Evaluation of UAV-Based RGB and Multispectral Vegetation Indices for Precision Agriculture in Palm Tree Cultivation

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Abstract

Precision farming relies on accurate vegetation monitoring to enhance crop productivity and promote sustainable agricultural practices. This study presents a comprehensive evaluation of Unmanned Aerial Vehicle (UAV)-based imaging for vegetation health assessment in a palm tree cultivation region in Dubai. By comparing multispectral and Red, Green, and Blue (RGB) image data, we demonstrate that RGB-based vegetation indices offer performance comparable to more expensive multispectral indices, providing a cost-effective alternative for large-scale agricultural monitoring. Using UAVs equipped with multispectral sensors, indices such as Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI) were computed to categorize vegetation into healthy, moderate, and stressed conditions. Simultaneously, RGB-based indices like Visible Atmospherically Resistant Index (VARI) and Modified Green Red Vegetation Index (MGRVI) delivered similar results in vegetation classification and stress detection. Our findings highlight the practical benefits of integrating RGB imagery into precision farming, reducing operational costs while maintaining accuracy in plant health monitoring. This research underscores the potential of UAV-based RGB imaging as a powerful tool for precision agriculture, enabling broader adoption of data-driven decision-making in crop management. By leveraging the strengths of both multispectral and RGB imaging, this work advances the state of UAV applications in agriculture, paving the way for more efficient and scalable farming solutions.

1. Introduction

Precision farming has become a pivotal approach in modern agriculture, aimed at boosting crop productivity, ensuring sustainable practices, and optimizing the use of resources (Getahun et al., 2024). A key component of precision farming is the accurate and timely monitoring of vegetation, which is essential for assessing plant health, detecting stress, and facilitating data-driven decisions in crop management(Paul et al., 2022). Traditional vegetation monitoring techniques often rely on labor intensive fieldwork, making them both time-consuming and costly. However, with the advent of Unmanned Aerial Vehicles (UAVs) equipped with advanced imaging sensors, the landscape of precision farming has shifted. UAV-based remote sensing offers a more efficient, scalable, and accurate method for gathering vital crop health data over large areas.

Multispectral sensors, widely used in UAVs, have been extensively researched for their ability to provide detailed information about plant health (Barbedo, 2019). Multispectral imaging is commonly employed to calculate vegetation indices like the Normalized Difference Vegetation Index (NDVI) and the Soil Adjusted Vegetation Index (SAVI), which are useful in classifying vegetation into healthy, moderate, and stressed categories (Qi et al., 1994). Despite their effectiveness, the high cost of multispectral sensors often limits their widespread application, especially in large-scale farming operations or regions with financial constraints.

This study is motivated by the need to explore more cost-effective alternatives to multispectral imaging while maintaining the accuracy required for vegetation monitoring. RGB cameras, which are more affordable and widely available, have shown promising potential for providing comparable vegetation indices. Indices like the Visible Atmospherically Resistant Index (VARI) and the Modified Green Red Vegetation Index (MGRVI) have demonstrated the ability to capture critical information about plant health using simple RGB imagery. Given the significant cost difference between RGB and multispectral sensors, understanding whether RGB-based vegetation indices can deliver comparable accuracy is essential for promoting the broader adoption of UAV technology in agriculture, especially in resource limited environments. The primary objective of this study is to evaluate the performance of RGB-based vegetation indices compared to traditional multispectral indices within the context of precision farming. Specifically, we focus on UAV-based monitoring of palm tree cultivation in Dubai, where both multispectral indices (NDVI, SAVI) and RGB-based indices (VARI, MGRVI) are computed to assess vegetation health. By comparing the performance of these indices, this research aims to demonstrate that RGB based monitoring provides a cost effective alternative to multispectral imaging without compromising accuracy. The findings of this study have the potential to improve the scalability and affordability of precision farming technologies, allowing for more widespread implementation of sustainable agricultural practices.

2. Literature Survey

UAVs have revolutionized precision agriculture, providing farmers with a fast, detailed, and cost-effective approach to monitoring crop health and optimizing yield. Equipped with multispectral sensors, UAVs capture high-resolution imagery that allows

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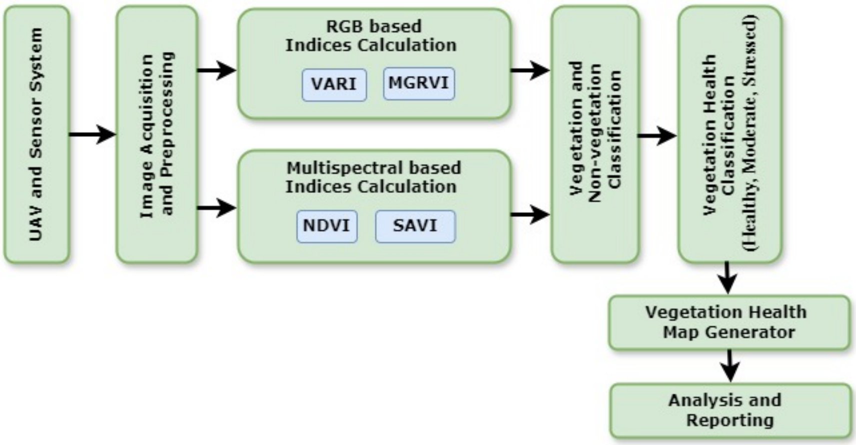


Figure 1. Flowchart of the methodology for UAV-based vegetation health assessment using RGB and multispectral indices.

for calculating various vegetation indices to assess plant health, detect stress levels, and monitor growth dynamics over time.

Multispectral sensors are widely adopted in UAV applications and have been extensively studied for vegetation monitoring. Indices like the NDVI and the SAVI are particularly valuable for their sensitivity to plant vigor. NDVI, one of the most commonly used indices, exploits the contrast between red and near-infrared (NIR) bands, with values ranging from -1 to 1 - higher values typically indicating healthier vegetation. However, NDVI may be less reliable in areas with exposed soil, where soil brightness can skew readings. To address this, SAVI was introduced, incorporating a soil brightness correction factor that improves accuracy in arid and semi-arid regions where vegetation is sparse, enhancing its utility for dry environments (Huete, 1988a, Dubbini et al., 2015).

Recent research has focused on the potential of RGB sensors as a cost-effective alternative to multispectral sensors, especially in resource-limited settings (Panthakkan et al., 2021). RGB-based vegetation indices, such as the VARI and the MGRVI, have shown promising results in assessing vegetation health using only visible light. Although RGB sensors lack the NIR band, indices like VARI still provide reliable information on vegetation health by emphasizing green reflectance, which correlates with chlorophyll content. Studies highlight VARI's robustness in detecting plant greenness and stress even under different atmospheric conditions, making it particularly suitable for widespread agricultural monitoring (Bendig et al., 2015, Gitelson et al., 2022). Additionally, MGRVI has been shown effective in distinguishing healthy from stressed vegetation by comparing chlorophyll concentrations in green and red bands (Bendig et al., 2015).

Comparative analyses of RGB and multispectral indices suggest that while multispectral indices offer detailed insights due to NIR data, RGB indices remain valuable for general vegetation monitoring. For example, studies by Dubbini et al. (Dubbini et al., 2015) emphasize that RGB indices provide a viable alternative for farmers in resource-constrained environments. Similarly, Marcial-Pablo et al. (Marcial-Pablo et al., 2019) examined RGB-based indices such as Excess Green (ExG) and the Colour Index of Vegetation (CIVE) alongside multispectral indices like NDVI and GNDVI in maize fields. Their findings reveal that RGB indices are well-suited for early-stage crop monitoring, while NIR-based indices yield higher accuracy at later growth stages, balancing the trade-off between cost and precision.

UAVs equipped with RGB and multispectral sensors have demonstrated applicability across various crop systems, from rice to vineyards to palm tree cultivation (Zhang and Kovacs, 2022). As UAV technology becomes more accessible, integrating both RGB and multispectral imagery promises cost-effective and scalable solutions for precision agriculture. Studies such as that by Wan et al. (Wan et al., 2020) show the potential of UAVs for yield prediction, integrating multi-temporal vegetation indices, canopy height, and coverage to enhance accuracy. Their findings illustrate the benefits of UAV-based imaging in tracking crop growth and predicting yield with high precision, highlighting the utility of UAV-derived indices in small-scale farmlands.

In regions with significant crop heterogeneity, multispectral imagery from UAVs has proven effective in monitoring diverse crop systems. Modica et al. (Modica et al., 2020) used UAV-derived indices like NDVI, SAVI, and the Normalized Difference Red Edge Index (NDRE) to classify vigor and detect stressed areas in citrus and olive orchards. Their approach incorporated object-based image analysis to extract individual tree crowns, supporting rapid and precise management decisions in precision farming. Nonetheless, the high implementation cost of these multispectral imaging technologies remains a challenge for widespread adoption in routine crop monitoring.

Although RGB-based indices present an attractive alternative, further research is necessary to refine their accuracy and sensitivity for large-scale applications. Future studies could explore advanced image processing techniques, potentially enhancing the precision of RGB-based monitoring in diverse crop environments and varying ecological conditions. As UAV technology and image processing methods continue to evolve, the potential to combine RGB and multispectral data offers a promising path for sustainable, precision-driven agriculture in both resource-rich and resource-constrained settings.

3. Methodology

The goal of this study is to evaluate the effectiveness of UAV based imaging for assessing vegetation health in palm tree cultivation, with a focus on comparing the performance of RGB and multispectral vegetation indices. UAVs equipped with multispectral sensors were deployed to capture high resolution images. Vegetation indices including NDVI, SAVI, VARI, and

((a)) Study Area

((b)) RGB ROI Image

Figure 2. Study Area: Palm Tree Region in Dubai

MGRVI were computed from the acquired imagery to assess plant health and classify vegetation into categories such as healthy, moderate, and stressed. This methodology follows a structured approach, starting with image acquisition, followed by data preprocessing, calculation of vegetation indices, and classification of vegetation health. The study emphasizes a comparative analysis of the cost-effectiveness and accuracy of RGB-based indices versus traditional multispectral indices, particularly in the context of arid regions like Dubai.

The block diagram in Figure 1 illustrates the overall workflow of the methodology used for evaluating vegetation health using UAV-based RGB and multispectral vegetation indices in palm tree cultivation. The process starts with a UAV and sensor system, where UAVs equipped with multispectral sensor capture high-resolution images of the target area. These images undergo image acquisition and preprocessing, which includes steps to correct noise and enhance image quality, ensuring that the data is ready for accurate analysis.

Once preprocessed, the images are split into two parallel processing streams. The first stream involves RGB-based indices calculation, where indices like VARI and MGRVI are computed. These indices use visible light data to assess vegetation health and offer a cost-effective solution. The second stream is dedicated to multispectral-based indices calculation, where NDVI and SAVI are computed from multispectral data. These indices utilize the near-infrared spectrum, which is highly sensitive to vegetation health, especially in areas where soil exposure is significant.

After the indices are calculated from both RGB and multispectral data, they undergo vegetation and non-vegetation classification, separating vegetation from non-vegetative elements such as soil, water, or infrastructure. The classified vegetation is then further divided into three categories based on health status: healthy, moderate, and stressed, depending on the vegetation index values.

Using the health classification, a vegetation health map is generated, providing a visual representation of the health status across the palm tree cultivation area. Finally, the process concludes with analysis and reporting, where the results are interpreted, and actionable insights are generated, including identifying stressed regions that may require intervention. This methodology leverages both cost-effective RGB data and more sensitive multispectral data to offer a comprehensive and scalable solution for precision agriculture.

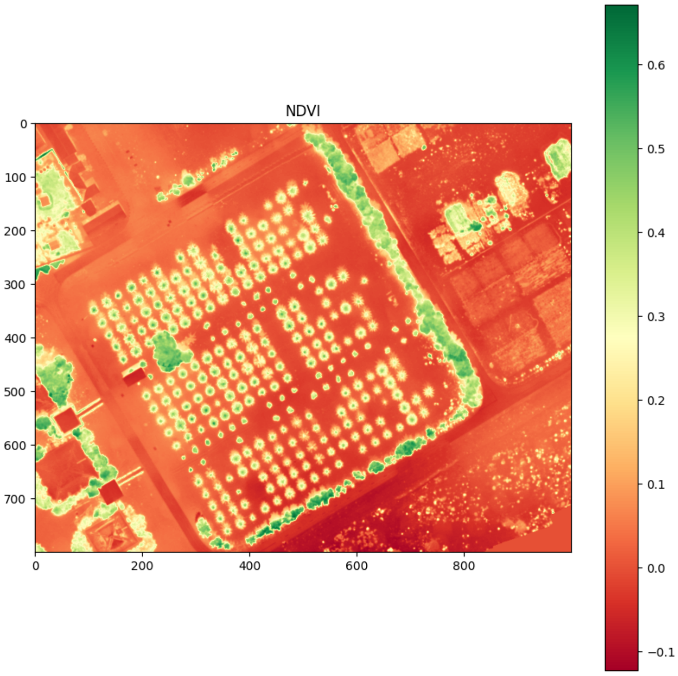
3.1 Database and Study Area

This study was conducted in a designated palm tree cultivation area in Dubai, United Arab Emirates (UAE), as shown in Figure 2. The arid climate of this region, with high temperatures and limited water resources, presents challenges for agriculture, making precision farming essential for optimizing palm tree health and productivity. UAV-based imaging over the study area (Figure 2(b)) enables an evaluation of vegetation health indices suited to these specific environmental constraints.

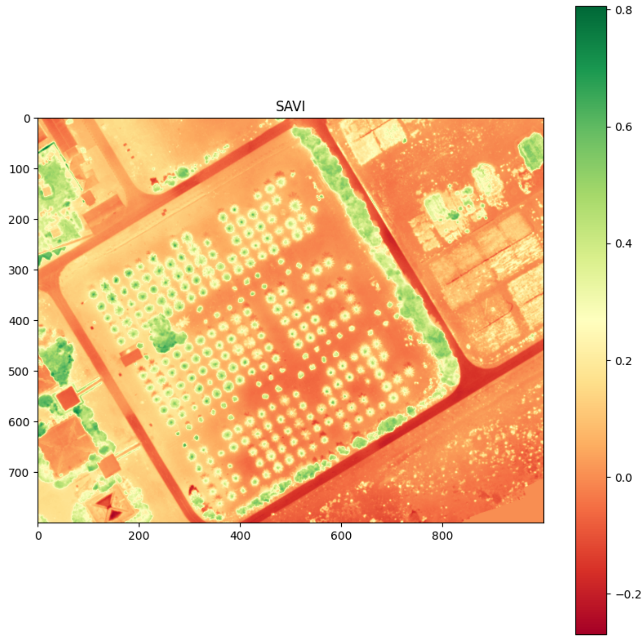
The dataset comprises high-resolution imagery captured by Falcon Eye Drones equipped with sensors covering five multispectral bands-Red, Green, Blue, Near-Infrared (NIR), and Red Edge-at a spatial resolution of 0.3 meters. Preprocessing steps applied to the imagery include (a) radiometric correction for accurate spectral reflectance, (b) geometric correction for spatial alignment, and (c) histogram equalization for enhanced contrast.

Located in southern Dubai (55° 23′ 27.36″E, 25° 5′ 41.55″N), this study area's multispectral and RGB data support applications in environmental monitoring, precision agriculture, and resource management. Capturing wavelengths from 400 to 2500 nm, with spatial resolutions ranging from 5 cm to 50 cm depending on flight altitude, the dataset enables detailed analysis of surface features such as vegetation, soil, and water. Data is stored in ENVI-compatible formats with GPS georeferencing, using sensors like the Headwall Nano-Hyperspec, offering a wide field of view (30°–60°) and flight durations of 60–90 minutes.

Both NDVI and SAVI indices were calculated from multispectral data to assess vegetation health and soil adjusted conditions, while RGB based indices such as VARI and MGRVI provided a cost-effective approach to vegetation analysis. These indices enabled classification of vegetation into healthy, moderate, and stressed conditions, supporting precision farming to optimize resource use and crop management in an arid environment.

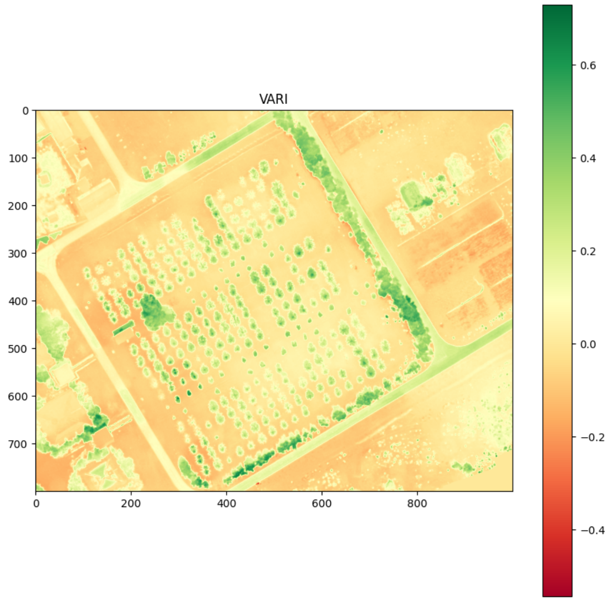


((a)) NDVI

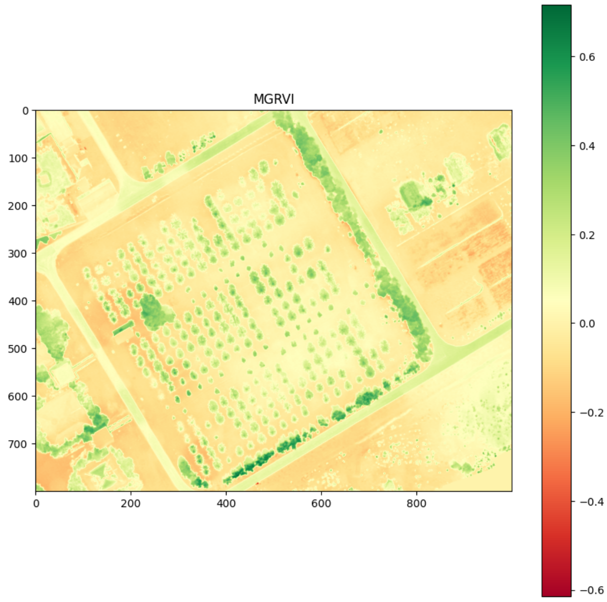


((b)) SAVI

Figure 3. NDVI and SAVI maps of the selected palm plot



((a)) VARI



((b)) MGRVI

Figure 4. VARI and MGRVI maps of the selected palm plot

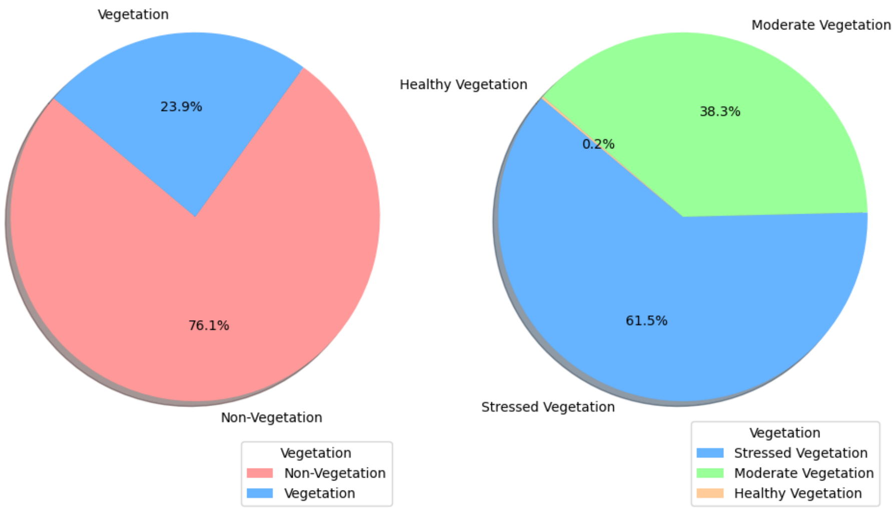
3.2 Vegetation Indices

Vegetation indices are mathematical tools used in remote sensing to assess plant health, growth, and stress by analyzing reflectance in different spectral bands. Common indices like NDVI and SAVI use near-infrared and red bands to monitor vegetation health, with NDVI being the most widely used. SAVI improves upon NDVI by reducing soil brightness effects, making it useful in arid regions. For more affordable RGB-based imaging, indices like VARI and MGRVI provide valuable insights into vegetation health. These indices are crucial in precision farming, allowing for efficient and cost-effective monitoring of crops and guiding resource management. The following sections provide details on the specific vegetation indices used in this study.

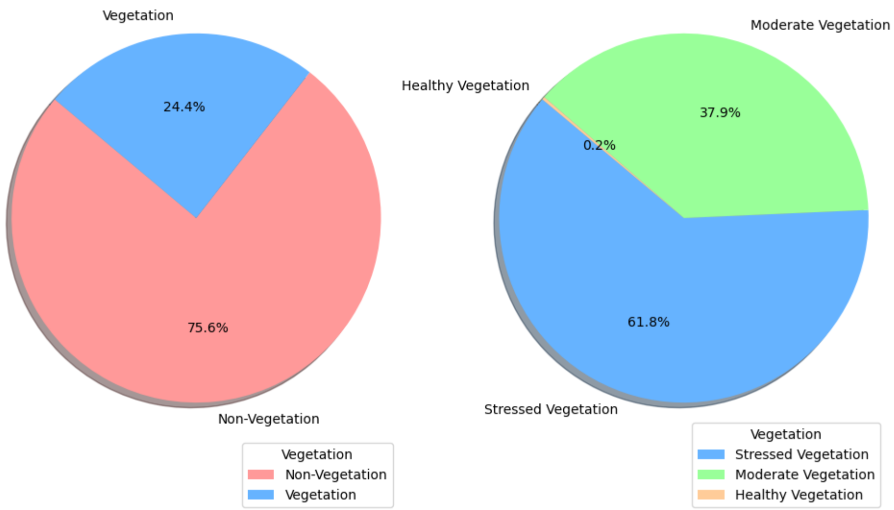
3.2.1 Normalized Difference Vegetation Index (NDVI) :

NDVI is a widely-used metric for assessing vegetation health by leveraging the reflectance differences in the red (R) and near-infrared (NIR) bands. It is calculated as:

$$\text{NDVI} = \frac{NIR - R}{NIR + R} \tag{1}$$



((a)) NDVI



((b)) SAVI

Figure 5. Pie chart of vegetation indices (NDVI and SAVI) using multispectral images

Higher NDVI values indicate healthier and denser vegetation, while lower values correspond to stressed or sparse vegetation. NDVI is commonly used in agriculture for monitoring crop health, detecting stress, and optimizing resource management, although it may saturate in areas with high biomass and be influenced by soil reflectance (Huang et al., 2021).

3.2.2 Soil-Adjusted Vegetation Index (SAVI) :

SAVI was developed to mitigate the influence of soil reflectance in regions with sparse vegetation. It introduces a correction factor L to reduce soil brightness effects and is calculated as:

$$\text{SAVI} = \frac{(NIR - R) \times (1 + L)}{NIR + R + L} \tag{2}$$

Typically, L is set to 0.5, but it can be adjusted depending on vegetation density. SAVI is particularly useful in arid and semi-arid regions, providing improved accuracy over NDVI in areas with exposed soil (Qi et al., 1994).

3.2.3 Visible Atmospherically Resistant Index (VARI) :

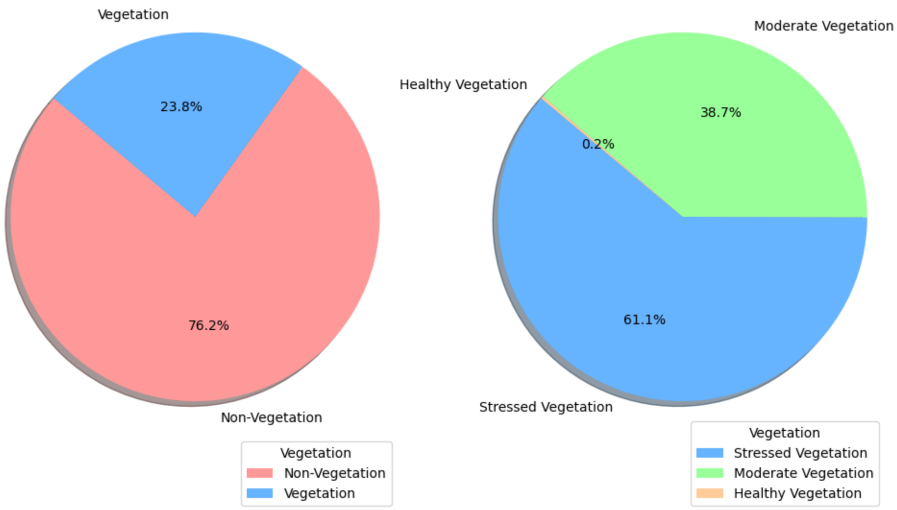
VARI uses only the visible spectrum (RGB) to estimate vegetation fraction, offering robustness to atmospheric variations. It is calculated as:

$$\text{VARI} = \frac{G - R}{G + R - B} \tag{3}$$

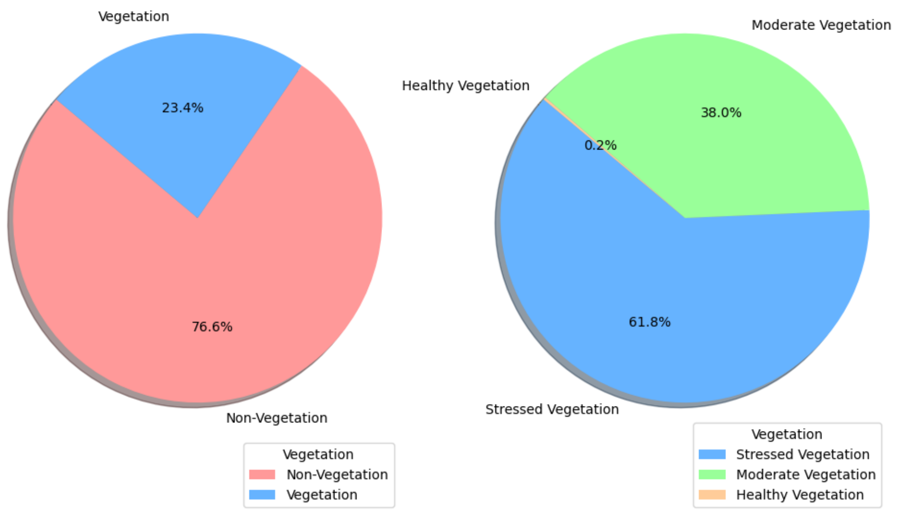
Where G, R, and B represent green, red, and blue reflectance values, respectively. VARI is advantageous for applications using standard RGB cameras and is commonly applied in agricultural settings to assess vegetation health in real-time (Anisa et al., 2020).

3.2.4 Modified Green Red Vegetation Index (MGRVI) :

MGRVI is used to differentiate between healthy and stressed



((a)) VARI



((b)) MGRVI

Figure 6. Pie chart of vegetation indices (VARI and MGRVI) of RGB images

vegetation by emphasizing green and red reflectance. It is calculated as:

$$\text{MGRVI} = \frac{G^2 - R^2}{G^2 + R^2} \tag{4}$$

Positive values indicate healthy vegetation, while negative values suggest stressed vegetation or bare soil. MGRVI enhances the sensitivity to chlorophyll content and is particularly effective in green-dominated environments.

4. Results and Discussion

This study evaluated the performance of both RGB and multispectral vegetation indices for assessing vegetation health in palm tree cultivation in Dubai. The following results are based on the generated vegetation maps and pie charts, as well as a comparative analysis of the vegetation index values.

4.1 Vegetation Indices Derived from Multispectral Imagery (NDVI and SAVI)

Figure 3 present the NDVI and SAVI maps for the palm tree plot, with Table 1 summarizing the percentage distribution of vegetation and non-vegetation areas. NDVI values range from -0.1223 to 0.67114, where 76.15% of the area is classified as non-vegetation
($NDVI \leq 0.1$) and 23.85% as vegetation ($NDVI > 0.1$). For SAVI, the range is from -0.2693 to 0.8061, with 75.59% non-vegetation ($SAVI \leq 0.16$) and 24.41% vegetation ($SAVI > 0.16$).

Further subdivision of the vegetation into stress, moderate, and dense categories is shown in Table 2. For NDVI, 61.49% of the vegetation was classified as stressed ($0.1 < NDVI \leq 0.3$), 38.30% as moderate ($0.3 < NDVI \leq 0.6$), and only 0.20%

Table 1. Vegetation indices derived from multispectral and RGB imagery, with index ranges and percentages for non-vegetation and vegetation areas

Index	Minimum	Maximum	Non-Vegetation		Vegetation	
			Range	Percentage	Range	Percentage
NDVI	-0.1223	0.6714	$-1 \leq$ NDVI ≤ 0.1	76.15%	$0.1 <$ NDVI ≤ 1	23.85%
SAVI	-0.2693	0.8061	$-1 \leq$ SAVI ≤ 0.16	75.59%	$0.16 <$ SAVI ≤ 1	24.41%
VARI	-0.5438	0.7297	$-1 \leq$ VARI ≤ 0.08	76.24%	$0.08 <$ VARI ≤ 1	23.76%
MGRVI	-0.614	0.7169	$-1 \leq$ MGRVI ≤ 0.08	76.58%	$0.08 <$ MGRVI ≤ 1	23.42%

Table 2. Vegetation indices derived from multispectral and RGB imagery, subdividing vegetation into stress, moderate, and dense categories with corresponding index ranges and percentages

Index	Stress Vegetation		Moderate Vegetation		Dense Vegetation	
	Range	Percentage	Range	Percentage	Range	Percentage
NDVI	$0.1 <$ NDVI ≤ 0.3	61.49%	$0.3 <$ NDVI ≤ 0.6	38.30%	$0.6 <$ NDVI ≤ 1	0.20%
SAVI	$0.16 <$ SAVI ≤ 0.33	61.81%	$0.33 <$ SAVI ≤ 0.64	37.94%	$0.64 <$ SAVI ≤ 1	0.25%
VARI	$0.08 <$ VARI ≤ 0.22	61.08%	$0.22 <$ VARI ≤ 0.59	38.70%	$0.59 <$ VARI ≤ 1	0.23%
MGRVI	$0.08 <$ MGRVI ≤ 0.2	61.81%	$0.2 <$ MGRVI ≤ 0.59	37.97%	$0.59 <$ MGRVI ≤ 1	0.22%

as dense ($NDVI > 0.6$). Similarly, for SAVI, 61.81% was stressed ($0.16 < SAVI \leq 0.33$), 37.94% moderate ($0.33 < SAVI \leq 0.64$), and 0.25% dense ($SAVI > 0.64$).

These results indicate that the majority of the vegetation in the study area is under stress, with a small portion categorized as healthy or dense vegetation.

4.2 Vegetation Indices Derived from RGB Imagery (VARI and MGRVI)

Figure 4 shows the vegetation maps for the RGB-based indices, VARI and MGRVI. Table 1 provides data on vegetation and non-vegetation areas. For VARI, the index ranges from -0.5438 to 0.72972, with 76.24% of the area classified as non-vegetation ($VARI \leq 0.08$) and 23.76% as vegetation ($VARI > 0.08$). Similarly, for MGRVI, the range is from -0.614 to 0.7169, with 76.58% non-vegetation ($MGRVI \leq 0.08$) and 23.42% vegetation ($MGRVI > 0.08$).

Table 2 further categorizes vegetation into stress, moderate, and dense categories. For VARI, 61.08% of the vegetation was stressed ($0.08 < VARI \leq 0.22$), 38.70% moderate ($0.22 < VARI \leq 0.59$), and 0.23% dense ($VARI > 0.59$). For MGRVI, 61.81% was stressed ($0.08 < MGRVI \leq 0.2$), 37.97% moderate ($0.2 < MGRVI \leq 0.59$), and 0.22% dense ($MGRVI > 0.59$).

4.3 Discussion

The threshold values presented in Table 1 and Table 2 were established based on a combination of prior literature and empirical observations specific to UAV-based vegetation monitoring. Studies have demonstrated that NDVI > 0.1 and SAVI > 0.16 effectively distinguish vegetation from non-vegetation, particularly in arid and semi-arid environments (Huete, 1988b), (Qi, 1994). Similarly, classification thresholds for RGB-based vegetation indices, such as VARI and MGRVI, were derived from established UAV applications in precision agriculture (Dubbini, 2015), (Marcial-Pablo, 2019). The segmentation of vegetation into stressed, moderate, and dense categories was informed by index distribution patterns observed in previous UAV-based assessments (Huang, 2021). To validate these thresholds, empirical observations of the study area were conducted, ensuring their applicability to palm tree cultivation. The classification methodology aligns with widely accepted remote sensing practices, enhancing consistency and comparability across different vegetation monitoring studies. Relevant citations have been incorporated to support the selection of these thresholds, ensuring methodological transparency and reproducibility.

The comparative analysis between multispectral (NDVI and SA VI) and RGB-based (VARI and MGRVI) vegetation indices reveals consistent patterns of vegetation stress across both datasets. A large portion of the vegetation was categorized as stressed, with a smaller percentage classified as moderate or dense. This indicates that RGB-based indices provide results comparable to multispectral indices, making them a cost-effective alternative for large-scale agricultural monitoring.

While RGB indices are generally less sensitive than multispectral ones, they still offer valuable insights into vegetation health. The use of RGB-based indices, such as VARI and MGRVI, is particularly advantageous in resource-limited environments where cost-effective monitoring is critical. However, for more precise assessments, especially in areas with dense vegetation, multispectral indices like NDVI and SAVI may offer better accuracy due to their ability to capture near-infrared information.

Overall, the study demonstrates that integrating RGB imagery into precision farming provides a scalable, affordable solution for vegetation monitoring, particularly in challenging environments such as the arid regions of Dubai.

4.4 Future Work

While this study demonstrates the effectiveness of UAV-derived vegetation indices for assessing vegetation health in palm tree cultivation, future research will focus on incorporating field data for validation. Ground-truth measurements, such as chlorophyll content, soil moisture levels, and canopy cover assessments, will be collected to validate the UAV-derived indices. Additionally, expert-based classification of vegetation health will be integrated to assess the reliability of automated classification results. By combining UAV data with in-situ observations, future studies aim to improve the accuracy and robustness of vegetation health assessments, ensuring more precise and actionable insights for precision agriculture.

5. Conclusion

This study demonstrated that UAV-based RGB vegetation indices, such as VARI and MGRVI, offer a cost-effective alternative to multispectral indices like NDVI and SAVI for monitoring vegetation health in palm tree cultivation. Both RGB and multispectral indices provided comparable results in classifying vegetation into stressed, moderate, and dense categories.

While multispectral indices offer greater sensitivity due to near-infrared data, RGB-based indices proved sufficient for meaningful vegetation assessments, particularly in resource-limited environments. This highlights the potential for affordable RGB-based solutions in precision agriculture, reducing costs without compromising accuracy.

This work encourages the broader adoption of UAV-based imaging for efficient and scalable vegetation monitoring, particularly in challenging environments like the arid regions of Dubai. Future research can explore enhancing the precision of RGB indices and their applicability across different crops and environments.

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