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Assessment of plant health status using remote sensing and GIS techniques

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Abstract

Stress is a major focus of agricultural research, due to the vast economic losses caused to cash crops. Plant stress affects crop quality and quantity therefore every possible measure must be taken to assess and address the issue of plant stress in cocoa crop production. Researches reveal that there has been a reduction in the level of cocoa production in Nigeria and this has directly or indirectly affected the economy of the country. Plant stress assessment in this study was carried out using integrated remote sensing and GIS techniques. The study was carried in the teaching and research farm of The Federal University of Technology, Akure. The cocoa plantation which consist of two portions of shaded and un shaded (the shaded portion is covered by canopies of other plants like plantain while the un shaded potion is opened to direct sunlight). Four factors were considered (temperature, soil type, soil mineral and nutrients, relative humidity). Soil analysis, Vegetation indices (NDVI and SAVI), spectroradiometer and IDW 141was used to obtain information about the plant and the soil. Cocoa plants in the un shaded portion of the study area are more healthier than plants in the shaded portion of the cocoa farm. Absorption during the spectral reflectance assessment occurred mostly in the VNIR (Near Infrared) 400-1200nm region of the electromagnetic spectrum. the maximum absorption for nitrate is at 540nm, the maximum absorption for phosphate is at 880nm and the maximum absorption for sulphate is at 450nm. The variance in soil composition and the amount of soil minerals on different part of the farm is majorly responsible for the difference in health status of the cocoa plants. It is recommended that the method used in this study can also be applied in assessing the health status of any other plant. Although the study area is small, this method will be very effective if applied to a larger study area.

Keywords: plant stress, spectroradiometer, cocoa, soil analysis, GIS

Introduction

Stress is a major focus of agricultural research, due to the vast economic losses caused to cash crops (Miltler, 2012). The relationship between stress and plant yield affects economic decisions as well as practical development. The impact of biotic injury on crop yield impacts population dynamics, plant-stressor coevolution, and ecosystem nutrient cycling.[1] Cocoa is the leading agricultural export of the country and Nigeria is currently the world's fourth largest producer of Cocoa, after Ivory Coast, Indonesia and Ghana (FAO, 2015), and the third largest exporter, after Ivory Coast and Ghana.[2] The crop was a major foreign exchange earner for Nigeria in the 1950s and 1960s and in 1970 the country was the second largest producer in the world but following investments in the oil sector in the 1970s and 1980s, Nigeria's share of world output declined. In 2010, Cocoa production accounted for only 0.3% of agricultural GDP (FAO, 2015). Average cocoa beans production in Nigeria between 2000 and 2010 was 389,272 tonnes per year (FAO, 2015) rising from 170,000 tonnes produced in 1999.[3] Fortunately, remote sensing technology can provide spatial distribution information of diseases and pests over a large area with relatively low cost.[4] The presence of diseases or insect feedings on plants or canopy surface causes changes in pigment, chemical concentrations, cell structure, nutrient, water uptake, and gas exchange. These changes result in differences in color and temperature of the canopy, and affect canopy reflectance characteristics, which can be detectable by remote sensing. Therefore, remote sensing provides a harmless, rapid, and cost-effective means of identifying and quantifying crop stress from differences in the spectral characteristics of canopy surfaces affected by biotic and abiotic stress agents.[5]

Study area characteristics

Geographic description: The study area is a cocoa plantation in the research farm of The Federal University of Technology, Akure (FUTA) It is located between latitude 7°18'26.0''N and 7°18'28.3''N and longitude 005°07'24.6''E and 005°07'23.8''E. It covers a total area of about 0.126 acre (510m^2). It is divided into two portions: shaded and unshaded The un-shaded portion covers an area of 0.084 acre while the shaded portion covers an area of 0.042 acre.

Biophysical characteristics

1. **Rainfall:** Being in the equatorial tropical hinterland, two distinct seasons are experienced;
2. **Dry season:** characteristically wet and ranges between April to October and
3. **Wet season:** which is characteristically dry and ranges between November and March.

Rainfall usually begins around March /April and reaches the maximum in June, decreasing from thereafter until September/October when it finally ebbs out. The south westerly moisture laden wind brings the rain while the North easterly wind brings harmatan during the dry season. Annual rainfall varies from 1150mm to 2550mm.

Temperature: Study area maintains a moderately high temperature line throughout the year. The maximum temperature of about 34% (86^{0}F) is usually in March while the minimum stand at about 22^{0}c (71.6^{0}F) with an average daily temperature between 30^{0}C (93.2^{0}F) and cloudy atmosphere reduces excessive high temperature. The annual mean temperatures is about 26.65^{0}C the diurnal range is usually very low often times not more than 70^{0}F in July and August.

Relative humidity

In the study area, high annual rainfall makes the relative humidity to be high throughout the year, and it ranges between 64% and 87%. In the morning times, during the raining season, 80% is commonly observed. In times of high temperature with high temperature with high relative humidity, the atmosphere could be pretty uncomfortable. However pleasant atmosphere is generally experienced at the raining season when the relative humidity generally falls. The mean maximal at 10:00am is 77% from December to May and 88% in August. The annual average maximum is 83%. The extreme mean at 4:00pm is 57.5% in January and 81.9% in July and August. The annual mean maximum humidity is 71.88% (Figure 1).

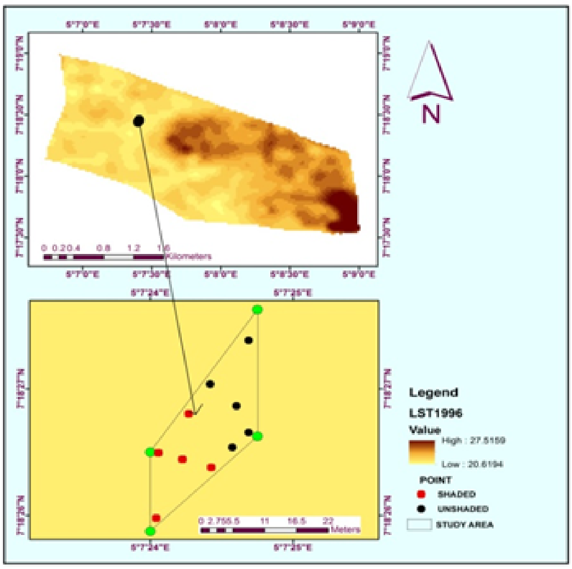

Figure 1 Land surface temperature map for 1996.

Materials and methods

This chapter presents the relevant data and materials used for the project, their source, relevance, the processing operations carried out and the overall methods used in order to achieve the desire aim and objectives. The criteria used for the analysis were fully explained in this chapter (Table 1).

Software used

a. Arcgis 10.5
b. ViewSpec2009
c. Microsoft word 2013
d. Microsoft excel 2013

Instrument used

a) GPS
b) Soil auger
c) Spectroradiometer

Methods used in the Study

Clipping or image sub-setting: This refers to clipping out an area of interest from available data set. It is also referred to as creating a sub-map. This is necessary because it limits one only to the area of interest. It also reduces working on very large extent of data. Clipping in image analysis helps to streamline the study into co incides area.

Vegetation index analysis using normalized difference vegetation indices (NDVI): Normalized Differential Vegetation Index (NDVI) for the study area was carried out using ARCGIS 10.5 edition by calculating the ratio between measured reflectivity in the red and near infrared (NIR) portions of the electromagnetic spectrum. The normalized difference vegetation index (NDVI) is an index of plant "greenness" or photosynthetic activity, and is one of the most commonly used vegetation indices.

Table 1 Characteristics of the data used

S/N	Data	Source	Year	Resolution	Relevance
1	Administrative map	OSGOF		1:130000	To extract the boundary of the LGAs that made up the study area
2	LANDSAT7 and LANDSAT8	USGS	199,620,032,018	30m	To extract LST and NDVI of the study area.
3	Soil Map	Centre for world food Studies.	1997		To extract the soil types within the study area
4	GPS coordinates	field survey	May ,2017	………….	To get the coordinate of sample
5	Relative humidity data	Era interim(ecmwf.in)			To extract humidity data for study area

Extraction of land surface temperature from the images: Land surface temperature (LST) is the radioactive temperature of land derived from solar radiation. LST is a basic determinant of terrestrial thermal behavior, as it controls the effective radiating temperature of the earth's surface. The LST for this study help to generate the temperature data for study area between 1996, 2013 and 2018. These process helps to know the temperature of the study area at these time. LST values were calculated using radian reflectance values of the three Landsat images which were transformed to radiant surface temperature.

Inverse distance weighted (IDW): The Inverse Distance Weighting interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing

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cell greater than those further away. A specified number of points, or all points within a specified radius can be used to determine the output value of each location. Use of this method assumes the variable being mapped decreases in influence with distance from its sampled location.

Soil adjusted vegetation index (SAVI): Soil Adjusted Vegetation Index (SAVI) is a type of vegetation index that account for the variation in soil type and soil properties. Empirically derived NDVI products have been shown to be unstable, varying with soil colour, soil moisture, and saturation effects from high density vegetation. In an attempt to improve NDVI,[6] developed a vegetation index that accounted for the differential red and near-infrared extinction through the vegetation canopy. The index is a transformation technique that minimizes soil brightness influences from spectral vegetation indices involving red and near-infrared (NIR) wavelengths.

The index is given as:

SAVI = (1+L) (NIR – RED)

(NIR+ RED = L)

Where L is a canopy background adjustment factor. An L value of 0.5 in reflectance space was found to minimize soil brightness variations and eliminate the need for additional calibration for different soils. The transformation was found to nearly eliminate soil-induced variations in vegetation indices.

Results

Land surface temperature analysis

In this study, the land surface temperature of the study area for three different years (1996, 2013 and 2018) was generated from the satellite imageries. The land surface temperature map and point values were used to determine the changes or the difference in the land surface temperature of the study area over the years and how it has possibly affect the growth and productivity of the crops. The analysis shows that there is increase in the land surface temperature point value between 1996 and 2013 and a slight increase between 2013 and 2018. The result shows that the LST values are the same for every point on the study area therefore LST might not be responsible for the variation in the plant health status. The Figures 2–4 below shows the classified images for the land surface temperature for the year 1996, 2013 and 2018 respectively. The table below shows the LST value of the soil sample points before the crops were planted (1996), at the very early stage of plantation(2013) and few years after planting the crops (2018) (Table 2).

Normalized differential vegetation indices (NDVI)

The NDVI maps and values of the study area shows the variation in the plant health status for the three years of study(1996, 2013.2018). The plantation started in 2013 therefore all the plant sample point have almost the same NDVI value , the NDVI values ranges from -1 to 1. In year 2018 the analysis shows higher NDVI values (P3, P4, P5) in the unshaded portion of the study area than in the shaded portion of the study area. Which means cocoa plants in the unshaded area are healthier than cocoa plants in the shaded area The result of the NVDI are shown in the Figures and Table below. Table 3 shows the NDVI value of the study area Figures 4–6 shows the map of NDVI for 1996, 2013 and 2018 respectively.

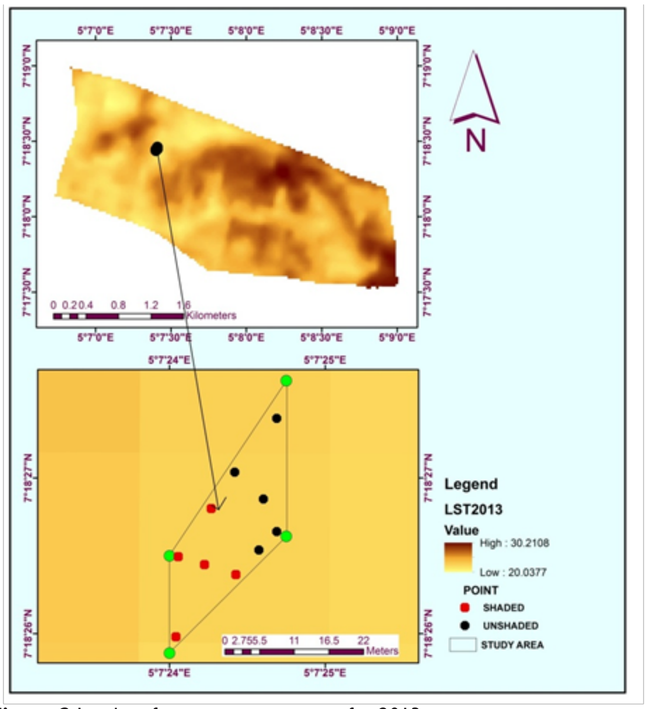

Figure 2 Land surface temperature map for 2013.

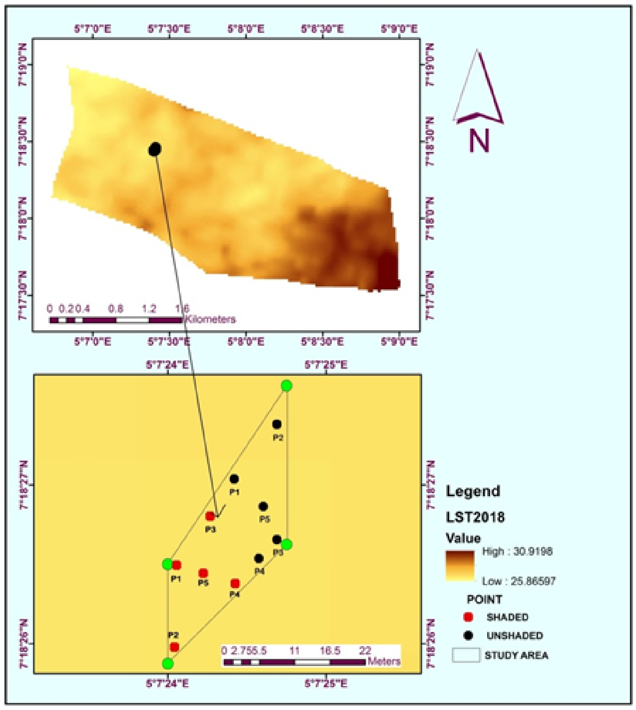

Figure 3 Land surface temperature map for 2018.

Soil Test and analysis

Soil test was carried out on the soil samples that were taken from both the shaded and the un shaded portion of the study area to test for the amount of nitrate, phosphate, and sulphate that is present in the soil and to also compare this result with the FEPA and WHO standard of permissible amount of this minerals. result shows that none of this samples exceed the permissible amount of nitrate, sulphate and phosphate percentage. Table 3 shows the result from the soil analysis.

Table 2 Land surface temperature distribution

Sample points	1996	2013	2018
Shaded1	21.061	28.51	29.31
Shaded2	21.061	28.51	29.31
Shaded3	21.061	28.51	29.31
Shaded4	21.061	28.51	29.31
Shaded5	21.061	28.51	29.31
Unshaded1	21.061	28.51	29.31
Unshaded2	21.061	28.79	29.31
Unshaded3	21.061	28.51	29.31
Unshaded4	21.061	28.51	29.31
Unshaded5	21.061	28.51	29.31

Table 3 NDVI values for 1996, 2013, 2018

Sample points	1996	2013	2018
Shaded 1	0.018	0.2155	0.456
Shaded 2	0.018	0.2155	0.406
Shaded 3	0.018	0.2155	0.406
Shaded 4	0.018	0.2155	0.525
Shaded 5	0.018	0.2155	0.456
Unshaded 1	0.018	0.2155	0.5024
Unshaded 2	0.017	0.213	0.4937
Unshaded 3	0.018	0.2155	0.525
Unshaded 4	0.018	0.2155	0.524
Unshaded 5	0.018	0.2155	0.524

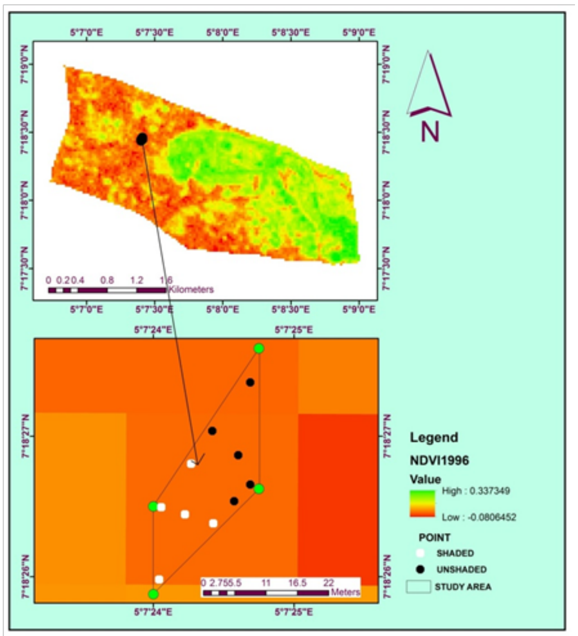

Figure 4 NDVI 1996.

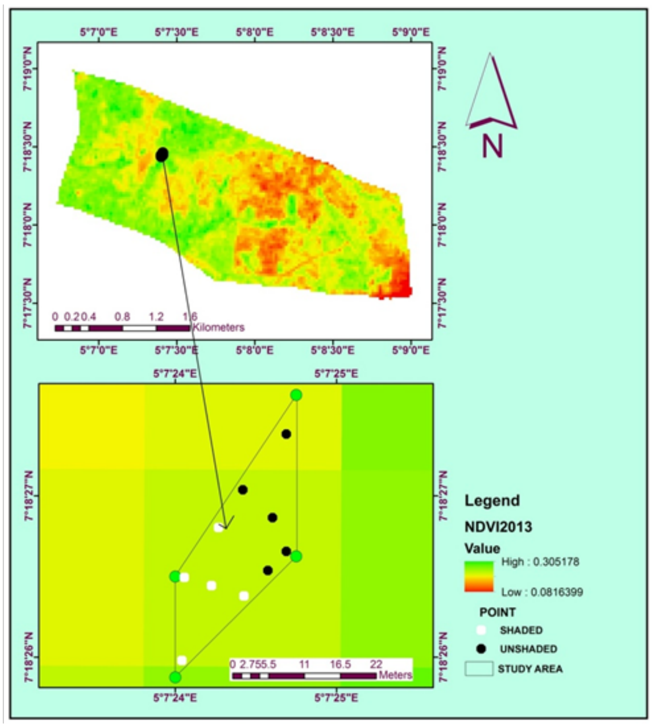

Figure 5 NDVI 2013.

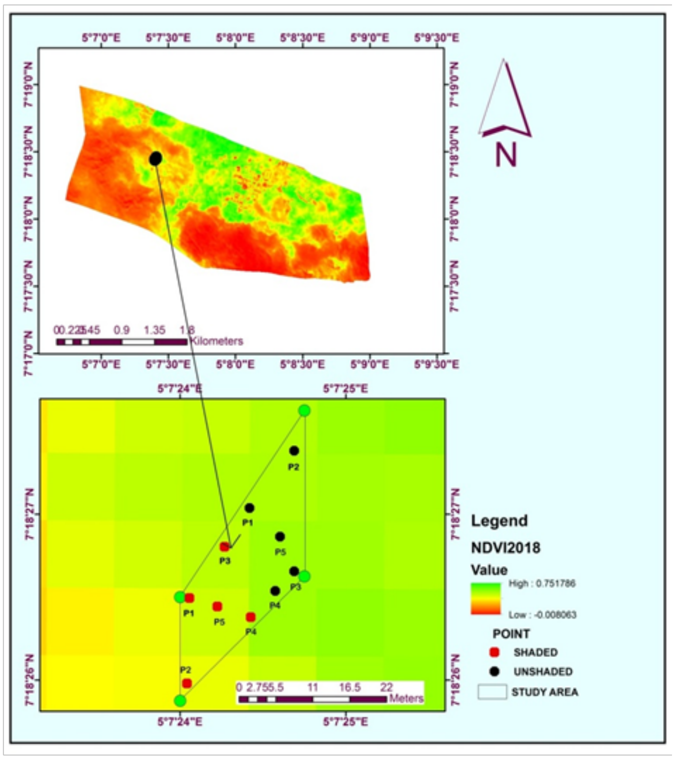

Figure 6 NDVI 2018.

Soil map

In this study the soil type of the study area is also considered as one of the factors that might be responsible for variation in the health status of the plants. The soil map shows that the soil type for both

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the shaded and he unshaded portion of the study area is the same, although the composition and the mineral contents area different. The Figure 7 below shows the soil map of the study area.

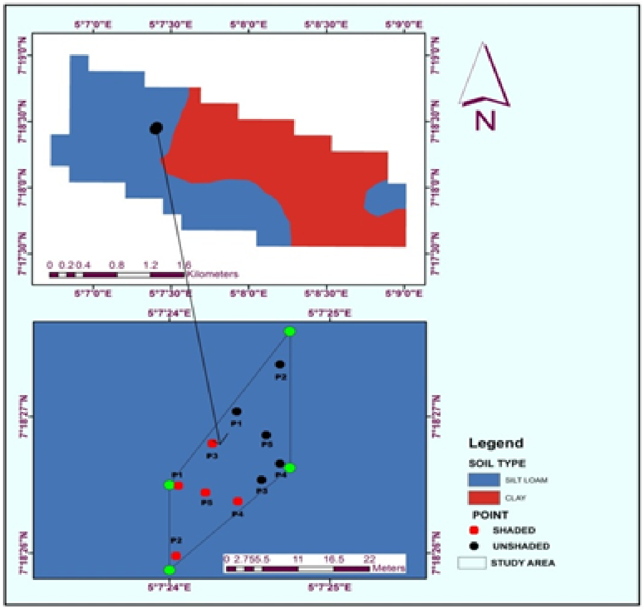

Figure 7 Soil map of the study area.

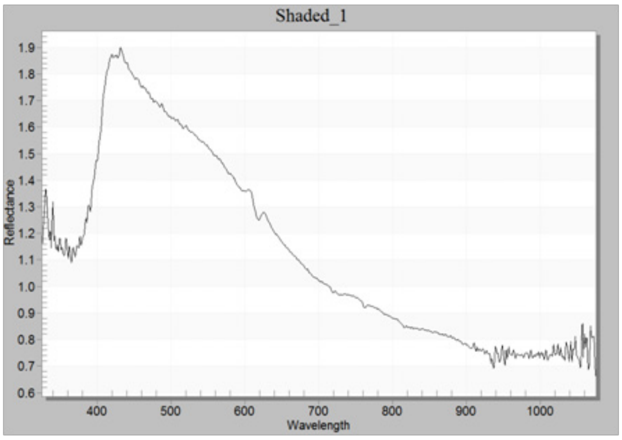

Figure 8 Reflectance curve for shaded point 1.

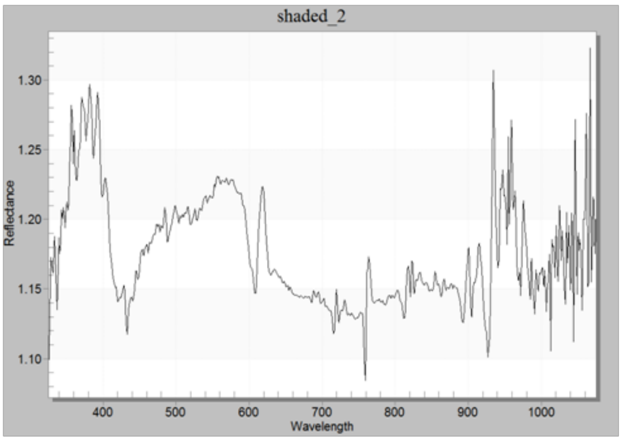

Figure 9 Reflectance curve for shaded point 2.

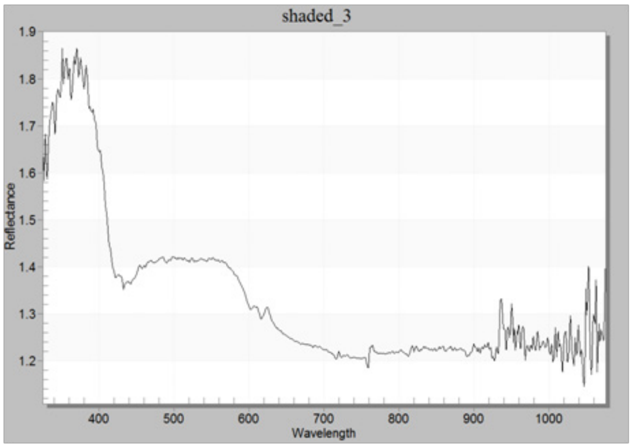

Figure 10 Reflectance curve for shaded point 3.

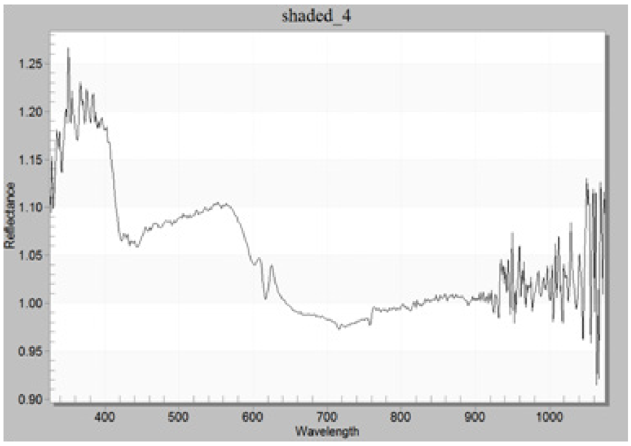

Figure 11 Reflectance curve for shaded point 4.

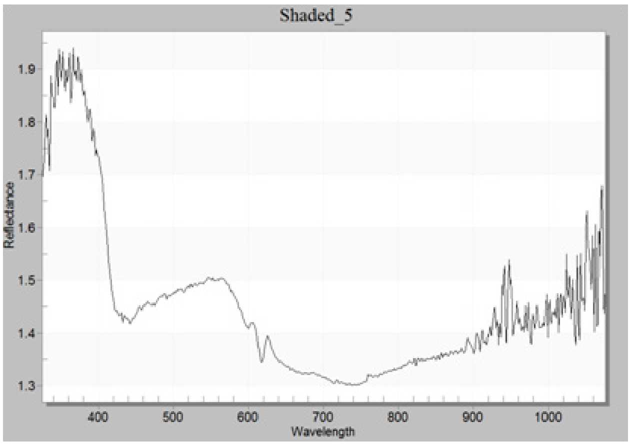

Figure 12 Reflectance curve for shaded point 5.

Spectral Reflectance

The reflectance curve shows information about the various soil samples based on the composition of materials in the soil samples. Peaks in the reflectance curve indicate reflection and points of recession, the curve indicate absorbance which is caused by the presence of minerals in the soil samples. This absorbance occurred mostly in the VNIR (Near Infrared) 400-1200nm region of the electromagnetic spectrum. The maximum absorption for nitrate is at 540nm, the maximum absorption for phosphate is at 880nm and the maximum absorption for sulphate is at 450nm Figures 8-18 below shows the spectral reflectance curve of the soil samples.

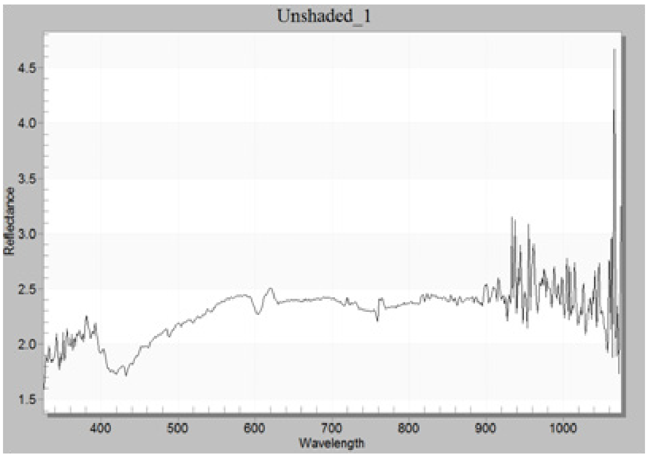

Figure 13 Reflectance curve for unshaded point 1.

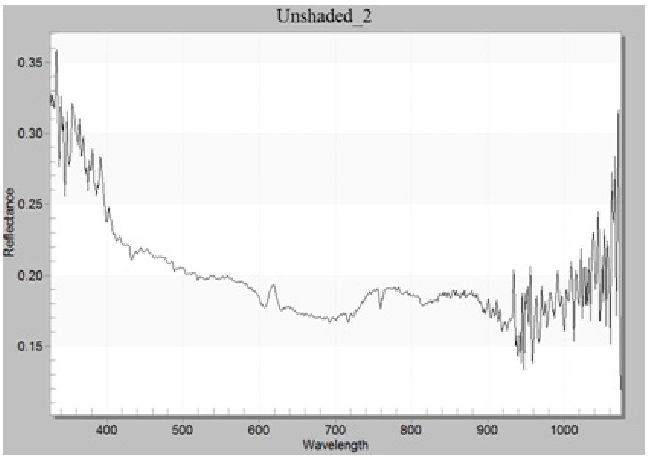

Figure 14 Reflectance curve for un shaded point 2.

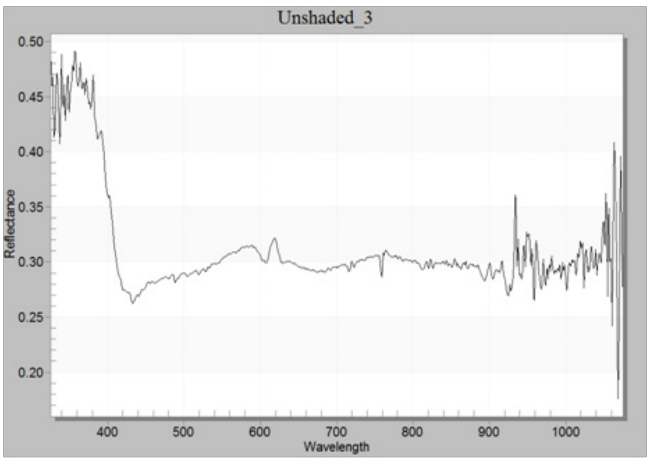

Figure 15 Reflectance curve for un shaded point 3.

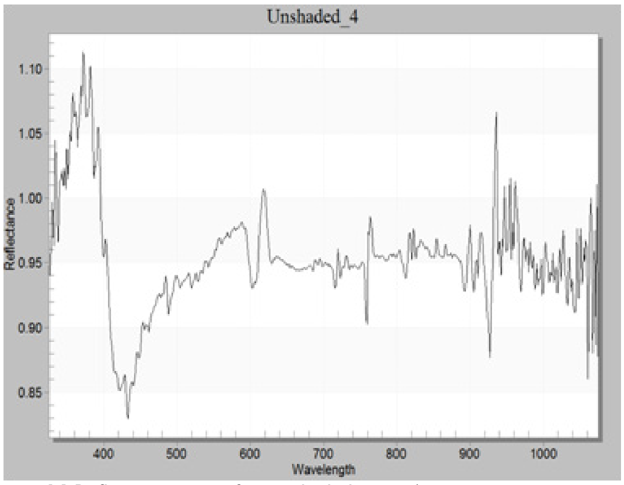

Figure 16 Reflectance curve for un shaded point 4.

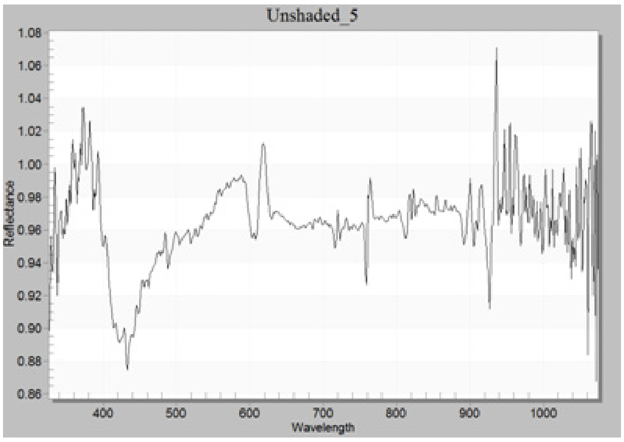

Figure 17 Reflectance curve for un shaded point 5.

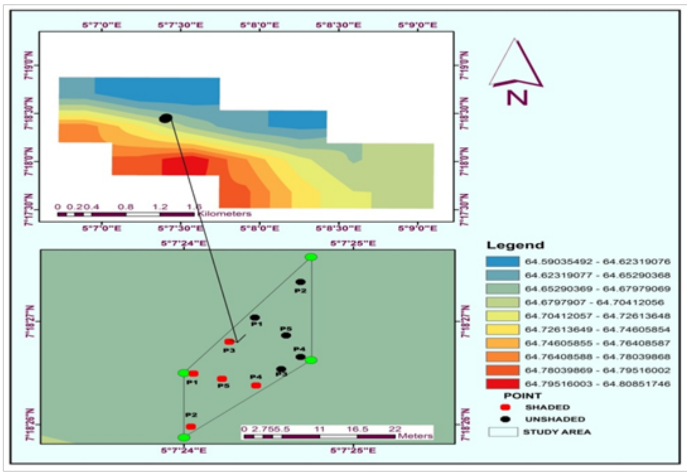

Figure 18 Relative humidity map.

Relative humidity map

In this study the relative humidity of the study area is also considered as one of the factors that might be responsible for variation in the health status of the plants. The relative humidity map shows that

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the relative humidity for both the shaded and he unshaded portion of the study area is the same, therefore it is not a factor responsible for the variation in the health status of the plants. The figure below shows the relative humidity map of the study area.

Soil Adjustment vegetation index

Soil Adjustment Vegetation Index (SAVI) is used in this study to assess the properties and the composition of the soil in the study area. Result and analysis shows that soil in the unshaded portion of the study area has high SAVI values than that of the shaded portion. This might account for the healthiness of plants in the unshaded portion over plants in the shaded portion because sample points (p3, p4, p5) in the unshaded portion and point 4 in the shaded portion (which is very close to the unshaded portion has the highest NDVI value. SAVI map of the study area is shown below in Figure 19.

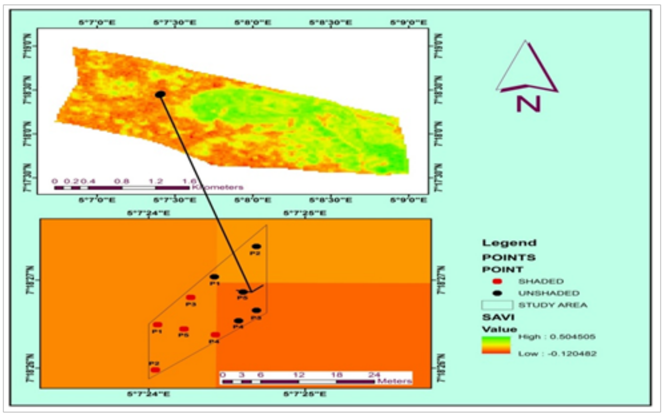

Figure 19 SAVI map of the study area.

Table 4 Soil analysis results

Sample points	Nitrate (%)	Sulphate (%)	Phosphate (%)	LONG	LAT
Shaded point 1	0.00146	0.0755	0.000848	5.1233	7.3074
Shaded point 2	0.009181	0.0809	0.000801	5.1233	7.3073
Shaded point 3	0.00435	0.03735	0.001112	5.1234	7.3075
Shaded point 4	0.001635	0.0795	0.000856	5.1234	7.3074
Shaded point 5	0.008621	0.047975	0.00106	5.1234	7.3074
Un Shaded point 1	0.006406	0.100025	0.001268	5.1234	7.3076
Un Shaded point 2	0.02392	0.09945	0.00106	5.1235	7.3076
Un Shaded point 3	0.007621	0.02585	0.000809	5.1235	7.3075
Un Shaded point 4	0.018035	0.08715	0.000964	5.1235	7.3075
Un Shaded point 5	0.002208	0.049275	0.001898	5.1235	7.3075
FEPA & WHO permissible mineral %	1.5	0.1	0.1		

Interpolation (IDW)

This interpolation technique was used to estimate or approximate the percentage of minerals for the unknown points on the study based on the known values from the soil analysis. The result shows that the unshaded portion of the study area has higher amount of nitrate phosphate and sulphate. This is possibly responsible for the healthiness of cocoa plants in the unshaded portion of the study area. Figures 20–22 bellows shows the maps for the interpolations.

Relationship between NDVI and the soil minerals

In the study, NDVI values and the mineral composition are directly proportional to each other although the soil minerals does not exceed FEPA and WHO standards. The higher the NDVI the higher the soil nutrient composition. The shaded area which has the highest NDVI values tends to have high value if these minerals, as shown in the map while the shaded area with low NDVI value has low amount of these minerals. The graph below Figures 23,24 showed clear relationship between the NDVI and the minerals (sulphate, phosphate and nitrate).

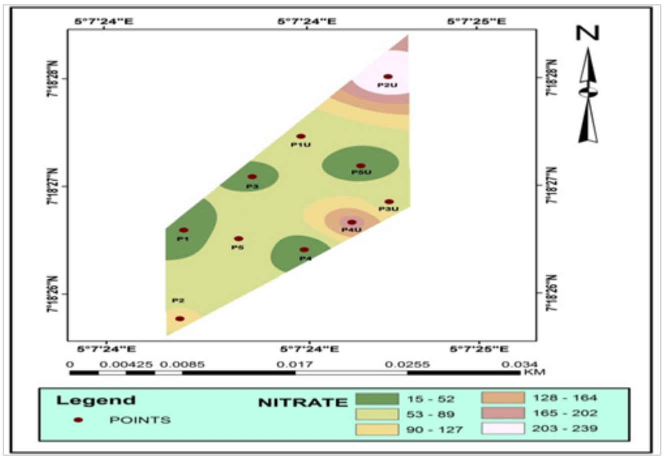

Figure 20 Map showing the spatial distribution of nitrate value of the study area.

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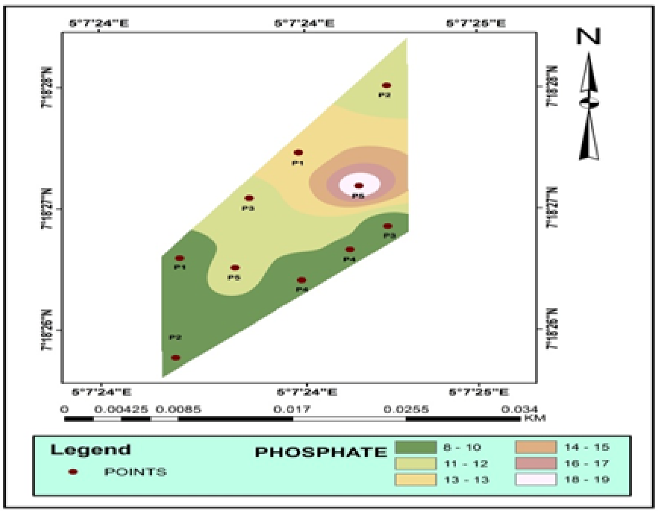

Figure 21 Map showing the spatial distribution of phosphate value of the study area.

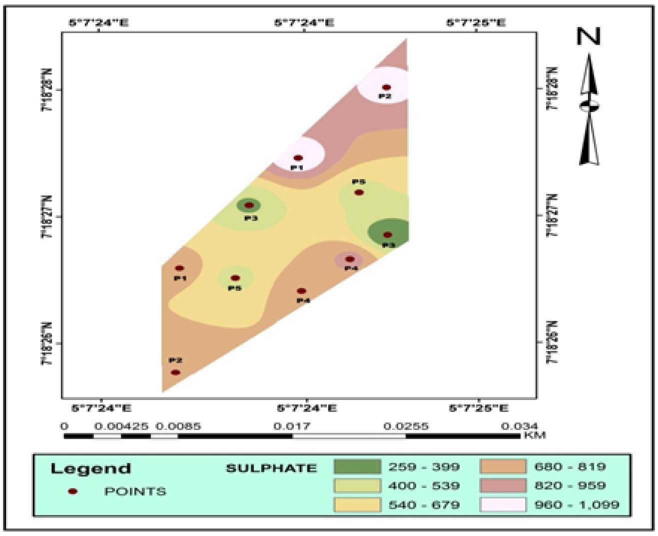

Figure 22 map showing the spatial distribution of sulphate value of the study area.

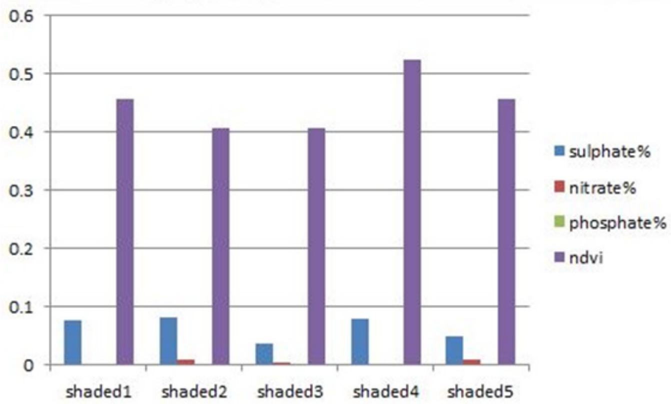

Figure 23 Bar chart showing the relationship between NDVI and minerals for the shaded portion.

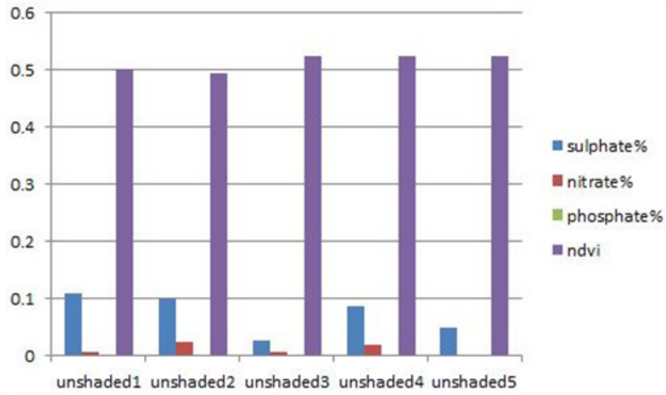

Figure 24 Bar chart showing the relationship between NDVI and minerals for the shaded portion.

Conclusion and recommendation

The study has indicated the potential use of remote sensing and GIS in the assessment of cocoa plant health status on a cocoa plantation in the research farm of FUTA. Integrated GIS techniques in this study has proved beyond doubt its capabilities of spatial analysis. In this study Land sat images were used satisfactorily to assess cocoa plant health. The study has shown the versatility of remote sensing data and GIS approach in assessing plant health using vegetation indices (NDVI and SAVI) and LST values of the different portion(shaded and unshaded) of the cocoa plantation. The study examined the spatial distribution of soil minerals in relation to the NDVI of the remotely sensed data of the study area which shows the health status of the cocoa plants. This study has help to generate the relationship between NDVI, SAVI and the soil mineral contents, it is deduced that NDVI is directly proportional to the percentage and composition of the soil minerals.[7–31]The study shows that the NDVI value in the unshaded portion of the study area have higher value than the values in the shaded portion of the study area. The study shows that the land surface temperature, relative humidity and the soil type of the study area are not really a factor to consider for the variation of the health status of the plants because the study area is a small area therefore both portion of the study area has the same value of land surface temperature, relative humidity and soil type. This study fuses remote sensing and GIS techniques and soil laboratory analysis to determine the health status of the plants and to also approximate the health status and the soil composition of the unknown points on the study area

Based on this study we can conclude that:

a. Remote sensing and GIS technique is very effective and can be employed in assessing plant health status or the level of stress in plants

b. Environmental or climatic factors such as land surface temperature, rainfall and relative humidity are not the factors responsible for the variation in the plant health status because every portion of the study area has the same values for these factors.

c. Cocoa pants in the un shaded portion of the study area are more healthier than plants in the shaded portion of the cocoa farm.

d. The variance in soil composition and the amount of soil minerals on different part of the farm is majorly responsible for the difference in health status of the cocoa plants.

I recommend that this particular method used in this study can also be applied in assessing the health status of any other plant. Although the study area is a small area this method will be very effective if applied to a bigger study area.

I also recommend that the soil composition and the soil minerals in the study area should be well examined and monitored in other to create a balance to the health status of the cocoa plants.

Acknowledgments

None.

Conflicts of interest

The authors declared there is no conflict of interest.

References

1. Gao JP, Chao DY, Lin HX. Understanding Abiotic Stress Tolerance Mechanisms: Recent Studies on Stress Response in Rice. *Journal of Integrative Plant Biology*. 2007;49(6):742–750.
2. Verter N, Bečvářová V. Analysis of some drivers of cocoa export in Nigeria in the era of trade liberation. *AGRIS on-line Papers in Economics and Informatics*. 2014;6(4):208–218.
3. IITA. Cocoa development in nigeria: The strategic role of STCP; 2015.
4. Pinter PJ, Hatfield JL, James S Schepers, et al. Remote Sensing for Crop management. *Photogrammetric Engineering & Remote Sensing*. 2003;69(6):647–664.
5. Wenjiang Huang, Juhua Luo, Jingcheng Zhang, et al. Crop Disease and Pest Monitoring by Remote Sensing. *Remote Sensing–Applications*. 2007;64(3):224.
6. Huete A, Didan K, van Leeuwen W, et al. MODIS vegetation indices. In: Land Remote Sensing and Global Environmental Change:NASA's Earth Observing System and the Science of ASTER and M O D I S , in press. 5, JR. (2006). Biophysical Remote sensing – Review Article. Annals of the Associations of American Geographers. 2008;73(1):111–132.
7. AGRODEP. Post liberation markets, export firm concerations and price transmission along Nigeria's cocoa supply chain.
8. Atkinson NJ, Urwin PE. The interaction of plant biotic and abiotic stresses: from genes to the field. *J Exp Bot*. 2012;63(10):3523–3544.
9. Aurthur WL. Tropical development 1880-1913; studies in economic progress 2010;10:157 p.
10. Barnes EM, Baker MG. Multispectral data for mapping soil texture: Possibilities and limitations. *Applied Eng Agric*. 2000;16(6):731–741.
11. Boateng KO. The impact of climate change on cocoa production in West Africa. International journal of climate change strategies and management. 2014;6(3):296.
12. Feng W, Yao X, Zhu Y, et al. Monitoring leaf nitrogen status with hyperspectral reflectance in wheat. *European Journal of Agronomy*. 2008;28(3):394–404.
13. Govender M, Dye PJ, Weiersbye IM, et al. Review of commonly used remote sensing and ground based technologies to measure plant stress. *Water SA*. 2009;35(5):69–74.
14. Haboudane D, Tremblay N, Miller J, et al. Remote estimation of Crop chlorophyll content using spectral indices derived from hyperspectral data. *IEEE Transactions on Geoscience and Remote Sensing*. 2008;46(2):423–437.
15. Karim S. Exploring plant tolerance to biotic and abiotic stresses. *Epsilon Open Archive*. 2007;46(3):167.
16. Krezhova D, Maneva S, Moskova I. Hyperspectral remote sensing application for early stress detection of young plants. 2015;47(Special Issue B):355–363.
17. Lelong CCD, Pinet PC, Poilve H. Hyperspectral images and stress mapping in agriculture: A case study on wheat in Beauce (France). *Remote Sens Environ*. 1998;66(2):179–191.
18. Luther JE, Fournier RA, Piercey DE, et al. Biomass mapping using forest type and structure derived from Landsat TM imagery. *International Journal of Applied Earth Observations and Geoinformation*. 2006;8:173–187.
19. Mahayan GR, Sahoo RN, Pandey RN, et al. Using Hyperspectral Remote sensing techniques to monitor Nitrogen, Phosphorus, Sulphur and Potatium in wheat. 2014;10:224–227.
20. Makinde EO, Salami AT. Remote sensing of vegetation stress and indicators. 2013;(20):121–129.
21. Mittler R. Abiotic stress, the field environment and stress combination. *Trends Plant Sci*. 2012;11(1):15–19.
22. Osborne SL, Schepers JS, Francis D, et al. Detection of phosphorus and nitrogen deficiencies in corn using spectral radiance measurements. *Agronomy Journal*. 2002;94:1215–1221.
23. Prasad ST, Ronald RN, Pauw ED. Hyperspectral vegetation indices and their relationships with agricultural crop characteristics. *Remote Sens Environ*. 2000;71(2):158–182.
24. Rondeaux G, Steven M, Baret F. Optimization of soil a d j u s t e d vegetation indices. *Remote Sensing of Environment*. 1996;55(2):95–107.
25. Ryu CS, Suguri M, Umeda M. A model for predicting the nitrogen content of rice at panicle initiation stage using data from airborne hyperspectral remote sensing. *Biosystems Engineering*. 2009;104(4):465–475.
26. Shikha DME, Waller P, Hunsaker D, et al. Ground based remote sensing for assessing water and nitrogen status of broccoli. *Agric Water Mgmt*. 2007;92(3):183–193.
27. Silva TA, Beyl CA. Changes in spectral reflectance of w h e a t leaves inresponse to specific macronutrient deficiency. *Adv Space Res*. 2005;35(2):305–317.
28. Suzuki N, Rivero RM, Shulaev V, et al. Abiotic and biotic stress combinations. *New Phytol*. 2014;203:32–43.
29. View Spec Pro (2008). View Spec Pro™User Manual. ASD Document 600555Rev.A. ASD Inc. www.asdi.com.
30. Zarco-Tejada PJ, Miller JR, Mohammed GG, et al. Chlorophyll Fluorescence Effects on Vegetation Apparent Reflectance: I. Leaf-Level Measurements and Model Simulation. *Rem Sens Environ*. 2000;74(3):582–595.
31. Zhao D, Raja Reddy K, Kakani VG, et al. Corn (Zea mays L.) growth, leaf pigment concentration, photosynthesis and leaf hyperspectral reflectance properties as affected by nitrogen supply. Plant and Soil, 2003;257(1):205–217.