Estimating Corn (*Zea Mays* L.) LAI Using UAV-Derived Vegetation Indices

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ABSTRACT: A more time-saving and accurate way of crop monitoring is what remote sensing can offer, spatial and temporal monitoring alike. This study focuses on using unmanned aerial vehicle equipped with specialized camera for monitoring leaf area index of corn (LAI) (*Zea mays* L.). The study was conducted during the wet season (August 2017 to November 2017) in a 2160 m^2 experimental plot. Four different fertilizer treatments: F0 (No Fertilizer Treatment), F1 (100% Conventional Fertilizer), F2 (100% Organic Fertilizer) and F3 (50% Conventional 50% Organic Fertilizer), were applied to four major plots to ensure variation in the vegetation cover, thus difference on the LAI. Aerial photographs were captured at 47 DAS (vegetative stage) to ensure that all the leaves are already emerged. These geo-referenced images were stitched and orthorectified to produce a single orthomosaic image. Using QGIS, the orthomosaic map was processed into blue NDVI (BNDVI), enhanced (ENDVI) and green NDVI (GNDVI) maps. Ground measurements of the LAI were also performed on the same stage of the crop growth. In the vegetative stage, the average corn LAI for treatments F0, F1, F2 and F3 are 0.9452, 1.9847, 0.9893 and 1.4158 respectively. This suggests that the different fertilizer treatments produce LAI variations. The correlation coefficients of BNDI, ENDVI and GNDVI with LAI are 0.7189, 0.0526 and 0.8192 respectively. Compared to other vegetation indices, GNDVI is a good predictor of LAI of corn. This relationship is useful enough in developing remote sensing protocols for a site-specific monitoring of LAI.

1. INTRODUCTION

One-third of Filipino farmers, or 1.8 million, depend on corn (*Zea mays*) as their major source of livelihood. Corn, second to rice, is the most important crop in the country. White corn is considered a substitute staple when there is a shortage in rice most especially in the rural areas. Yellow corn is the primary source of feed for the animal industry in the country. The production, however, is extremely challenged under climate-changed scenarios (Gerpacio et al, 2004).

Climate Change being one of the effect of global warming is becoming more and more eminent. Many studies have been and are being conducted to adapt to these climate-changing scenarios. With regards to climate change, Leaf Area Index (LAI) is a vital parameter in many models that includes atmosphere-vegetation interactions.

Under climate change scenarios, monitoring the distribution of changes of Leaf Area Index (LAI) is important for evaluating growth and vigor of vegetation. In climate models, LAI is a fundamentally important parameter in land-surface processes and parameterizations. Leaf Area Index is a representation of the amount of leaf material in ecosystems and it controls the links between biosphere and atmosphere through various processes such as photosynthesis, transpiration, respiration and rain interception (Gobron, 2009).

Due to its knowingly importance, much interest in information on LAI distribution and changes has grown significantly. From ground-based data measurements, emerging LAI estimation over large areas using airborne and satellite measurements have been developed.

Using a special camera that captures particular wavelengths of light, contrast is being made by a processor of different channels that results to a normalized difference by post-processing. The Normalized Difference Vegetation Index (NDVI) is a common parameter in remote sensing that detects whether the target being observed contains green vegetation or not (Genik, 2016).

Using optical space bourne sensors, space agencies and other institutional providers generate maps of LAI at several spatial resolutions for a specific time frame all over the globe. LAI, however, globally and freely available, the spatial resolution for a specific place may not fit for its probable use that is why, LAI values are normally measured locally, through ground-based measurements over a range of land-cover types (FAO, 2009).

Using a simple multi-spectral camera mounted on an unmanned aerial vehicle (UAV), this method that is rapid, accurate, inexpensive and simple, aims to determine the leaf area index of a corn crop in a given area.

Remote sensing with unmanned aerial vehicles (UAVs) has more potential for with-in season crop management than conventional satellite imagery because (1) pixels have very high resolution, (2) cloud cover would not prevent acquisition during critical periods of growth, and (3) quick delivery of information to the user is possible (Hunt, 2008)

Aerial color and color-infrared photography have been used in crop monitoring for more than decades now. These methods are currently being re-assessed for analyzing within-field spatial variability for precision agriculture management, due to the reason that aerial imagery can be obtained rapidly during periods of rapid crop growth. Large-format cameras are commonly used to acquire data using manned aircraft, which are costly compared to other types of imagery. There are a wide range of variety of sensors, power supplies and data storage options available based on the payload capacity. Unmanned Aerial Vehicles (UAVs) have potentially lower cost however lower payload capacity than the manned aircraft. Moreover, UAVs can be flown at lower altitudes, thus increasing the spatial resolution (Hunt, 2010).

Using a digital camera mounted in a drone to obtain Blue, Green and Near-Infrared photographs of wheat plantations, it was found out that the color-infrared photographs revealed large spatial variation in biomass and leaf area index (Hunt, 2010).

Kalisperakis et. al (2015) compared and evaluated LAI estimation in vineyards from different UAV image datasets namely, (1) hyperspectral data, (2) 2D RGB orthophotomosaics, and (3) 3D crop surface models. Relationships with the measured LAI on ground from several vines in Nemea, Greece were established using the computed canopy levels. The results showed that the estimated canopy levels were correlated (r^2 > 73%) with the in-situ, ground truth LAI measurements.

2. STUDY AREA

The study site is at Central Field No. A-9, Central Experimental Station, University of the Philippines Los Baños, College, Laguna, Philippines. Laguna, which is a province located in the southern part of Luzon is home to many mountains and to country’s largest lake, Laguna de Bay. Areas near the lake are considered flat and narrow, while terrains become more rugged further inland towards the mountainous areas. A huge part of the province falls under Type 1 climate, which means that there are two pronounced seasons in a year. On the other hand, eastern parts of the province falls under Type III climate, which means that these areas experience short dry season.

Figure 1. Laguna Province (NSO, 2000)

3. METHODOLOGY

Ground data and photographs were collected at Central Field No. A-9, Central Experimental Station, University of the Philippines Los Baños, College, Laguna, Philippines. The experiment was located within the latitude of 14˚11'N and longitude of 121˚15'E with 21.7 m adjacent to UPLB National Agrometeorological Station (NAS).

Using four varieties: 1) UPLB Variety 6, 2) USM Variety 10, 3) UPLB Variety 11 and 4) CSC Variety 1, the field layout was based on a split-plot arrangement in randomized complete block design with three replications. Four fertilizer treatments; F0) No Fertilizer Treatment, F1) 100% Conventional Fertilizer, F2) 100% Organic Fertilizer and F3) 50% Conventional 50% Organic Fertilizer, were randomly allocated to the four permanents 150 m^2 main plots in each replicate to ensure variations in the LAI across the plots.

3.1 Collection of Data

A rotary-wing hexacopter was used in this study. It is also a Vertical Take-off Landing drone that does not need a runway, considering its ability to take-off and land on a vertical direction. It is composed of 6 propellers for control of its body in 3 directions. The drone was equipped with a Canon SX260 HS commercial-grade digital camera was used as the sensor. It can acquire photographs in blue, green and Near Infra-Red (NIR) bands together with its technical specifications. The normal camera captures RGB (Red-Green-Blue) images however, this camera was professionally converted to capture NGB (NIR-Green-Blue) images. This modification was done to cover the bands necessary for establishing the mathematical algorithm for different Normalized Difference Vegetation Indices.

Image acquisition were done during noontime, 12:00 – 1:00 PM, during clear sky and sunny day condition to guarantee quality images at 47 Days after Sowing (DAS) while ground measurements of LAI were determined using a plant canopy analyzer 2 days before image-acquisition using UAV.

The geo-tagged images captured by the sensor using UAV were screened prior to stitching and analyzed (Figure 2).

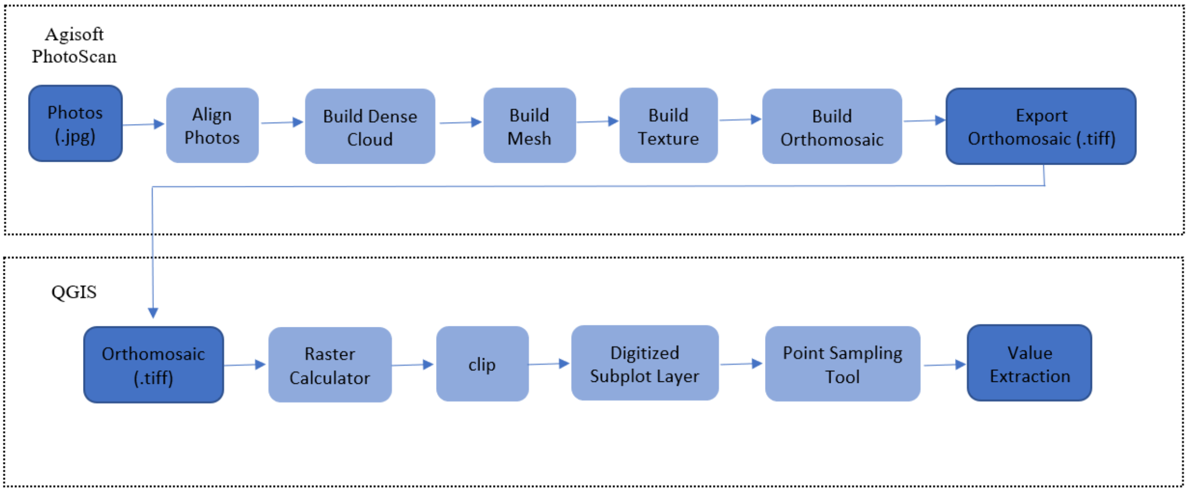

Figure 2. Image processing workflow on stitching and generation of different Vegetation Indices values.

3.2 Computation of Vegetation Indices through GIS processing

The Agisoft Photoscan version 1.2.4 professional edition was used to stitch the images into a single orthomosaic. For the analysis of the image, an open-source, user-friendly Geographic Information System Application was used. QGIS 2.18 'Las Palmas' is the specific software that was used in this study. The raster calculator tool from raster analysis was used for computing the Enhanced Normalized Difference Vegetation Index, Blue Normalized Difference Vegetation Index, and Green Normalized Vegetation Index using equations 1, 2 and 3. The generated images were then clipped to the different subplot layers. Afterwards, a random sampling points of 1000 was generated using Generate Random Sample inside the Polygon tool in statistical analysis under vector processing. The random points were generated inside the digitized subplot polygon to ensure there will be sampling points per treatment and replicates.

After generating sampling points, the value of the vegetative indices was extracted from ENDVI, GNDVI, and BNDVI images using sampling point tool plugin. The attribute table consist of Treatment, ENDVI, GNDVI, and BNDVI columns. Quality Analysis and Checking was employed to filter sampling points that represents values of ground and weed. This was done to make sure the vegetative indices of each plot were the average of that of corn. The average of vegetative indices (60 points) in each subplot were obtained and recorded.

3.3 Statistical Analysis

The Variance for each treatment and each variety were compared to know if there is significant difference between each parameter using Analysis of Variance (ANOVA): Two way with Replicate using Analysis Tool Package in Microsoft Excel.

The values of ENDVI, BNDVI, and GNDVI were plotted against LAI measured using LAI canopy meter using scatter plot graph in Microsoft Excel. Afterwards, the coefficient of variance (R^2) and trendline equation were obtained. Given the correlations of different vegetation indices with the Leaf Area Index (LAI) measured using canopy analyzer, the vegetation index having the line with the best fit was selected.

4. RESULTS AND DISCUSSION

4.1 NGB Image of Corn Experimental Plots

Photograph images of corn experimental plots at 47 DAS (Days After Sowing) were captured using NGB (NIR-Green-Blue) Filtered camera. The corn experimental plot (Figure 3) has a total area of 2160 m^2. The main plots with 100% conventional fertilizer treatment show the densest vegetation in all three replicates while main plot with 100% organic fertilizer have the least vegetation in the first replicate and the control main plots (0% Fertilizer) have the least vegetation within replicates 2 and 3.

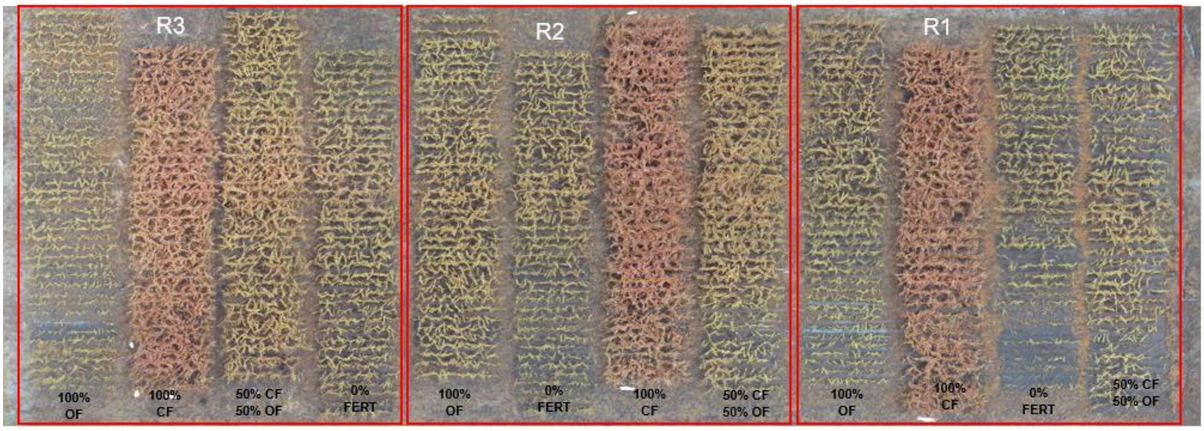

Figure 3. The corn experimental plot at 47 DAS.

With the weeds present inside the plots, data captured both by the camera and the canopy meter might affect the vegetation indices and leaf area index of the target area. Stagnant water is also evident in the experimental plot, this just proves that the field was not correctly levelled, this also affects the data captured by the sensors since it registered a different reflectance signature.

4.2 Photograph Images with Different Vegetation Indices

Images of different Vegetation Indices were generated using NGB-band sensor. BNDVI Image (Figure 4) of the corn experimental plot at 47 DAS has 0.5555 index value as its highest value and -0.3035 as its lowest index value. On the ENDVI Image (Figure 5), the highest index value obtained was 0.4747 while the lowest index value was -0.2167. With the GNDVI Image generated (Figure 6), its maximum index value is 0.4308 and with a minimum index value of -0.2111. These low values of different vegetation indices indicate the value of that of field since the covered area has no vegetation. The high vegetation indices values are on the area covered with vegetation especially the greenest vegetations.

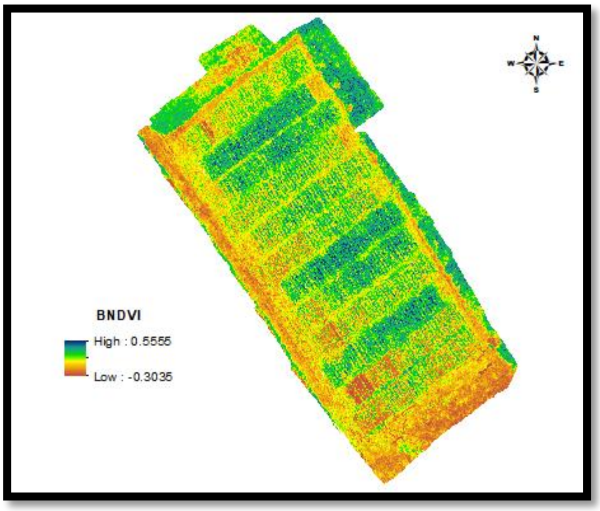

Figure 4. BNDVI Image of the corn experimental plot at 47 DAS.

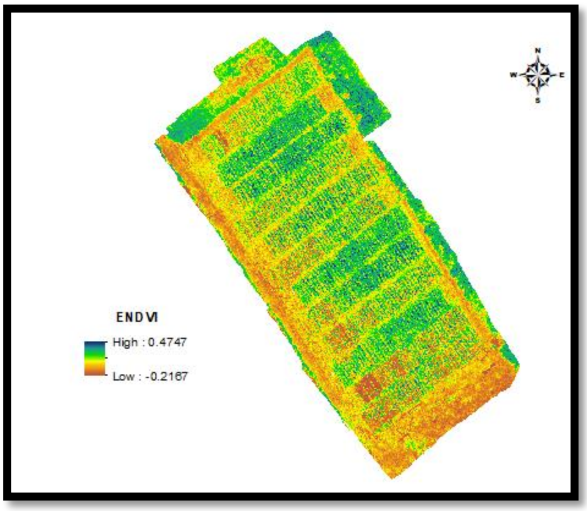

Figure 5. ENDVI Image of the corn experimental plot at 47 DAS.

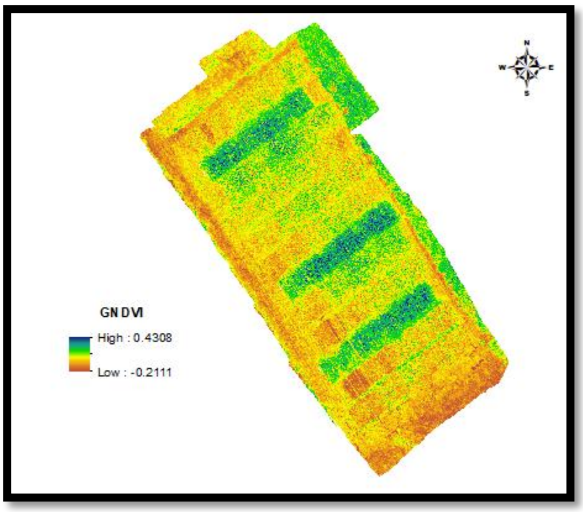

Figure 6. GNDVI Image of the corn experimental plot at 47 DAS.

The lowest average index values for all (BNDVI, ENDVI and GNDVI Images) were recorded in the same subplot at replicate 1 with 0% fertilizer treatment using USM corn variety 10. It can be visually seen even from the raw image that the vegetation for the said subplot is very sparse, thus the value of vegetation index. The highest vegetation index values obtained for both BNDVI and GNDVI Image are at replicate 2, in the subplot with 100% conventional fertilizer treatment while the highest value recorded for ENDVI Image is in the subplot at replicate 2 with 50% conventional and 50% organic fertilizer treatment. It can be seen in the orthomosaic image that the plots with 100% conventional fertilizer treatment have the densest vegetation within a replicate. The indices depend heavily on the vegetation of a target area, however other factors associated with the crop may affect the different vegetation indices.

4.3 Vegetation Index Distribution at Different Fertilizer Treatments

The average vegetation indices for different fertilizer treatments were obtained (Figure 7). It can be seen that the range of GNDVI values were lower compared to BNDVI and ENDVI values. The variability in the values of GNDVI per fertilizer treatment is also evident. The treatment with 100% conventional fertilizer is highest in terms of GNDVI and BNDVI values while the highest ENDVI average value is the treatment with 50% conventional and 50% organic fertilizer. The treatment with 100% organic fertilizer and 0% fertilizer are almost similar for all the vegetation indices, this shows that introducing 100% organic fertilizer for all the varieties given gives no effect on the vegetation indices.

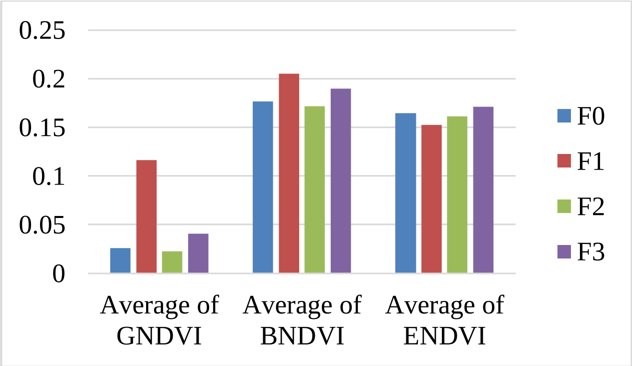

Figure 7. Average vegetation indices distribution of different fertilizer treatments at 47 DAS.

4.4 Vegetation Index Distribution at Different Corn Varieties

In terms of the average distribution of different vegetation indices with regards to corn varieties used, the variability is low for all the vegetation indices (Figure 8). The values are close to each other regardless of the variety. However, compared to BNDVI and ENDVI, the range of values of GNDVI is relatively smaller.

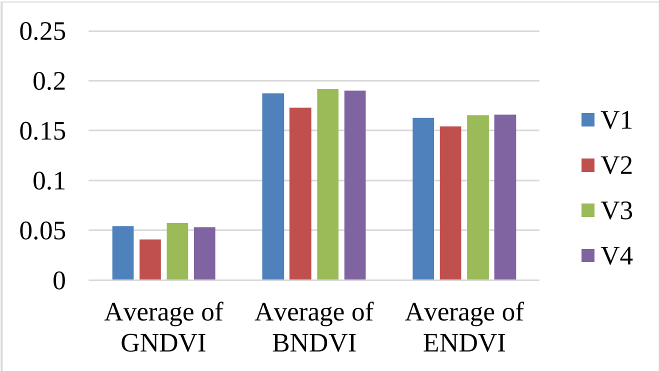

Figure 8. Average vegetation index distribution of different corn varieties at 47 DAS.

4.5 Average Leaf Area Index Values per Subplot

Given the subplots within different fertilizer treatments, leaf area indices were determined. The highest average leaf area index value is 2.4760, located in the subplot at replicate 2 with 100% conventional fertilizer treatment using CSC corn variety 1, while having the lowest average leaf area index value of 0.3187 located in the subplot at replicate 1 with 0% fertilizer treatment using USM corn variety 10.

4.6 Vegetation Index Distribution at Different Fertilizer Treatments

The Leaf Area Index distribution at different fertilizer treatments (Figure 9) is highest at 100% conventional fertilizer treatment (F1). The treatments with 0% fertilizer (F0) and 100% organic fertilizer(F2) are close to each other, while the treatment with 50% conventional and 50% organic fertilizer (F3) higher than the latter two. The close value of F0 and F2 shows that there is not much effect in the Leaf Area Index of corn of any given variety with 100% organic fertilizer treatment. On the contrary, a difference in LAI shows an effect of the treatments on corn of any given variety, with the 100% conventional fertilizer treatment giving higher effect than 50% conventional and 50% organic fertilizer treatment.

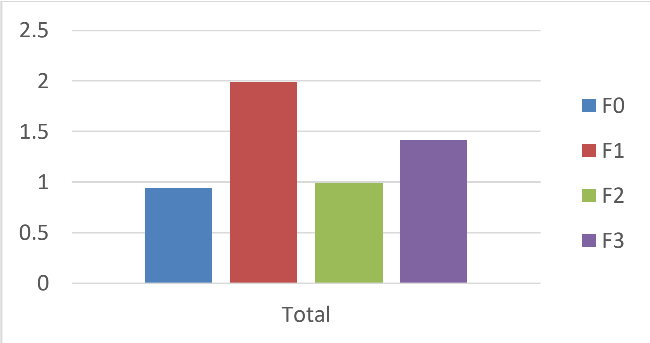

Figure 9. Average LAI distribution of different fertilizer treatments at 47 DAS.

4.7 Statistical Analysis

The two-way Analysis on Variance validated that there is a significant difference on the fertilizer treatment given the P-value computed using 95% level of significance (Table 1). On the other hand, the use of different varieties shows no significant difference on their means (Table 1). This suggests that the fertilizer treatment shows significant effect on the vegetation indices and leaf area index, whereas the use of different has no significant effect.

Table 1. Summary of parameters with significant difference on fertilizer treatment and corn variety at α = 0.05.

Parameter	Fertilizer Treatment	P-Value	Corn Variety	P-Value
BNDVI	With significant difference	0.0002396	Without significant difference	0.2543034
ENDVI	With significant difference	0.0065160	Without significant difference	0.2352195
GNDVI	With significant difference	7.8179E-16	Without significant difference	0.8411918
LAI	With significant difference	1.00692E-08	Without significant difference	0.6374759

4.8 Relationships Between LAI and Different Vegetation Indices

Given the 48 pairs of data in each vegetation indices, Linear Regression Analysis was used between Leaf Area Index and different vegetation indices. There is a strong linear relationship between Leaf Area Index and Blue Normalized Vegetation Index (Figure 10). A very weak linear relationship was observed among Leaf Area Index and Enhanced Normalized Vegetation Index (Figure 11). Lastly, there is a very strong linear relationship established between Leaf Area Index and Green Normalized Vegetation Index (Figure 12). The summary is shown in Table 2. Of all the vegetation indices used, the GNDVI gives the best correlation, with $R^2 = 0.8192$, followed by the BNDVI, with $R^2 = 0.7189$ and ENDVI, with $R^2 = 0.0526$.

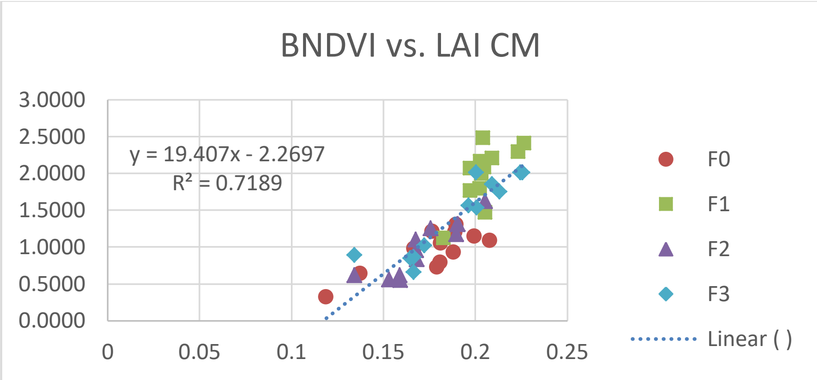

Figure 10. Scatter plot showing the relationship between Leaf Area Index and Blue Normalized Difference Vegetation Index at 47 DAS.

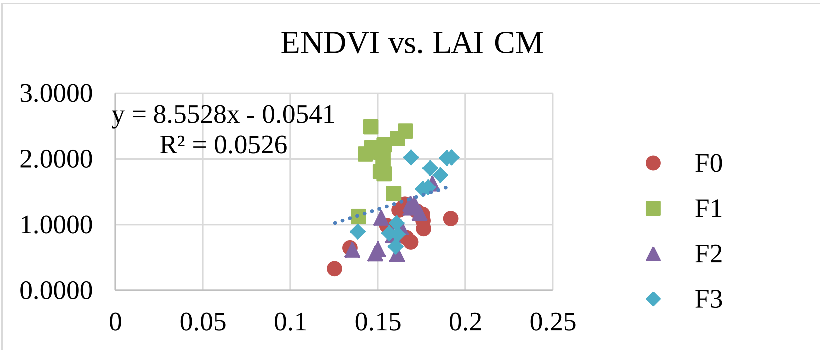

Figure 11. Scatter plot showing the relationship between Leaf Area Index and Enhanced Normalized Difference Vegetation Index at 47 DAS.

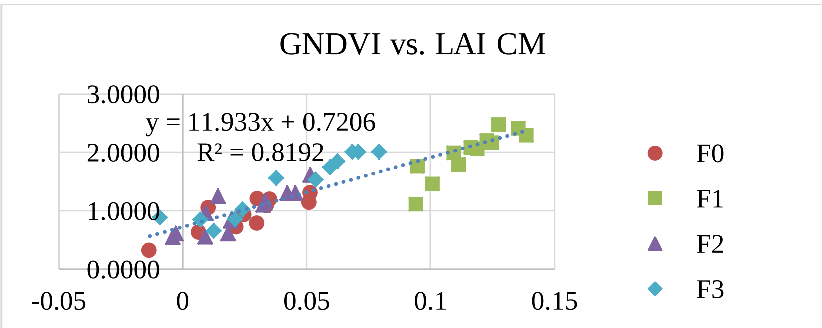

Figure 12. Scatter plot showing the relationship between Leaf Area Index and Green Normalized Difference Vegetation Index at 47 DAS.

Table 2. Summary of the goodness of fit of different vegetation indices.

Vegetation Index	R^2
BNDVI	0.7189
ENDVI	0.0526
GNDVI	0.8192

5. CONCLUSION

Leaf Area Index (LAI) holds a vital role in many models describing vegetation-atmosphere interactions, particularly. LAI is an indicator of the amount of leaf material in an ecosystem, which imposes important controls on photosynthesis, respiration, rain interception, and other processes that link vegetation to climate (GCOS, 2004).

In this study, Unmanned Aerial Vehicle (UAV) equipped with NIR-Green-Blue (NGB) camera was used to capture photograph images of corn during its vegetative stage (47 DAS) and generate vegetation index images using low-altitude remote sensing. This was used in the correlation of different vegetation indices with the leaf area index measured using plant canopy analyzer at 45 DAS.

Different fertilizer treatments (F0 - 0% fertilizer treatment, F1 - 100% conventional fertilizer treatment, F2 - 100% organic fertilizer treatment and F3 - 50% conventional and 50% organic fertilizer treatment) and varieties (V1 - UPLB corn variety 6, V2 - USM corn variety 10, V3 - UPLB corn variety 11 and V4 - CSC corn variety 1) were applied in the corn experiment.

The raw images were stitched to create a single orthomosaic image to come up with the Blue Normalized Difference Vegetation Index (BNDVI) image, Enhanced Normalized Difference Vegetation Index (ENDVI) image and Green Normalized Difference Vegetation Index (GNDVI) image.

Using the two-way ANOVA, it was found out that there is a significant difference at 95% level of significance on the means of BNDVI subplot value, ENDVI subplot value, GNDVI subplot value and LAI subplot value given different fertilizer treatments, hence there is a significant effect on varying the fertilizer treatment on these parameters. On the contrary, with the same method, at $\alpha = 0.05$, there is no significant difference on the means of these parameters using different varieties. The averages of different vegetation indices and leaf area index in each fertilizer treatments were obtained. It can be seen that among the treatments the percent difference of F0 and F2 with regards to BNDVI subplot value, ENDVI subplot value, GNDVI subplot value and LAI subplot value are 2.63%, 1.95%, 12.83% and 4.56% respectively. These suggest that there is no significant effect in applying 100% organic fertilizer on these parameters.

Using linear regression, the LAI measured were compared with the different vegetation indices extracted. The R^2 for BNDVI, ENDVI and GNDVI are 0.7189, 0.0526 and 0.8192 respectively. Having GNDVI with the highest R^2 suggests that among the three vegetation indices used to correlate the LAI measured, GNDVI has the best goodness of fit of the model. Consequently, it is best to use GNDVI in the correlation of LAI measured using canopy analyzer given the set-up.

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