with seeds obtained from MARDI, Kuala Linggi, Melaka. The paddy was grown in Melaka Series soil (Xanthic Hapludox, clayey-skeletal, kaolinitic, isohyperthermic), which has good water retention suitable for paddy cultivation, with a soil pH of 6.55 measured using a Sensolab pH meter. This soil was sourced directly from Sawah Pengkalan Samak, Merlimau, Melaka (2°08'20"N 102°24'51"E).

A total of 25 pots (26 cm width × 26 cm diameter × 26 cm height) were used in both the greenhouse to maintain uniformity in planting conditions and were arranged according to a Randomized Complete Block Design (RCBD). Each pot was filled with approximately 12 kg of field soil. Under greenhouse conditions, the pots were placed on raised platforms to facilitate water drainage and management. During the early growth stage, the water level in each pot was maintained at 1–2 cm above the soil surface, later increased to 5–7 cm during the vegetative and reproductive growth stages to mimic standard paddy water management practices [6].

NPK fertilizers were applied according to the recommended rates from Buletin MARDI for MR303 rice: 1.17 g/pot (equivalent to 115.3 kg/ha) for Nitrogen, 0.621 g/pot (67.9 kg/ha) for Phosphorus, and 1.76 g/pot (99.9 kg/ha) for Potassium. All fertilizers were applied at 15 DAS, with additional Urea top-dressed at 35 DAS, followed by applications at 55 DAS and 75 DAS. Standard rice cultivation practices, such as weed control, pest observation, and water management, were conducted throughout according to MARDI guidelines [7].

2.2 NDVI, LUX meter, SPAD and NCS measurement

The measurement of NDVI value were using a MAPIR Survey3 camera with a 12-megapixel resolution with filter Red+Green+NIR (RGN). The NDVI data collection period was taken at reproductive stage, starting in panicle initiation in week 6,7, and 8 after transplanting. The NDVI images was taken three times: in the morning (7.00 a.m.-8.00a.m.), noon (11.00 a.m.- 12.00p.m.), and evening (6.00 p.m.7.00p.m.). The NDVI data were taken in the same light intensity to reduce the noise in NDVI image, and the distance of the camera from plant was about 100-140 cm from the plant and the Multispectral camera were calibrated using MAPIR Reflectance Calibration Target provide by MAPIR [8]. After the NDVI image was taken, it was processed and analysed in Mapir camera control (MCC) to generate the average NDVI value.

In the greenhouse, light intensity was measured using the UNI-T UT383 Mini Light Meter to assess illumination received by the plants. Lux readings were recorded at the same time intervals as NDVI imaging: morning (7:00 a.m.–8:00 a.m.), noon (11:00 a.m.–12:00 p.m.), and evening (6:00 p.m.–7:00 p.m.). In contrast, for field measurements, the same light meter was used to record light intensity at these intervals to ensure consistency with the greenhouse measurements and allow reliable comparison across environments. Due to certain limitations, such as uneven ground surfaces and unstable areas in the field, the ability to conduct LUX observations was sometimes restricted. During measurements, the light meter was held directly above the plant canopy, with the sensor facing the sun, and extra care was taken to avoid shadows, cloud interference, or movement that could affect readings. The device's position and height were standardized for each measurement session to ensure accuracy. Readings were allowed to stabilize before recording, and the "HOLD" function was used when necessary. After each session, the meter was turned off and stored safely to preserve battery life and protect the sensor from dust and weather exposure in the field.

SPAD values were measured using a SPAD-502 Plus Meter to assess chlorophyll content as an indicator of nitrogen status and overall plant health [9]. Readings were taken from the upper third area of the leaf tip on 6–10 different tillers per pot, specifically from the fourth fully expanded leaf, as this leaf is most responsive to nitrogen status changes [10]. Outlier data were identified and removed before computing the mean SPAD value for analysis. Data collection was conducted weekly to correlate with NDVI and other growth parameters.

3. Results

3.1 Temporal analysis of LUX reading

The bar chart (Figure 1) presents the mean lux readings recorded at three different times of day (morning, noon, and evening) with corresponding standard deviations. Statistical analysis using the Tukey test indicates that the afternoon lux reading (47,304 ± 20,422) is significantly higher ($p < 0.05$) than those recorded in the morning (6,615 ± 2,568) and evening (4,829 ± 1,935), which do not differ significantly from each other.

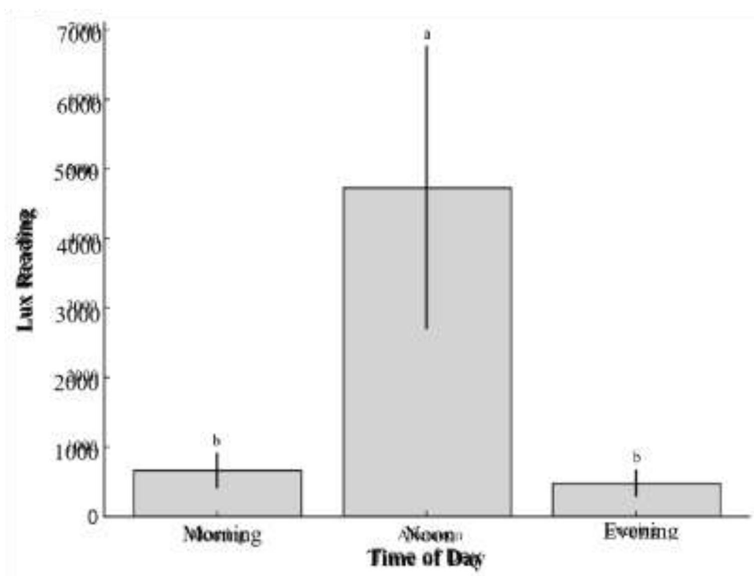

Figure 1. Mean lux readings with standard deviations recorded at different times of day. Different letters indicate significant differences ($p < 0.05$).

3.2 Temporal analysis of NDVI value

The bar chart (Figure 2) illustrates the NDVI values measured under greenhouse and field trial conditions during the reproductive growth stage. NDVI readings were highest in the morning and evening, while significantly lower values were observed at noon across both environments. The bar chart (Figure 2) illustrates the NDVI values measured under greenhouse and field trial conditions during the reproductive growth stage. NDVI readings were highest in the morning and evening, while significantly lower values were observed at noon across both environments. Correspondingly, SPAD values in both the greenhouse and field trials exceeded 40, indicating adequate chlorophyll content and nitrogen status during the measurement period [11]

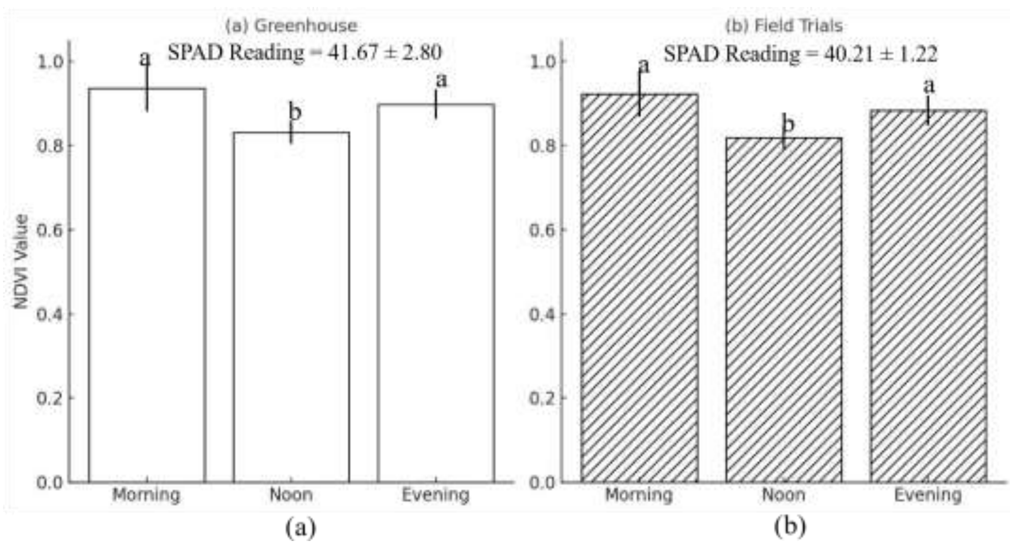

Figure 2. Mean values of NDVI value with standard deviations recorded at different times of day under (a) greenhouse and (b) field trial conditions. Different letters indicate significant differences ($p < 0.05$).

3.3 NDVI value between greenhouse and field trials

Table 1 presents the mean NDVI values with standard deviations recorded under greenhouse and field trial conditions at three different times of day. At each time point (morning, noon, and evening) the NDVI values between greenhouse and field trials were comparable, with no statistically significant differences observed.

Table1. Mean of NDVI with Standard Deviation at different times of the day.

Time of Day	NDVI Value	
	Greenhouse	Field Trials
Morning	0.937 ± 0.05a	0.923 ± 0.005a
Noon	0.831 ± 0.003a	0.818 ± 0.03a
Evening	0.898 ± 0.02a	0.883 ± 0.02a

Different letters indicate statistically significant differences ($p < 0.05$).

4. Discussion

Diurnal variability in light conditions particularly changes in solar zenith angle and the ratio of direct to diffuse radiation has a critical influence on the accuracy and stability of vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and the Green-Red Vegetation Index (GRVI). During the early morning and late afternoon, lower solar elevation results in increased atmospheric scattering and a greater proportion of diffuse radiation. These conditions enhance multiple scattering within the canopy, particularly in vegetatively dense systems, thereby increasing near-infrared reflectance and boosting NDVI values due to the amplified spectral contrast between the red and near-infrared regions [12]. In contrast, at solar noon, although the incoming solar radiation is highest, the more vertical solar angle reduces within canopy scattering. This leads to a diminished spectral contrast and, consequently, a temporary decrease in NDVI values, even under optimal sky conditions [13]. These patterns are particularly evident during the mid to late stages of crop development, when leaf area index and chlorophyll concentration are maximal and thus more sensitive to angular light variation.

Vegetation indices captured at different times of the day, even under consistent atmospheric conditions, should therefore not be directly compared without temporal standardization or radiometric correction. Diurnal changes in NDVI are minimal during early growth stages but become increasingly pronounced as the canopy develops, underscoring the role of crop phenology in mediating light vegetation interactions [14]. Furthermore, differences in measurement geometry such as sensor height, viewing angle, and platform type compound these temporal effects. For example, proximal sensors may capture finer structural variations within the canopy but are more susceptible to angle dependent reflectance artifacts, whereas aerial or satellite-based sensors are influenced by sun–target– sensor alignment and atmospheric path length [15]. These factors can lead to inconsistent assessments of crop nitrogen status and productivity if time-of-day variability is not adequately addressed.

The data in Table 1 demonstrate that NDVI values measured under both greenhouse and field trial conditions were consistently comparable across all three time points (morning, noon, and evening), with no statistically significant differences observed between the two environments. However, it is important to note that NDVI values within the greenhouse were consistently slightly higher compared to the field across all time points, although these differences were not statistically significant. This could be attributed to differences in structural environment, such as light scattering effects within the greenhouse, and microclimatic conditions despite similar LUX readings in both environments. While LUX values were comparable, because both sites were located near each other within the same district, structural factors within the greenhouse may still influence NDVI independently. This consistency can be attributed to the fact that NDVI, as a ratio-based vegetation index, is inherently robust against certain types of environmental noise, particularly when the canopy structure and phenological stage are similar [16]. NDVI is primarily driven by red light absorption due to chlorophyll and high near-infrared reflectance from leaf cellular structures [17]. Given that the experimental plants in both settings were likely at similar reproductive stages with comparable chlorophyll content and canopy cover, the spectral reflectance characteristics and thus the NDVI would be expected to align closely, regardless of location. This interpretation is supported by findings from [18], who observed minimal NDVI variation in evergreen species across spatially distinct but phenologically synchronized environments.

Therefore, while our study found no statistically significant differences in NDVI between environments, caution should be taken when generalizing results, as structural differences, microclimate variations, and light quality differences could influence NDVI readings even under similar ambient light intensities. Future studies should consider including additional light quality measurements (e.g. PAR sensors or full spectrum analysis) alongside LUX readings to better interpret environmental effects on vegetation indices.

In precision agriculture, particularly for nitrogen management in rice production systems, the integration of time-of-day considerations is vital for optimizing the interpretability of remotely sensed data. Consistent observation windows and correction algorithms that account for solar geometry and atmospheric conditions are essential to reduce error margins and improve the robustness of vegetation index-based monitoring tools. Future advancements should prioritize the development of time-aware remote sensing models and machine learning frameworks that can dynamically adjust for diurnal reflectance variability, thereby enhancing the temporal fidelity of spectral diagnostics in crop health and nutrient assessment.

5. Conclusion

Our study reveals that both low and high light environments can produce valid NDVI measurements when interpreted correctly. The key to accurate assessment lies in maintaining consistent timing and light intensity conditions for comparative measurements. Our results showed that NDVI values were influenced by time of day, with lower readings recorded at noon and higher readings in the morning and evening across both greenhouse and field environments, suggesting that diurnal variation does affect NDVI measurement outcomes. Although LUX readings were similar between environments, slightly higher NDVI values were consistently observed in the greenhouse, which may be influenced by structural or microclimatic differences rather than light intensity alone. Therefore, standardizing the time of day for NDVI measurements and considering environmental conditions are crucial to improving the accuracy of precision agriculture techniques and optimizing nitrogen management in rice cultivation. Future studies should further investigate the combined effects of light intensity, light quality, and structural environment on NDVI measurements to develop more robust and environment-specific remote sensing protocols.

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