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Evaluation of Multiple Proximal Sensors for Estimating Nitrogen Nutritional Content of Matured Oil Palm

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ABSTRACT

Nitrogen (N) is one of the important elements for optimum growth as well as high yield in oil palm plantation industry. Hence, estimation of N content in plant tissue is crucial for plantation management to minimize cost of production to produce high yields. Conventional method such as foliar analysis is expensive and not a real time analysis. Implementation of chlorophyll meter and spectral approaches has been used widely in estimation of N in various types of crops but a few studies have been carried out with regard to oil palm. Therefore, this study was conducted to evaluate multiple proximal sensors for N estimation in mature oil palm. The experiment was conducted in a plantation setup in Randomized Complete Block Design (RCBD) with three replications. Three levels of N treatments; 0, 1 and 2 kg N per palm per year as ammonium chloride were applied in split applications within two different planting years' plots. The data was collected in February and October 2014. The combination of physiological and spectral models fit the best (R^2 = 1.00) for foliar N or N rate estimation in matured oil palm. Generally, SPAD meter was not suitable to estimate N content in matured oil palm leaves but the function can be compensated by the spectroradiometer. The variation of single and combination of single physiological or spectral models in estimating N was highly influenced by age and sampling time. Palm stem diameter was important in this study though it is not sensor-measured.

Key words: LAI, SPAD, diameter, height, spectroradiometer

INTRODUCTION

Like many other cash crops, good agronomic practices involving oil palm nutrient management is undeniably essential to optimize the yield production per hectare. Since the crop constantly removed nutrients through the harvested Fresh Fruit Bunch (FFB) or sequestered in the standing biomass, the consumed nutrients must be abundantly replenished (Wahid *et al*., 2005). According to the amount required for oil palm growth, N ranked after K and mostly taken up by the plant in the form of soluble nitrate ion (NO_3^-).

Insufficient N will affect chloroplast development and functions, leaf area index (Goh and Hardter, 2003), palms height (Uwumarongie-Ilori *et al*., 2012) and consequently oil and Fresh Fruit Bunch (FFB) (Goh and Hardter, 2003). On the other hand, excessive N applications will increase the susceptibility to disease and insect pest such as leaf-eating caterpillars and bagworms (Goh and Hardter, 2003). Over-application of N may also induce B deficiency which leads to white stripe (Goh and Hardter, 2003). Additionally, the largest portion of the oil palm production cost is attributed to fertilizers where their prices are highly fluctuated (Goh *et al*., 2003). It is estimated that the oil palm industry will benefit RM 117.25 million per year if excessive ammonium nitrate application as much as 0.25 kg/palm/year can be avoided (Goh and Po, 2005). Thus, it is of an equal importance to be able to estimate the optimum requirement of N to prevent economic loss in plantation industry and for producing maximum oil palm yield.

Foliar analysis is conventionally being practiced to observe nutrient status in palms. However, considering Malaysia alone planted a total of 5.3 million ha (MPOC., 2014) of oil palm, this practice is not feasible since it is costly, time consuming, labour intensive and not accessible for small scale plantations or individual oil palm planters. In seeking for alternative to the conventional foliar analysis, the indirect chlorophyll estimation by the employment of Chlorophyll Content Meter (CCM) has become popular in recent years. The non-destructive, portable and real time instrument has been illustrated to dependably indicate foliar N of perennial crops such as for jatropha (R^2 = 0.99) (Nyi *et al*., 2012), Asian pear (R^2 = 0.76) (Ghasemi *et al*., 2011) and timber trees (R^2 = 0.85-0.93) (Percival *et al*., 2008). The basic principle of the CCM operation is based on the level of photon absorbed by chlorophyll at red (650 nm) and near infrared (940 nm) wavelengths (Peterson *et al*., 1993; Blackmer *et al*., 1994) and hence the close connection between extractable leaf chlorophyll ($C_xH_xO_xN_4Mg$) and N content.

Nonetheless, in oil palm related study, the CCM has been limitedly explored. Law *et al*. (2014) tested the SPAD 502 in oil palm seedlings and found that the meter provided reliable estimate of foliar N (r = 0.73). However, Jifon *et al*. (2005) and Pinkard *et al*. (2006) demonstrated that the relationship between SPAD-502 meter and foliar leaf N observed from controlled-environment crops cannot be simply up-scaled to the crops grown in the field, mainly due to the thickening of leaves through the rearrangement of leaf cell during the exposure to direct sunlight that changes the characteristics of light absorption and transmission and hence the meter's readings. In comparing the strength of relationship between SPAD-502 meter and foliar N, they also found that the crops grown under controlled environment resulted in stronger relationships than for ones that were field-grown. It is also worth noting that the relationship describing the CCM measurements and foliar N is often influenced by other secondary factors such as crop N partitioning characteristic (Turnbull *et al*., 2007), variety (Schaper and Chacko, 1991; Shaahan *et al*., 1999; Jifon *et al*., 2005) growing condition (Simorte *et al*., 2001; Liu *et al*., 2012; Jifon *et al*., 2005), sampling time (Neto *et al*., 2011), nutrient deficiencies, water stress and pest and diseases (Peryea and Kammereck, 1997; Pestana *et al*., 2005).

On the other hand, Leaf Area Index (LAI) is among the physiological parameters of interest measured in oil palm studies since it indicates photosynthetic efficiency (Noor and Harun, 2004). Besides, LAI is crucial for crop monitoring and productivity as well as important components for canopy structure analysis (Pocock *et al*., 2010). LAI increase as plant grows as it influences the light interception (Ewert, 2004). Comparable to the conventional foliar nutrient analysis, the manual method of measuring LAI is inconvenient for efficient plantation management. Based upon this argument, researchers such as Awal and Wan Ishak (2008) and Noor *et al*. (2002) had evaluated the use of indirect technique of estimating LAI such as the LAI-2000 Plant Canopy Analyzer (PCA), where the former authors found that the correlation coefficient between manually measured LAI and PCA LAI is weak (r = 0.57). They also reported that the PCA give inconsistent LAI readings in oil palms. However, Behera *et al*. (2010) found high correlation coefficient (r = 0.99) between manual LAI measurement and PCA for jatropha at sensor angle of 90°. Other than factors of age and sensor angle position, N concentration also influences LAI reading (Pierce *et al*., 1994).

In mature oil palm nutrient study, plant growth indicator such as height and diameter has not been intensively studied in relation to N response. Nevertheless, since N application rates can induce differences in physiological parameters as such chlorophyll concentration, LAI and net assimilation rate (Corley and Mok, 1972; Uwumarongie-Ilori *et al*., 2012), these two parameters can also provide information regarding crop growth and health independent of chlorosis. For oil palm seedlings, N organic fertilizers were found to significantly influence the seedlings height and diameter reading (Uwumarongie-Ilori *et al*., 2012). This result is concurrent with the finding by Gul *et al*. (2006) and Owolabi *et al*. (2013) who reported that N organic fertilizers increased the plant height and diameter in oil palm seedlings, respectively.

Numerous efforts towards spectral approach in the study of plant N have been done for perennial crops (Min and Lee, 2005; Perry and Davenport, 2007; Gomez-Casero *et al*., 2007). Min and Lee (2005) reported that the blue, red, near-infrared and shortwave-infrared bands were worthy for N detection in oranges using spectrophotometer. Following the study by Perry and Davenport (2007), who reported that the narrow band indices such as MCARI and RVSI sensitive to N treatment of apples. Meanwhile, study of Gomez-Casero *et al*. (2007) indicated the NIR as the most sensitive wavelengths in distinguishing the N treatment in olive. However, the study of foliar nitrogen in oil palm using spectral approach is still lacking in Malaysia. While Nguyen *et al*. (1995) used SPOT image to estimate macro and micro nutrients of oil palm. In a different study utilizing Landsat-5 TM image, Nor Azleen *et al*. (2003) tested three vegetation indexes including Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Atmospherically Resistant Vegetation Index (ARVI). The best accuracy is achieved by SAVI (91%) which also give the only positive correlation to foliar N content. However, the performance of the equation is limited by characteristics; site specific, need more effort to make it more accurate and insensitive to the small changes in foliar N contents.

While relative chlorophyll content measured using spectral techniques has been a major subject of study to examine N response in matured oil palm, there are few studies that explore the effects of indirect measurement of physiological parameters such as LAI, plant height and diameter in relation to oil palm N status. Thus, the objectives of this study are:

- To investigate potential multiple proximal sensors such as chlorophyll meter, LAI Plant Canopy Analyser, clinometer and spectroradiometer (exception of measuring tape for diameter) for estimating nitrogen nutritional content of matured oil palm
- To construct mathematical model for N detection in oil palm, based on results derived from the previous objective

MATERIALS AND METHODS

Study area: The study was carried out in oil palm plantation belonging to United Malacca Berhad located in Melaka Pinda, Malacca, Malaysia. Two plots of Tenera palms with different planting years were selected, 2005 (henceforth MP05; 2.377779°N and 102.265658°E) and 2002 (henceforth MP02; 2.380374°N and 102.238012°E). At the measurement time, the palm's age was 9 and 12 years, respectively. The study area included 147 and 148 standing palm per hectare (SPH) for field MP02 and MP05, respectively. In 2013, the total rainfall recorded was 1213 mm with average of 101.08 mm monthly. In early stage of this study, soil samples at depths of 0-15 cm were collected and analysed according to wet digestion method for N content in the soil.

Treatments: Ammonium Chlorite (AC) was applied as N fertilizer in four split applications which were made in November, March, Jun and September. There were three levels of N treatments, 0, 1 and 2 kg AC per palm. The application rate is based on the agronomic practices as implemented by the plantation to minimize disturbance to the palm. Other nutrients were applied as standard agronomic practices. The fertilizers were broadcast around the weeded circle as practiced by the estate.

Experimental design: The experiment was conducted in Randomized Completely Block Design (RCBD) design with 3 replications. Therefore, the experimental field comprises of a total of 18 subplots. The treatments were randomly assigned to each subplot and each subplot contained 16 uniform palms based on visual observation. The plots were carefully selected to ensure that the appearance and growth of the 16 palms were uniform.

Measurements: Two types of data was collected in this study which was physiology and spectral data. Physiology data included LAI, height, diameter, relative chlorophyll content and N tissue content. Intensive field measurements were conducted from 5th-10th February and 8th until 13th October in 2014. The average rainfall during intensive field measurement is shown in Fig. 1. Three and eight oil palm stands in each subplot were selected for physiological and spectral data measurements in February and October 2014, respectively. The LAI was measured on the selected palms using the LAI-2000 Plant Canopy Analyser. Readings were taken at 5 points which included 1 point for open sky and the rest 4 points is taken below canopy reading. The height and

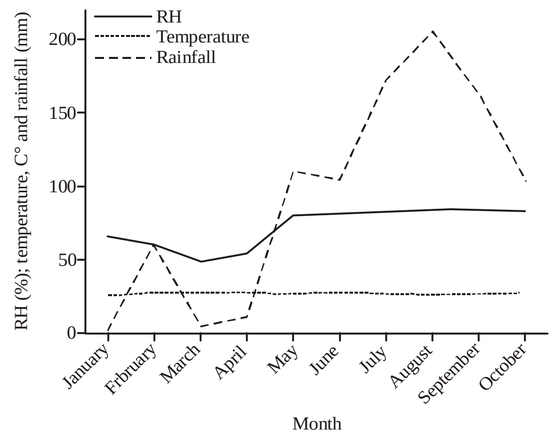

Fig. 1: Distribution of Relative Humidity (RH), temperature and rainfall od UMB estate

diameter were measured on each 3 and 8 selected palms within the subplot using clinometer and measurement tape, respectively. The clinometer measures the angle of the target which was the crown. Then the height is calculated using the Eq. 1:

$$\text{Height (m)} = (\tan^\circ * \text{distance}) + \text{height} \quad (1)$$

where, ° is the angle measured by clinometer, distance (m) is from palm base to the observer position, height is observer height from ground to eye level.

$$\text{Diameter} = \frac{\text{Circumference}}{3.14} \quad (2)$$

where, circumference is the measurement reading from tape.

The diameter was taken at breast height and calculated by Eq. 2. SPAD chlorophyll meter readings were measured on 6 leaflets from frond 17 for each previous selected palm by SPAD Minolta 502 and the readings were averaged. The leaflets chosen were at the end part of fronds located after the thorn position. The same leaflets were used for leaf N nutrient content analysis. The leaflets were oven dried at 70°C for 72 h then ground in the grinder. Then, the sample was analysed by conducting wet digestion using sulphuric acid and hydrogen peroxide for N determination (Miller and Miller, 1948).

Spectral data was collected using spectroradiometer GER 1500 model. It covers spectral wavelength from 350-1050 nm. The spectroradiometer was used to measure the 6 individual leaflets aforementioned that were detached from frond 17. The reflectance reading was taken from 2 h before and after solar noon during clear sky. The position of the fiber optic was ensured to be close enough to the sample so that it avoided the forecasted shadow. The spectroradiometer was calibrated using white spectralon. The data was imported to Microsoft Excel for further processing, where the average of blue, green, red and NIR reflectance were obtained by averaging reflectance of wavelengths ranging from 430-470, 530-570, 630-670 and 700-1100 nm, respectively.

Statistical analysis: The N effects on the ground data and spectral measurements were established by analysis of variance using PROC ANOVA in SAS software. The means were compared using Least Significant Difference (LSD) at 0.05 level of probability. Standard regression analysis was performed using PROC REG to analyse the relationship between the actual ground data and spectral data of N tissue content or N rate. Coefficient of determination (R^2) was used as metrics for measuring the relative amount of variations explained by the relationships and the efficiency of the indices. Standard correlation was conducted using PROC CORR to analyse the correlation between each parameters measured and N content.

RESULTS

Single model: Almost all single physiological and spectral models for both MP02 and MPO5 demonstrate weak regression below 0.500 to N rate and foliar N content, as presented in Table 1 and 2. In most of conditions, single physiological and spectral models give better relation with N rate compared to foliar N content regardless of age and sampling time. Only SPAD-N rate relationship in MP05 shows the highest regression of 0.661. Height shows consistency in N rate models while Height and Diameter is the most consistent model describing foliar N. For the spectral model, the highest R^2 with regard to N rate is shown by the Green (R^2 = 0.292) model of MP05 in October. All four spectral of MP02-foliar N models display the highest r^2 during October sampling.

Correlation: All physiological and spectral models with regard to age and sampling time demonstrated non-significant correlation to N rate and foliar N (Table 1 and 2). Again, only the SPAD-N rate relationship of MP05 shows strong significant correlation of r = 0.813. For MP02, correlation values for all physiological models to estimate foliar N measured in February severely decreased in October. On the other hand, the spectral models illustrated a contradict pattern where the correlation values were initially low in February but later increased in October. For MP05, there was no distinct pattern on correlation values for both N rate and foliar N models either for physiological or spectral models. Similar observation was made for MP02 for the N rate models.

Combination of single physiological or spectral model: Irrespective to age and sampling time, the combination of all physiological or spectral parameters consistently demonstrated the best relationship to N rate and foliar N content, as displayed in (Table 3 and 4). The best physiological model is LAI+SPAD+Height+Diameter (N rate = 0.389-0.767, foliar N = 0.183-0.798) while the spectral model is expressed as Blue+Green+Red+NIR (N rate = 0.407-0.742, foliar N = 0.242-0.766). In comparing the performance of the physiological model and spectral model for N rate and foliar N estimation, the latter depicted stronger relationship in many conditions.

Table 1: Linear regression and Pearson correlation coefficient between physiological and spectral parameters with N rate and foliar N for MP02 and MP05 in February

Fields and parameters	MP02 (R^2) N Rate	MP02 (R^2) Foliar N	MP02 (r) N Rate	MP02 (r) Foliar N	MP05 (R^2) N Rate	MP05 (R^2) Foliar N	MP05 (r) N Rate	MP05 (r) Foliar N
Physiological								
SPAD	0.002	0.036	0.049^{NS}	-0.190^{NS}	0.661	0.095	0.813**	-0.309^{NS}
LAI	0.009	0.072	0.097^{NS}	0.268^{NS}	0.129	0.026	0.359^{NS}	0.161^{NS}
Height	0.267	0.306	-0.517^{NS}	-0.553^{NS}	0.028	0.026	0.166^{NS}	0.161^{NS}
Diameter	0.126	0.091	-0.368^{NS}	0.302^{NS}	0.025	0.155	-0.159^{NS}	0.394^{NS}
Spectral								
Red	0.070	0.001	-0.264^{NS}	-0.022^{NS}	0.031	0.025	-0.175^{NS}	0.158^{NS}
NIR	0.001	0.190	0.035^{NS}	-0.435^{NS}	0.280	0.055	0.529^{NS}	0.234^{NS}
Green	0.088	0.001	-0.296^{NS}	-0.038^{NS}	0.061	0.021	-0.247^{NS}	0.145^{NS}
Blue	0.123	0.000	-0.351^{NS}	-0.014^{NS}	0.039	0.019	-0.198^{NS}	0.137^{NS}

NS: Non significant, **Significant at p = 0.05

Table 2: Linear regression and Pearson correlation coefficient between physiological and spectral parameters with N rate and foliar N for MP02 and MP05 in October

Fields and parameters	MP02 (R^2) N Rate	MP02 (R^2) Foliar N	MP02 (r) N Rate	MP02 (r) Foliar N	MP05 (R^2) N Rate	MP05 (R^2) Foliar N	MP05 (r) N Rate	MP05 (r) Foliar N
Physiological								
SPAD	0.113	0.004	0.336^{NS}	-0.063^{NS}	0.038	0.017	0.195^{NS}	-0.131^{NS}
LAI	0.181	0.040	0.426^{NS}	-0.201^{NS}	0.051	0.000	-0.227^{NS}	0.020^{NS}
Height	0.018	0.022	-0.136^{NS}	-0.147^{NS}	0.089	0.105	0.299^{NS}	0.324^{NS}
Diameter	0.107	0.068	0.327^{NS}	-0.261^{NS}	0.008	0.025	-0.087^{NS}	-0.158^{NS}
Spectral								
RED	0.056	0.430	-0.236^{NS}	0.655^{NS}	0.210	0.025	-0.459^{NS}	-0.157^{NS}
NIR	0.001	0.276	-0.032^{NS}	0.526^{NS}	0.090	0.010	-0.030^{NS}	0.101^{NS}
Green	0.121	0.302	-0.347^{NS}	0.549^{NS}	0.292	0.062	-0.541^{NS}	-0.249^{NS}
Blue	0.063	0.391	-0.250^{NS}	0.625^{NS}	0.180	0.044	-0.424^{NS}	-0.211^{NS}

NS: Non significant, **Significant at p = 0.05

Table 3: Linear regression coefficient for combination of physiological and spectral type for MP02 and MP05 in February

	MP02		MP05	
Fields and parameters	N Rate	Foliar N	N Rate	Foliar N
Physiological				
LAI+SPAD+Height+Diameter	0.389	0.566	0.767	0.450
LAI+Height+Diameter	0.388	0.561	0.135	0.369
SPAD+Height+Diameter	0.361	0.451	0.767	0.406
Height+Diameter	0.359	0.449	0.035	0.354
LAI+SPAD+Height	0.292	0.336	0.767	0.144
LAI+Height	0.268	0.327	0.131	0.033
SPAD+Height	0.291	0.313	0.767	0.106
LAI+SPAD+Diameter	0.147	0.294	0.720	0.404
LAI+Diameter	0.141	0.291	0.130	0.257
LAI+SPAD	0.011	0.114	0.710	0.143
SPAD+Diameter	0.140	0.101	0.691	0.255
Spectral				
Blue+Green+Red+NIR	0.719	0.512	0.407	0.242
Green+Red+NIR	0.147	0.462	0.392	0.222
Blue+Green+NIR	0.214	0.297	0.407	0.229
Blue+Red+NIR	0.340	0.288	0.357	0.234
Blue+NIR	0.161	0.287	0.335	0.227
Red+NIR	0.087	0.287	0.327	0.218
Green+NIR	0.101	0.262	0.301	0.221
Blue+Green+Red	0.595	0.016	0.230	0.065
Green+Red	0.138	0.015	0.183	0.028
Blue+Green	0.145	0.008	0.101	0.022
Blue+Red	0.300	0.002	0.081	0.062

Table 4: Linear regression coefficient for combination of physiological and spectral type for MP02 and MP05 in October

	MP02		MP05	
Fields and parameters	N Rate	Foliar N	N Rate	Foliar N
Physiological				
LAI+SPAD+Height+Diameter	0.460	0.183	0.552	0.798
LAI+Height+Diameter	0.422	0.171	0.550	0.750
SPAD+Height+Diameter	0.434	0.115	0.507	0.789
Height+Diameter	0.117	0.082	0.487	0.749
LAI+SPAD+Height	0.419	0.088	0.125	0.153
LAI+Height	0.213	0.069	0.122	0.111
SPAD+Height	0.418	0.082	0.105	0.153
LAI+SPAD+Diameter	0.404	0.182	0.087	0.038
LAI+Diameter	0.403	0.152	0.070	0.025
LAI+SPAD	0.199	0.043	0.064	0.019
SPAD+Diameter	0.196	0.069	0.056	0.035
Spectral				
Blue+Green+Red+NIR	0.522	0.766	0.742	0.397
Green+Red+NIR	0.518	0.751	0.591	0.375
Blue+Green+NIR	0.241	0.435	0.738	0.285
Blue+Red+NIR	0.106	0.442	0.390	0.216
Blue+NIR	0.106	0.405	0.181	0.212
Red+NIR	0.089	0.440	0.231	0.196
Green+NIR	0.193	0.347	0.322	0.263
Blue+Green+Red	0.513	0.766	0.742	0.394
Green+Red	0.505	0.749	0.513	0.373
Blue+Green	0.208	0.424	0.733	0.108
Blue+RED	0.063	0.430	0.252	0.169

It is found that N foliar estimation using both physiological and spectral models for both fields were affected by the sampling time. The R^2 values explaining the relationship to foliar N at first were low and moderate in February but increased to moderate and high values in October. However, an exception could be made to physiological model of MP02. For the N rate, it is observed that variation in sampling time did not affect the strength of the relationship. Although the LAI+SPAD+Height+Diameter and Blue+Green+Red+NIR models demonstrate the highest R^2, these models are applicable only to certain conditions. For e.g., the spectral model of MP02 is applicable to both N rate and foliar N but the application is restricted in February for N rate and in October for foliar N. The inconsistency in the application of different models is also observed for MP05, where the estimation of N rate is best done using the physiological model in February but in October, the spectral model is best implemented. Meanwhile, the physiological model is worth for foliar N estimation in October.

Combination of physiological and spectral model: Regardless to all conditions, the LAI+SPAD+Height+ Diameter+Blue+Green+Red+NIR is the perfect model to estimate both N rate and foliar N (Table 5-12). This model with all eight physiological and spectral parameters exhibited the highest $R^2 = 1.000$. Among the top five foliar N models, the models excluding SPAD display strong relationships to foliar N with R^2 values range from 0.930-1.000 as listed in (Table 5, 7, 9 and 11). For the N rate models, only MP02-February and MP05-October show strong relationships without the SPAD combination but for MP02-October and MP05-February, SPAD readings were required to achieve strong relationship ($R^2 = 0.949$-1.000).

Table 5: Linear regression coefficient for combination of physiological and spectral indices by Foliar N for MP02 in February

Parameters	Foliar N
LAI+SPAD+HEIGHT+Diameter+Blue+Green+RED+NIR	1.000
LAI+SPAD+Diameter+Blue+Green+Red+NIR	0.987
LAI+Height+Diameter+Blue+Green+Red+NIR	0.973
LAI+Height+Diameter+Green+Red+NIR	0.952
LAI+SPAD+Height+Diameter+Green+Red+NIR	0.952
LAI+SPAD+Diameter+Green+Red+NIR	0.941
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.933
LAI+SPAD+Height+Diameter+Red+NIR	0.932
LAI+SPAD+Height+Diameter+Blue+Green+NIR	0.922
LAI+SPAD+Height+Diameter+Green+NIR	0.920
LAI+Diameter+Blue+Green+Red+NIR	0.913
LAI+SPAD+Height+Diameter+Blue+NIR	0.911

Table 6: Linear regression coefficient for combination of physiological and spectral indices by N rate for MP02 in February

Parameters	N Rate
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+SPAD+Height+Diameter+Green+Red+NIR	0.999
LAI+Height+Diameter+Green+Red+NIR	0.999
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.978
LAI+SPAD+Height+Blue+Green+Red+NIR	0.970
LAI+SPAD+Height+Green+Red+NIR	0.970
LAI+Height+Green+Red+NIR	0.970
LAI+Height+Blue+Green+Red+NIR	0.970
LAI+SPAD+Height+Diameter+Red+NIR	0.961
LAI+SPAD+Height+Diameter+Blue+Green+NIR	0.960
LAI+SPAD+Height+Blue+Red+NIR	0.952
LAI+SPAD+Height+Diameter+Green+NIR	0.943
LAI+SPAD+Height+Blue+Green+NIR	0.934
LAI+SPAD+Height+Red+NIR	0.922
LAI+SPAD+Height+Green+NIR	0.902

Table 7: Linear regression coefficient for combination of physiological and spectral indices by Foliar N for MP05 in February

Parameters	Foliar N
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
SPAD+Height+Diameter+Blue+Green+Red+NIR	0.973
LAI+Height+Diameter+Blue+Green+Red+NIR	0.930
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.759

For estimating N rate or foliar N content, stem diameter is a must parameter in any top five models regardless of age

Table 8: Linear regression coefficient for combination of physiological and spectral indices by N rate for MP05 in February

Parameters	N Rate
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+SPAD+Diameter+Blue+Green+Red+NIR	1.000
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.999
LAI+SPAD+Height+Diameter+Blue+Green+NIR	0.998
LAI+SPAD+Diameter+Blue+Red+NIR	0.998
SPAD+Height+Diameter+Blue+Green+Red+NIR	0.996
SPAD+Height+Diameter+Blue+Red+NIR	0.996
SPAD+Diameter+Blue+Green+Red+NIR	0.996
LAI+SPAD+Height+Diameter+Blue+Green+Red	0.995
LAI+SPAD+Height+Diameter+Green+Red+NIR	0.994
LAI+SPAD+Height+Diameter+Green+Red	0.992
LAI+SPAD+Height+Blue+Green+Red+NIR	0.992
SPAD+Height+Blue+Green+Red+NIR	0.992
LAI+SPAD+Height+Blue+Red+NIR	0.991
SPAD+Height+Blue+Red+NIR	0.991
LAI+SPAD+Height+Diameter+Blue+Green	0.990
SPAD+Diameter+Blue+Red+NIR	0.988
SPAD+Height+Diameter+Blue+Green+NIR	0.988
SPAD+Height+Diameter+Blue+Green+Red	0.983
SPAD+Height+Diameter+Blue+Green	0.980
LAI+SPAD+Blue+Green+Red+NIR	0.979
SPAD+Height+Diameter+Green+Red+NIR	0.978
SPAD+Height+Diameter+Green+Red	0.977
LAI+SPAD+Blue+Red+NIR	0.976
SPAD+Blue+Green+Red+NIR	0.976
SPAD+Blue+Red+NIR	0.966
LAI+SPAD+Height+Diameter+Blue+NIR	0.964
LAI+SPAD+Height+Diameter+Blue+Red	0.960
LAI+SPAD+Height+Diameter+Blue	0.959
LAI+SPAD+Height+Blue+Green+NIR	0.954
LAI+SPAD+Diameter+Blue+Green+NIR	0.954
SPAD+Diameter+Blue+Green+NIR	0.953
SPAD+Height+Blue+Green+NIR	0.953
LAI+SPAD+Height+Diameter+Red+NIR	0.950
LAI+SPAD+Height+Diameter+Red	0.950
LAI+SPAD+Blue+Green+NIR	0.940
SPAD+Blue+Green+NIR	0.939
LAI+SPAD+Diameter+Blue+Green+Red	0.938
SPAD+Diameter+Blue+Green+Red	0.937
LAI+SPAD+Height+Blue+Green+Red	0.936
SPAD+Height+Blue+Green+Red	0.934
LAI+SPAD+Height+Blue+Green	0.934
SPAD+Height+Blue+Green	0.933
SPAD+Height+Diameter+Blue+Red	0.932
LAI+SPAD+Height+Green+Red+NIR	0.932
LAI+SPAD+Diameter+Blue+Green	0.932
LAI+SPAD+Height+Green+Red	0.930
SPAD+Diameter+Blue+Green	0.929
SPAD+Height+Diameter+Blue+NIR	0.929
SPAD+Height+Green+Red+NIR	0.928
SPAD+Height+Green+Red	0.927
SPAD+Height+Diameter+Blue	0.923
LAI+SPAD+Blue+Green+Red	0.915
SPAD+Blue+Green+Red	0.913
LAI+SPAD+Diameter+Blue+Red	0.913
LAI+SPAD+Blue+Green	0.912
SPAD+Diameter+Blue+Red	0.911
SPAD+Height+Diameter+Red+NIR	0.911
SPAD+Height+Diameter+Red	0.910
SPAD+Blue+Green	0.910
LAI+SPAD+Height+Blue+NIR	0.909

Table 9: Linear regression coefficient for combination of physiological and spectral indices by Foliar N for MP02 in October

Parameters	Foliar N
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+SPAD+Diameter+Blue+Green+Red+NIR	1.000
LAI+Height+Diameter+Blue+Green+Red+NIR	0.989
SPAD+Height+Diameter+Blue+Green+Red+NIR	0.979
LAI+SPAD+Height+Diameter+Blue+Green+Red	0.976
LAI+SPAD+Diameter+Blue+Green+Red	0.976
Height+Diameter+Blue+Green+Red+NIR	0.974
LAI+SPAD+Height+Diameter+Green+Red+NIR	0.973
SPAD+Height+Diameter+Green+Red+NIR	0.973
LAI+Height+Diameter+Blue+Green+Red	0.972
LAI+Height+Diameter+Green+Red+NIR	0.971
Height+Diameter+Green+Red+NIR	0.970
SPAD+Height+Diameter+Blue+Green+Red	0.964
LAI+SPAD+Height+Diameter+Green+Red	0.960
SPAD+Height+Diameter+Green+Red	0.960
LAI+SPAD+Height+Blue+Green+Red+NIR	0.957
LAI+SPAD+Height+Green+Red+NIR	0.957
LAI+Height+Diameter+Green+Red	0.957
Height+Diameter+Blue+Green+Red	0.955
Height+Diameter+Green+Red	0.954
LAI+SPAD+Height+Blue+Green+Red	0.946
LAI+SPAD+Height+Green+Red	0.945
SPAD+Height+Blue+Green+Red+NIR	0.940
SPAD+Height+Green+Red+NIR	0.936
LAI+Height+Blue+Green+Red+NIR	0.929
LAI+Height+Green+Red+NIR	0.929
SPAD+Height+Blue+Green+Red	0.928
Height+Blue+Green+Red+NIR	0.927
Height+Green+Red+NIR	0.926
SPAD+Height+Green+Red	0.926
LAI+SPAD+Diameter+Green+Red+NIR	0.917
LAI+Height+Blue+Green+Red	0.911
LAI+Height+Green+Red	0.911
Height+Blue+Green+Red	0.910
Height+Green+Red	0.910
LAI+SPAD+Diameter+Green+Red	0.909

Table 10: Linear regression coefficient for combination of physiological and spectral indices by N rate for MP02 in October

Parameters	N Rate
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+SPAD+Height+Diameter+Blue+Green+Red	0.962
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.949

Table 11: Linear regression coefficient for combination of physiological and spectral indices by foliar N for MP05 in October

Parameters	Foliar N
LAI+ SPAD+Height+Diameter+Blue+Green +Red +NIR	1.000
LAI +Height+Diameter+Blue+GREEN+Red+NIR	1.000
LAI +Height +Diameter +Blue+Green+Red	0.999
LAI +SPAD +Height+Diameter+Blue+Green+Red	0.999
LAI+SPAD+Height+Diameter+Green+Red+NIR	0.998
LAI+Height+Diameter+Green+Red+NIR	0.998
LAI+SPAD+Height+Diameter+Green+Red	0.994
LAI+Height+Diameter+Green+Red	0.993
SPAD+Height+Diameter+Blue+Green+Red+NIR	0.939
SPAD+Height+Diameter+Blue+Green+Red	0.939
LAI+SPAD+Height+Diameter+Blue+Green+NIR	0.928
SPAD+Height+Diameter+Blue+Green+NIR	0.928
LAI+SPAD+Height+Diameter+Blue+Green	0.921
SPAD+Height+Diameter+Blue+Green	0.919
Height+Diameter+Blue+Green+Red+NIR	0.906
Height+Diameter+Blue+Green+Red	0.903

Table 12: Linear regression coefficient for combination of physiological and spectral indices by N rate for MP05 in October

Parameters	N Rate
LAI+SPAD+Height+Diameter+Blue+Green+Red+NIR	1.000
LAI+Height+Diameter+Blue+Green+Red+NIR	0.985
LAI+SPAD+Height+Diameter+Blue+Green+Red	0.977
LAI+SPAD+Height+Diameter+Blue+Red+NIR	0.975
LAI+Height+Diameter+Blue+Red+NIR	0.974
LAI+Height+Diameter+Blue+Green+Red	0.967
LAI+SPAD+Height+Diameter+Blue+Red	0.961
LAI+Height+Diameter+Blue+Red	0.961
LAI+SPAD+Height+Blue+Green+Red+NIR	0.933
LAI+Height+Blue+Green+Red+NIR	0.929
LAI+SPAD+Height+Blue+Green+Red	0.916
SPAD+Height+Diameter+Blue+Green+Red+NIR	0.910
LAI+Height+Blue+Green+Red	0.909
SPAD+Height+Blue+Green+Red+NIR	0.909
Height+Diameter+Blue+Green+Red+NIR	0.903

and sampling times. For foliar N models, diameter, green and red are required in the combination of high R^2 models. However, for effective N rate models, LAI and height are essential additional besides diameter.

DISCUSSION

Single model: From the result, all single models neither physiological nor spectral are efficient for N rate or foliar N estimation in matured oil palm with the exception of SPAD-N rate model of MP05. However, the SPAD-N rate model is not applicable to all conditions as the model is restricted to age and time. SPAD has been utilized in N detection for oil palm seedling (Law *et al*., 2014); while the result from this study shows that the sensor is incompetent for matured oil palm with an exception to MP05. This may be due to variation in SPAD reading related to leaf age as supported by Percival *et al.* (2008). Besides, there was poor responses between N applied and foliar N which may influence the SPAD reading. Furthermore, the N status of plant affect the SPAD reading (Netto *et al*., 2005). Secondary factors such as leaf thickness (Campbell *et al*., 1990), varieties (Law *et al*., 2014), chlorophyll or foliar N distribution and sampling season (Chang and Robison, 2003) and complex sink-source of N partitioning (Loh *et al*., 2002) were also influencing SPAD performance. Although there is limitation in using SPAD but the application is near to real time and better than the expensive foliar analysis in monitoring N.

The Green model shows consistency to N rate model even though the value is low. The Green N rate-model can be applied if a single parameter have to be used in estimation of N as many authors found the used of green wavelengths gave positive results in N estimation. Gitelson *et al.* (2003) reported the reciprocal reflectance of green band (520-550 nm) was sensitive to chlorophyll content of beech, wild vine, maple and chestnut. Datt (1998) also reported that model based on green and NIR was sensitive to different ranges of chlorophyll content among Eucalyptus species.

Combination of single physiological or spectral model: This model displays better R^2 values compared to single model. LAI+SPAD+Height+Diameter and Blue+Green+Red+NIR models can be used for N rate or foliar N estimation in matured oil palm. In most of conditions, both physiological and spectral model shows moderate to strong relationship to foliar N or N rate in younger oil palm (MP05) compared to older oil palm (MP02). Thus, the age factor contributed in differences of N estimation in oil palm. This finding is concurrent with Hartley (1988) and Foster (2003) that reported foliar N concentration in oil palm decreased with age. Similar observation was also made by Kamau *et al.* (2008) in tea plantation. According to Sari *et al.* (2006), the accurate result from spectral properties is the reflection of the internal and external structure of plants which are age and growth stages dependent.

The sampling time affected either the foliar N or N rate estimation models regardless to palm age. Most of N foliar models display higher R^2 in October may cause by contribution of high Relative Humidity (RH) and rainfall. The RH above 75% throughout the year are favorable for optimum oil palm growth (Verheye, 2010; Carr, 2011). Meanwhile in February, low RH and less than 65 mm rainfall were recorded in Fig. 1. Besides, there was water scarcity during the sampling time as there was little rainfall in January, February and March consecutively. Thus, this low RH increased transpiration in palm and also inadequate water for root uptake during the transpiration process that leads to partial or full stomatal closure (Smith, 1989). The closure of stomata will block the entry of CO_2, eventually disturbed the photosynthesis and others physiological process in the palm. Hence, sampling time must be taken for consideration during data collection.

Generally, the spectral model demonstrated strong relation to N rate or foliar N in most conditions. Numerous studies have been conducted using spectral responses and have been used widely in many crops for N prediction (Davenport *et al.*, 2005; Alchanatis *et al.*, 2005; Suarez and Berni, 2012). In addition, integration of multiple spectral bands from the visible and NIR bands in a model do increase the probability of model succession especially for wide range species (Blackburn, 2007). However, implementation of these models also constrained to sampling time and palm age.

Mostly, N rate models demonstrated better result rather than foliar N models in estimation of N in matured oil palm regardless of sampling time and age. The differences in foliar N estimation are related to N uptake and the complex sink-source relationship of N allocation within perennial crops. The N uptake in oil palm corresponded with age (Von Uexkull and Fairhurst, 1991) , varieties (Law *et al.*, 2012), length and distribution of functional root system (Corley and Tinker, 2003). Besides, factors such as age and plant genotype (Osaki *et al.*, 1993), N supply (Millard and Neilsen, 1989), light and temperature (Muller *et al.*, 2005) influenced the allocation of N in crops. Therefore, these factors may cause the difference in foliar N models.

Combination of physiological and spectral model: Combination of both physiological and spectral information has yielded the perfect model since the N allocation in palm is distributed all over the palm organs such as stem, roots and rachis (Ng *et al.*, 1968). Thus, the model that accommodates all of N sinks is appropriate to estimate N content of matured oil palm. Spectral model alone, for instance, is not efficient in estimating N as the spectral model is characterized by the variations of N that is only available at the foliar level.

Combination of single and physiological model with exclusion of SPAD frequently displayed strong relationship with foliar N. Spectroradiometer have the ability to compensate the function of SPAD in N estimation. Regarding to information availability, only single index value is obtained from SPAD whereas the spectroradiometer provided a lot of information from the reflectance reading. SPAD only covers in red (640 nm) and NIR (940 nm) region (Munoz-Huerta *et al.*, 2013) whereas, spectroradiometer spans visible and NIR region. A blue and red wavelength was well-known to be sensitive to chlorophyll absorption while the green wavelength reflects the health status of plant (Reddy and Matcha, 2010). Meanwhile, the NIR wavelength associates with the leaf structure such as spongy mesophyll cell which give the information about the plant stress or senescence (Knipling, 1970).

Diameter is important parameters in all top five of foliar N or N rate models as it contribute to the perfectness of N estimation models although it was not measured by proximal sensor. Diameter was found to relate better with N estimation than the SPAD, LAI and height in mature oil palm. Due to close relation between diameter and height, the height can be estimated through diameter by using allometric relationships. There was strong relationship between height and diameter as reported by Avsar (2004) in pines tree and later supported with finding by Avsar and Ayyildiz (2005) in cedar trees.

CONCLUSION

In conclusion, results of this study displayed the combination of physiological and spectral models fit the best either for N rate or foliar N estimation of matured oil palm irrespectively to sampling time and age. The limitation of SPAD in this study makes the application optional. Without SPAD, the models are still feasible to estimate N in matured oil palm. On other hand, the single and combination of single physiological or spectral models are age and sampling time dependant. Nevertheless, Diameter or Green model is applicable if only single parameter is available for N estimation but the expected result of R^2 will be relatively low. In this study, the N rate models display good result compared to foliar N model.

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REFERENCES

Alchanatis, V., Z. Schmilovitch and M. Meron, 2005. In-field assessment of single leaf nitrogen status by spectral reflectance measurements. Precis. Agric., 6: 25-39.

Avsar, M.D., 2004. The relationships between diameter at breast height, tree height and crown diameter in Calabrian pines (Pinus brutia Ten.) of Baskonus Mountain, Kahramanmaras, Turkey. J. Biol. Sci., 4: 437-440.

Avsar, M.D. and V. Ayyildiz, 2005. The relationships between diameter at breast height, tree height and crown diameter in Lebanon cedars (Cedrus libani A. Rich.) of the Yavsan Mountain, Kahramanmaras, Turkey. Pak. J. Biol. Sci., 8: 1228-1232.

Awal, M.A. and W.I. Wan Ishak, 2008. Measurement of oil palm Lai by manual and LAI-2000 method. Asian J. Scient. Res., 1: 49-56.

Behera, S.K., P. Srivastava, U.V. Pathre and R. Tuli, 2010. An indirect method of estimating leaf area index in *Jatropha curcas* L. using LAI-2000 plant canopy analyzer. Agric. For. Meteorol., 150: 307-311.

Blackburn, G.A., 2007. Hyperspectral remote sensing of plant pigments. J. Exp. Bot., 58: 855-867.

Blackmer, T.M., J.S. Schepers and G.E. Varvel, 1994. Light reflectance compared with other nitrogen stress measurements in corn leaves. Agron. J., 86: 934-938.

Campbell, R.J., K.N. Mobley, R.P. Marini and D.G. Pfeiffer, 1990. Growing conditions alter the relationship between SPAD-501 values and apple leaf chlorophyll. Hortscience, 25: 330-331.

Carr, M.K.V., 2011. The water relations and irrigation requirements of oil palm (*Elaeis guineensis*): A review. Exp. Agric., 47: 629-652.

Chang, S.X. and D.S. Robison, 2003. Nondestructive and rapid estimation of hardwood foliar nitrogen status using the SPAD-502 chlorophyll meter. For. Ecol. Manage., 181: 331-338.

Corley, R.H.V. and C.K. Mok, 1972. Effects of nitrogen, phosphorus, potassium and magnesium on growth of the oil palm. Exp. Agric., 8: 347-353.

Corley, R.H.V. and P.B.H. Tinker, 2003. Mineral Nutrition of the Oil Palm. In: The Oil Palm, Corley, R.H.V. and P.B.H. Tinker (Eds.). 4th Edn., Chapter 11, Blackwell Science Ltd., Oxford, ISBN-13: 9780470750360, pp: 327-389.

Datt, B., 1998. Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a+b and total carotenoid content in eucalyptus leaves. Remote Sens. Environ., 66: 111-121.

Davenport, J.R., R.G. Stevens, E.M. Perry and N.S. Lang, 2005. Leaf spectral reflectance for nondestructive measurement of plant nutrient status. Horttechnology, 15: 31-35.

Ewert, F., 2004. Modelling plant responses to elevated CO2: How important is leaf area index? Ann. Bot., 93: 619-627.

Foster, H.L., 2003. Assessment of Oil Palm Fertilizer Requirements. In: The Oil Palm: Management for Large and Sustainable Yields, Fairhurst, T.H. and R. Hardter (Eds.). Potash and Phosphate Institute of Canada, Canada, pp: 231-257.

Ghasemi, M., K. Arzani, A. Yadollahi, S. Ghasemi and S.S. Khorrami, 2011. Estimate of leaf chlorophyll and nitrogen content in Asian pear (*Pyrus serotina* Rehd.) by CCM-200. Notulae Scientia Biologicae, 3: 91-94.

Gitelson, A.A., Y. Gritz and M.N. Merzlyak, 2003. Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. J. Plant Physiol., 160: 271-282.

Goh, K.J., R. Hardter and T.H. Fairhurst, 2003. Fertilizing for Maximum Return. In: The Oil Palm: Management for Large and Sustainable Yields, Fairhurst, T.H. and R. Hardter (Eds.). Potash and Phosphate Institute of Canada, Canada, pp: 279-306.

Goh, K.J. and R. Hardter, 2003. General Oil Palm Nutrition. In: Oil Palm: Management for Large and Sustainable Yields, Fairhurst, T. (Eds.). Potash and Phosphate Institute, Singapore, pp: 191-230.

Goh, K.J. and S.B. Po, 2005. Fertilizer Recommendation Systems for Oil Palm: Estimating the Fertilizer Rates. In: MOSTA Best Practices Workshops 2004: Proceedings of Agronomy and Crop Management, 27 March-14 August 2004, Chew, P.S. and Y.P. Tan (Eds.). Malaysian Oil Scientists and Technologists Association, Malaysia, ISBN-13: 9789834262501, pp: 235-268.

Gomez-Casero, M.T., F. Lopez-Granados, J.M. Pena-Barragan, M. Jurado-Exposito, L. Garcia-Torres and R. Fernandez-Escobar, 2007. Assessing nitrogen and potassium deficiencies in olive orchards through discriminant analysis of hyperspectral data. J. Am. Soc. Horticult. Sci., 132: 611-618.

Gul, H., A.M. Khattak and N. Amin, 2006. Accelerating the growth of (*Araucaria heterophylla*) seedlings through different gibberellic acid concentrations and nitrogen levels. J. Agric. Biol. Sci., 1: 25-29.

Hartley, C.W.S., 1988. The Oil Palm. 3rd Edn., Longman Scientific and Technical, London, UK., ISBN-13: 9780582404007, Pages: 761.

Jifon, J.L., J.P. Syvertsen and E. Whaley, 2005. Growth environment and leaf anatomy affect nondestructive estimates of chlorophyll and nitrogen in *Citrus* sp. leaves. J. Am. Soc. Horticult. Sci., 130: 152-158.

Kamau, D.M., J.H.J. Spiertz and O. Oenema, 2008. Carbon and nutrient stocks of tea plantations differing in age, genotype and plant population density. Plant Soil, 307: 29-39.

Knipling, E.B., 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sens. Environ., 1: 155-159.

Law, C.C., A.R. Zaharah, M.H.A. Husni and A.S.N. Akmar, 2012. Evaluation of Nitrogen uptake efficiency of different oil palm genotypes using ^{15}N isotope labelling method. Pertanika J. Trop. Agric. Sci., 35: 743-754.

Law, C.C., A.R. Zaharah, M.H.A. Husni and A.S.N. Akmar, 2014. Leaf nitrogen content in oil palm seedlings and their relationship to SPAD chlorophyll meter readings. J. Oil Palm Environ. Health, 5: 8-17.

Liu, Z.A., J.P. Yang and Z.C. Yang, 2012. Using a chlorophyll meter to estimate tea leaf chlorophyll and nitrogen contents. J. Soil Sci. Plant Nutr., 12: 339-348.

Loh, F.C.W., J.C. Grabosky and N.L. Bassuk, 2002. Using the SPAD 502 meter to assess chlorophyll and nitrogen content of Benjamin Fig and Cottonwood leaves. HortTechnology, 12: 682-686.

MPOC., 2014. The oil palm tree. Malaysian Palm Oil Council (MPOC), Malaysia. http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx.

Millard, P. and G.H. Neilsen, 1989. The influence of nitrogen supply on the uptake and remobilization of stored N for the seasonal growth of apple trees. Ann. Bot., 63: 301-309.

Miller, G.L. and E.E. Miller, 1948. Determination of nitrogen in biological materials. Anal. Chem., 20: 481-488.

Min, M. and W.S. Lee, 2005. Determination of significant wavelengths and prediction of nitrogen content for citrus. Trans. ASAE., 48: 455-461.

Muller, O., K. Hikosaka and T. Hirose, 2005. Seasonal changes in light and temperature affect the balance between light harvesting and light utilisation components of photosynthesis in an evergreen understory shrub. Oecologia, 143: 501-508.

Munoz-Huerta, R.F., R.G. Guevara-Gonzalez, L.M. Contreras-Medina, I. Torres-Pacheco, J. Prado-Olivarez and R.V. Ocampo-Velazquez, 2013. A review of methods for sensing the nitrogen status in plants: Advantages, disadvantages and recent advances. Sensors, 13: 10823-10843.

Neto, C.B., C. Carranca, J. Clemente and A. de Varennes, 2011. Assessing the nitrogen nutritional status of young non-bearing Rocha pear trees grown in a Mediterranean region by using a chlorophyll meter. J. Plant Nutr., 34: 627-639.

Netto, A.T., E. Campostrini, J.G. de Oliveira and R.E. Bressan-Smith, 2005. Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Scientia Horticulturae, 104: 199-209.

Ng, S.K., S. Thamboo and P. de Souza, 1968. Nutrient contents of oil palms in Malaysa. II. Nutrients in vegetative tissues. Malaysian Agric. J., 46: 332-391.

Nguyen, H.V., E. Lukman, J.P. Caliman and A. Flori, 1995. Spot Image as a Visual Tool to Assess Sanitary, Nutrient and General Status of Estate Oil Palm Plantation. In: Proceedings of the 1993 PORIM International Palm Oils Congress, Agriculture, Jalani, B.S. (Ed.). Palm Oil Research Institute, Kuala Lumpur, Malaysia, pp: 548-554.

Noor, M.R.M. and M.H. Harun, 2004. The role of Leaf Area Index (LAI) in oil palm. Oil Palm Bull., 48: 11-16.

Noor, M.R.M., M.H. Harun, S.N.A. Mustakin, A. Badrishah and M. Ahmad, 2002. Indirect methods for measuring oil palm Leaf Area Index (LAI). MPOB Information Series No. 147, MPOB TT No. 130, Malaysian Palm Oil Board (MPOB), Ministry of Primary Industries, Malaysia, May 2002.

Nor Azleen, A.R., B.O. Wahid, A.M Tarmizi and W. Basri, 2003. Remote sensing for oil palm foliar nitrogen. MPOB Information Series No. 190, MPOB TT No. 177, Malaysian Palm Oil Board, Ministry of Primary Industries, Malaysia, June 2003.

Nyi, N., W. Sridokchan, W. Chai-arree and P. Srinives, 2012. Nondestructive measurement of photosynthetic pigments and nitrogen status in Jatropha (*Jatropha curcas* L.) by chlorophyll meter. Philippine Agric. Scientist, 95: 139-145.

Osaki, M., K. Morikawa, M. M atsumoto, T. Shinano, M. Iyoda and T. Tadano, 1993. Productivity of high-yielding crops. Soil Sci. Plant Nutr., 39: 399-408.

Owolabi, J.F., E. Opoola, M. Taiwo, I.D. Foby and J.D. Olarewaju, 2013. Effect of poultry manure on the growth and development of oil palm (*Elaeis guineensis* L.) seedling in a screen house. Standard Scient. Res. Essays, 2: 1-4.

Percival, G.C., I.P. Keary and K. Noviss, 2008. The potential of a chlorophyll content SPAD meter to quantify nutrient stress in foliar tissue of sycamore (*Acer pseudoplatanus*), English oak (*Quercus robur*) and European beech (*Fagus sylvatica*). Arboricult. Urban For., 34: 89-100.

Perry, E.M. and J.R. Davenport, 2007. Spectral and spatial differences in response of vegetation indices to nitrogen treatments on apple. Comput. Electron. Agric., 59: 56-65.

Peryea, F.J. and R. Kammereck, 1997. Use of Minolta SPAD-502 chlorophyll meter to quantify the effectiveness of mid summer trunk injection of iron on chlorotic pear trees. J. Plant Nutr., 20: 1457-1463.

Pestana, M., A. de Varennes, J. Abadia and E.A. Faria, 2005. Differential tolerance to iron deficiency of citrus rootstocks grown in nutrient solution. Scientia Horticulturae, 104: 25-36.

Peterson, T.A., T.M. Blackmer, D.D. Francis and J.S. Schepers, 1993. Using a Chlorophyll Meter to Improve N Management. Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, USA., pp: 4.

Pierce, L.L., S.W. Running and J. Walker, 1994. Regional-scale relationships of leaf area index to specific leaf area and leaf nitrogen content. Ecol. Applic., 4: 313-321.

Pinkard, E.A., V. Patel and C. Mohammed, 2006. Chlorophyll and nitrogen determination for plantation-grown *Eucalyptus nitens* and *E. globulus* using a non-destructive meter. For. Ecol. Manage., 223: 211-217.

Pocock, M.J., D.M. Evans and J. Memmott, 2010. The impact of farm management on species-specific Leaf Area Index (LAI): Farm-scale data and predictive models. Agric. Ecosyst. Environ., 135: 279-287.

Reddy, K.R. and S.K. Matcha, 2010. Remote sensing algorithms for castor bean nitrogen and pigment assessment for fertility management. Ind. Crops Prod., 32: 411-419.

Sari, M., N.K. Sonmez and M. Karaca, 2006. Relationship between chlorophyll content and canopy reflectance in Washington navel orange trees (*Citrus sinensis* L.) Osbeck). Pak. J. Bot., 38: 1093-1102.

Schaper, H. and E.K. Chacko, 1991. Relation between extractable chlorophyll and portable chlorophyll meter readings in leaves of eight tropical and subtropical fruit- tree species. J. Plant Physiol., 138: 674-677.

Shaahan, M.M., A.A. El-Sayed and E.A.A. Abou El-Nour, 1999. Predicting nitrogen, magnesium and iron nutritional status in some perennial crops using a portable chlorophyll meter. Scientia Horticulturae, 82: 339-348.

Simorte, V., G. Bertoni, C. Dupraz and P. Masson, 2001. Assessment of nitrogen nutrition of walnut trees using foliar analysis and chlorophyll measurements. J. Plant Nutr., 24: 1645-1660.

Smith, B.G., 1989. The effects of soil water and atmospheric vapour pressure deficit on stomatal behaviour and photosynthesis in the oil palm. J. Exp. Bot., 40: 647-651.

Suarez, L. and J.A.J. Berni, 2012. Spectral Response of Citrus and their Application to Nutrient and Water Constraints Diagnosis. In: Advances in Citrus Nutrition, Srivastava, A.K. (Ed.). Springer Science and Business Media, Dordrecht, ISBN-13: 9789400741713, pp: 125-142.

Turnbull, T.L., N. Kelly, M.A. Adams and C.R. Warren, 2007. Within-canopy nitrogen and photosynthetic gradients are unaffected by soil fertility in field-grown *Eucalyptus globulus*. Tree Physiol., 27: 1607-1617.

Uwumarongie-Ilori, E.G., B.B. Sulaiman-Ilobu, O. Ederion, A. Imogie, B.O. Imoisi, N. Garuba and M. Ugbah, 2012. Vegetative growth performance of oil palm (*Elaeis guineensis*) seedlings in response to inorganic and organic fertilizers. Greener J. Agric. Sci., 2: 26-30.

Verheye, W., 2010. Growth and Production of Oil Palm. In: Land Use, Land Cover and Soil Sciences. Encyclopedia of Life Support Systems (EOLSS), Verheye, W. (Ed.). UNESCO-EOLSS Publishers, Oxford, UK.

Von Uexkull, H.R. and T.H. Fairhurst, 1991. Fertilizing for High Yield and Quality: The Oil Palm. International Potash Institute, Bern, Switzerland, Pages: 79.

Wahid, M.B., S.N.A. Abdullah and I.E. Henson, 2005. Oil palm: Achievements and potential. Plant Prod. Sci., 8: 288-297.