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Research Article
Nitrogen Effects on Growth and Spectral Characteristics of Immature and Mature Oil Palms

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Abstract

Background and Objective: Nitrogen (N) plays crucial roles in sustain ability of oil palm (*Elaeis guineensis*) production, environmentally and economically. Adequate nutrient supply especially N is the most important in producing high yield oil palm. However, assessing N status of tall perennial crops such as oil palm is complex and not straightforward in comparison to annual crops due to complex nitrogen partitioning and age. The objectives of this study were to examine growth and spectral responses of N fertilization on different oil palm's growth stages; immature, young mature and prime mature and compare foliar N content and relative chlorophyll content as indicators of oil palm N status. **Methodology:** Nitrogen fertilization rates applied were varied from 0-2 kg N/palm/year according to the growth stages requirements. Growth and spectral parameters measured for this study included height, diameter, leaf area index (LAI) and spectral reflectance in visible and near infra-red (NIR) regions measured from a ground spectro radiometer and satellite images. For statistical analysis, one-way analysis of variance (ANOVA) and correlation analysis were conducted. **Results:** The results illustrated that growth and spectral parameters responses were age-dependent, primarily due to different allocation of nitrogen as the palms matured. Correlation analysis indicated that the spectral parameter was more sensitive to foliar nitrogen, especially ones that were acquired from satellite images and therefore have potential in predicting N nutrition status of oil palm. **Conclusion:** Foliar N content was found to be less influenced by the palm growth stages, while relative chlorophyll content measured using the SPAD meter should be carefully interpreted along the palm age.

Key words: Oil palm, foliar nitrogen, spectral reflectance, remote sensing, proximal sensing

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Oil palm is an important source of oils and fats since its price is more affordable and is capable to produce about four folds of oil yield/hectare compared to other oil crops such as soybean, sunflower and rapeseed[1]. There are several factors that contribute to high yield of oil palm such as good agronomic practices, adequate nutrient supply, planting material and climate[2-4]. Among the aforementioned factors, adequate nutrient supply especially Nitrogen (N) is the most important in producing high yield oil palm. Nitrogen is a component of many essential organic compounds such as amino acid, proteins and nucleic acids that plays important roles in many physiological processes including photosynthesis, respiration and transpiration[5]. The N application has been reported to influence the palm height[6], chloroplast development, leaf area index (LAI), susceptibility to pest and disease and consequently, bunch and oil quality[5].

Nitrogen use efficiency (NUE) of oil palms depends on several factors, such as age, plant species, type of soil, timing of application and methods of fertilizer placement[3]. Losses of N are caused by leaching, surface run off, denitrification, volatilization and ammonium fixation by clay minerals and strongly affect nutrient uptake[5]. Generally, N deficiency was shown to cause stunted palms and yellowing of leaves. Necrosis results if deficiency is severe. Inadequate N supply also may delay crop production up to 36 months[5]. In contrast, excessive N application not only causes economic loss and environment pollution but also can result in reduction of bunch yield. N application beyond the optimal limit has been found to restrict micro nutrient uptake, such as boron and increase the occurrence of leaf-eating pests, such as caterpillars and bagworms[5].

In oil palm production, fertilizer accounts for the largest portion of production costing[7]. The prices of the fertilizers are unstable and fluctuate from time to time. For example, the price of urea skyrocketed from USD 84.29 in 1993 to USD 316.21/metric ton in 2014[8]. The excessive application of fertilizers is not only harmful to the environment but also represents economic loss. Based upon Goh and Po[9], current estimation shows that the oil palm industry will save USD 56 million/year if only an extra ammonium nitrate of 0.25 kg/palm/year can be avoided. Thus, it is vital to estimate the optimal requirement of N for plant uptake in order to sustain the environment and the industry itself.

As a perennial crop with a 25 years life-cycle, predicting N status of oil palm is difficult. Many factors can hinder precise and accurate prediction, such as complex N partitioning, age, light interception, soil properties, planting materials and fertilizer treatments[4]. Additionally, biomass was tested as an indicator of NUE that reflects the distribution of assimilates among the vegetative parts of the plant and indirectly provides information about the N content. However, the fresh, above ground biomass of mature oil palm weighs on average between 594 and 728 kg, which includes the palm trunk, leaflets, rachis, spears, cabbage and frond bases[3]. This weight makes this crop parameter inconvenient as an NUE indicator. On the other hand, leaf production rate is low during the early time of planting and increases with age, becoming constant after palms reach an age between 8 and 12 years[4]. Although N increases the leaf area, the effect of N is confounded in the mature palm because the distribution of N to the leaflets will gradually decrease as a result of the increased amount of N that will be allocated to the trunk. This processes subsequently increases palm height[10].

Conventionally, foliar analysis is the mostly applied method to assess N status of oil palm. However, this practice is impractical for large plantation companies because the procedures are time consuming, labor intensive and expensive. The availability of modern technologies such as remote sensing (RS) has created opportunities to implement this technology to assess foliar nutrients. Remote sensing is a technique that collects information of an object from the surface of earth without any physical contact using sensors such as aerial photography, radar and satellite imaging. This technique manipulated spectral data received by the sensor as each object reflects unique spectrum of wavelength which can be interpreted as spectral signature. This technique is reliable, cost effective and non-destructive. Numerous efforts towards remote sensing approach in study of plant have been done for annual crops such as corn, wheat, cotton and rice.

Few efforts have been made to study foliar N in oil palm using this approach in Malaysia. While Nguyen *et al.*[11] use RS to estimate macro and micro nutrients of oil palm, Nor Azleen[12] use RS to detect N content of oil palm. In a different study utilizing Landsat-5 TM image, Nor Azleen *et al.*[13] tested three vegetation indexes including Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Atmospherically Resistant Vegetation Index (ARVI). They reported that only SAVI performed the best with the accuracy of $R^2 = 0.91$. However, this study was conducted on 23 years oil palms that are closed to replanting age. In order to explore the potential of significant growth and spectral parameters that could be utilized for monitoring N content of multi-ages oil palms, this study was conducted with the following objectives:

- To assess the growth and spectral response (from leaf and canopy levels) of N fertilization on different growth stages of oil palm

- To compare foliar N content and relative chlorophyll content as indicators of oil palm N status, especially as affected by the growth and spectral parameters of immature and mature oil palms

MATERIALS AND METHODS

Nursery experiment for immature oil palms: The experiment was conducted at Field 10, Faculty of Agriculture, Universiti Putra Malaysia (2.990298°N and 101.715406°E), designed using a Randomized Complete Block Design (RCBD) with six levels of N treatments, four replications and three samples for each replication. The treatments selected for this study were 0.011, 0.021, 0.032, 0.042, 0.053 and 0.063 kg N. In this experiment, each of the *Tenera* seedling was grown with a mixture of 16 kg of Munchong series soil (Xanthic Hapludox) and were arranged in a triangular planting design (Fig. 1) with a planting distance of 90×90 cm. Nitrogen fertilizer was applied to the seedlings through thirteen split applications by applying the fertilizer into the pocket around the seedlings.

The growth and spectral data collection was made when the seedlings were 13 months old. Measurements of plant height were carried out by measuring the height from the base of the bole to the tip of the longest of the first upper five fronds by using a measuring tape. For the measurement of bole diameter, a vernier caliper was used to measure the East-West and North-South direction width and these two readings were then averaged. A SPAD chlorophyll meter (Minolta Corporation, Japan) was utilized to measure relative chlorophyll content of four leaflets sampled from the middle part of the third frond. Further, these leaflets were detached and scanned for leaf area using a LI-3100C Leaf Area Meter (LI-COR Inc., USA). The LAI of immature stage were calculated using Eq. 1a[14]:

$$\text{LAI} = \left(\frac{\text{A} \times \text{F}}{\text{CA}}\right) \quad (1a)$$

where, A is the leaf area of frond 3 (m^2), F is the number of frond/palm and CA is the canopy area (m^2), calculated using Eq. 1b[15] as illustrated in Fig. 1:

$$\begin{aligned} \text{h} &= 0.5\text{a} \tan 60° \\ &= 0.866\text{a} \\ \text{Area } \Delta &= 0.5 \times \text{a} \times 0.866\text{a} \\ &= 0.433\text{a}^2 \\ \text{CA (m}^2) \triangledown\!\!\!\!\triangle &= 0.433 \times 2 \\ &= 0.866\text{a}^2 \end{aligned} \quad (1b)$$

For the foliar N, all the leaflets were oven-dried at 65°C for 24 h, grinded and determined for the total N (%) using a LECO TruMac Series CNS Carbon/Nitrogen/Sulfur analyzer instrument, LECO, USA.

Spectral measurements were made by using the GER 1500 spectro radiometer (Spectra Vista Corp., Poughkeepsie, NY, USA) connected to a fiber optic. The spectro radiometer covers the spectral wavelength from 350-1050 nm. Reflectance measurements were confined to clear days and 2 h before and after local solar noon. The spectro radiometer was calibrated using a white reference panel prior to leaf spectral reflectance measurement and the fiber optic was positioned closely to the leaflets. Leaf reflectance spectra were calculated by dividing leaf radiance with reference radiance from the calibration panel. Then, the reflectance from 350- 1050 nm were grouped into $\text{blue}_{\text{leaf}}$, $\text{green}_{\text{leaf}}$, red_{leaf}

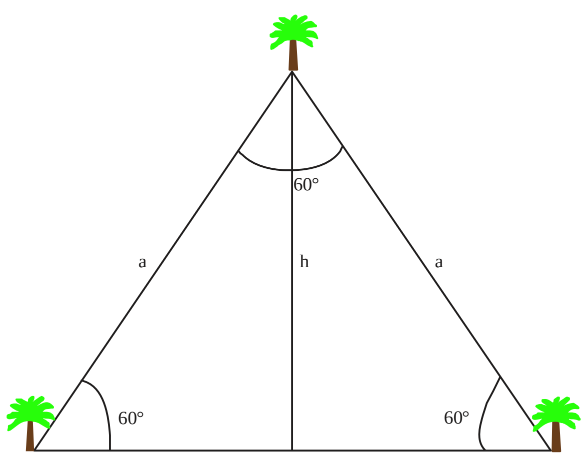

Fig. 1: Triangulation used to arrange the oil palm seedlings and thus to calculate the canopy area. The ‘a’ is the planting distance between palms

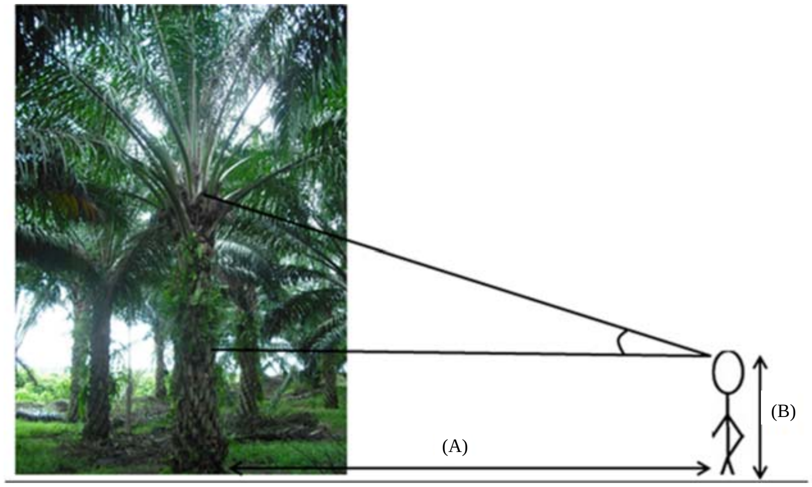

Fig. 2: Method in measuring palm height using clinometer and measurement tape, (A) Defined as the distance (in meters) from the palm base to the observer position and (B) Is the observer's height (in meter)

and NIR_{leaf} band by averaging reflectance of wavelengths into these specific regions: 430-470, 530-570, 630-670 and 700-1050 nm.

Field experiments for mature oil palms: The field experiments were carried out in Melaka Pinda Estate, United Malacca Berhad plantation in Melaka, Malaysia. Two different ages of *Tenera* palms were used in this experiment that were 9 years (young mature) (2.377779°N, 102.265658°E) and 12 years (prime mature) (2.380374°N and 102.238012°E). The planting density was 148 and 147 standing trees for the young mature and prime mature, respectively[16]. The soil series of this experimental site is the Melaka series (Typic Hapludox).

The experimental design for the field experiment was a Randomized Complete Block Design (RCBD) with 3 levels of N treatments, 3 replications and 16 samples for each replication. There were three levels of N treatments, 0, 1 and 2 kg N/palm. Nitrogen rates were applied as AC in four split applications that were hand-broadcasted around the weeded circle areas. Before the beginning of the field experiment, soil sampling was conducted at depths of 0-15 cm. For each replication, three soil samples were taken at random points and pooled according to replication for soil N analysis through the wet digestion method.

For growth measurements, two field campaigns were carried out in February and October, 2014. A total of three and eight oil palm stands in each subplot were sampled in February and October, respectively. The height, diameter and LAI were taken on an increment basis by subtracting the measurements taken on the October campaign with the average measurement of the three palms in the February campaign.

For the measurement of palm height, an observer stood on the flat ground and took the reading at an angle (in degree) relative to its eyes position to the palm crown using a clinometer (Fig. 2). The distance (in meters) from the palm base to the observer position (A) and the observer's height (in meter) (B) was then measured using a measurement tape. The palm height was calculated using the law of trigonometry following this Eq[17]:

$$\text{Height (m)} = (\tan \theta \times A) + B \quad (2)$$

The circumference of the palms at the breast height was also measured and the diameter was calculated by using Eq. 3[17]:

$$\text{Diameter (m)} = \left(\frac{\text{Circumference}}{\pi}\right) \quad (3)$$

LAI measurements were taken by using the LAI-2000 plant canopy analyzer following Awal and Wan Ishak[18]. For the SPAD readings, 6 leaflets (both sides) located after the thorn position from frond 17 for each palm sample were measured. In each leaflet, 6 readings were taken from the middle part of the leaflet and the readings were averaged. For the foliar N, all the leaflets were oven-dried at 70°C for 72 h, grinded and determined following Gupta[19] and by using an auto-analyzer machine (QuikChem 8000 series FIA+System, Lachat Instrument, USA).

The procedure of the spectral measurement and calculation was similar for that previously performed for immature palms. Additionally, two SPOT-6 pan-sharp images with 1.5 m spatial resolution acquired on 14th Feb and 20th

November, 2014 were analyzed to represent reflectance of the oil palm canopy. Due to the Northeast Monsoon[20], the image obtained in November had a gap of 40 days from the field measurements. Image processing conducted to the images included atmospheric and geometric correction as well as conversion to a digital number for reflectance following Chander and Markham[21]. The canopy reflectance in blue, red, green and NIR region were extracted and denoted as $blue_{canopy}$, red_{canopy}, $green_{canopy}$ and NIR_{canopy} correspondingly.

The data for both growth and spectral parameters were individually analyzed according to each palm age class and/or pooled across all age classes. The significant effects of N treatments on the growth and spectral parameters were detected by one-way ANOVA using PROC GLIMMIX in SAS software version 9.3[22]. The least square means were compared at the 0.05 level of probability. The Pearson correlation coefficient (r) was conducted using PROC CORR to analyze the correlation between growth and spectral parameters measured with plant N indicators.

RESULTS

Initial soil N: Soil N taken prior to N fertilization program shows similarly low N levels ranging from 0.27-0.60 N g kg^{-1} soil in both fields cultivated with young and prime mature palms. The ANOVA showed that there was no significant difference between the N treatments with soil N contents for both young and prime mature palms.

Plant N indicators: Among the palm growth stages, foliar N showed significant N effects in immature palms only (Table 1). In immature oil palm, there was a distinct pattern of foliar N with N treatments. Generally, foliar N contents increased along with the N treatments. Similar to the foliar N, relative chlorophyll content as measured by the SPAD readings for the immature palm was affected by the N fertilization. The SPAD readings increased rapidly from the N treatment equalled to 0.011 kg N/palm until 0.042 kg N/palm treatment before declining at the highest N rate of 0.063 kg N/palm.

Growth parameters: N treatments clearly affected plant growth parameters, such as height, leaf area index (LAI) and diameter of immature palms but not the mature ones, neither young mature nor prime mature (Table 1). The growth parameters, such as the height and diameter readings increased in keeping with N treatments until the optimum N rate that was 0.042 kg N/palm.

Table 1: Analysis of variance of plant N indicators and growth parameters as affected by N treatments in immature and mature oil palm stands

		Plant N indicators		Growth parameters		
Maturity stages	N treatment (kg/palm)	Foliar N content (%)	SPAD reading	Height/height increment (m)	LAI/LAI increment	Diameter/Diameter increment (m)
Immature (13 months)	0.011	1.594±0.032[d]*	37.392±0.780[d]*	1.018±0.022[bc]*	0.458±0.058[ab]*	0.064±0.002[abc]*
	0.021	1.753±0.043[d]*	43.358±1.635[c]*	1.024±0.030[bc]*	0.508±0.057[ab]*	0.067±0.002[ab]*
	0.032	2.033±0.065[c]*	47.583±1.448[b]*	1.094±0.019[ab]*	0.565±0.106[a]*	0.068±0.002[a]*
	0.042	2.313±0.076[b]*	52.492±1.353[a]*	1.117±0.040[a]*	0.596±0.082[a]*	0.064±0.002[ab]*
	0.053	2.393±0.075[b]*	54.258±1.333[a]*	1.016±0.039[bc]*	0.466±0.066[ab]*	0.059±0.003[c]*
	0.063	2.516±0.076[a]*	53.220±0.677[a]*	0.981±0.036[c]*	0.308±0.025[b]*	0.060±0.002[bc]*
Young mature (9 years)	0	2.210±0.088[a]	72.792±1.320[a]	0.112±0.142[a] (4.12)	0.115±0.035[a] (1.96)	0.033±0.011[a] (0.78)
	1	2.297±0.085[a]	73.878±1.166[a]	0.152±0.058[a] (4.66)	0.148±0.014[a] (2.26)	0.058±0.009[a] (0.79)
	2	2.258±0.050[a]	74.600±0.880[a]	0.147±0.156[a] (4.36)	0.152±0.116[a] (2.12)	0.072±0.016[a] (0.73)
Prime mature (12 years)	0	2.257±0.044[a]	71.511±1.941[a]	0.177±0.045[a] (4.83)	0.167±0.028[a] (2.30)	0.007±0.018[a] (0.78)
	1	2.277±0.049[a]	73.155±2.436[a]	0.323±0.091[a] (4.99)	0.210±0.039[a] (2.28)	0.027±0.015[a] (0.79)
	2	2.288±0.064[a]	72.835±1.266[a]	0.467±0.126[a] (4.45)	0.240±0.070[a] (2.51)	0.040±0.017[a] (0.77)

*Data with significant interactions between N treatments and listed parameters. Means with different letters in the same column according to age are significantly different at $p<0.05$ (±SE), Values in parentheses are mean height, LAI and diameter values

Table 2: Analysis of variance of spectral parameters as affected by N treatments in immature and mature oil palm stands

Maturity stages	N Treatment (kg/palm)	Spectral parameters $Blue_{leaf}$ (%)	$Green_{leaf}$ (%)	Red_{leaf} (%)	NIR_{leaf} (%)
Immature (13 months)	0.011	8.024±0.692[a]	17.998±1.168[a]	9.823±0.848[a]	76.996±2.494[a]
	0.021	7.163±0.486[a]	15.379±0.824[b]	8.396±0.567[a]	74.787±3.441[a]
	0.032	7.621±0.587[a]	14.868±0.874[b]	8.628±0.645[a]	75.000±1.960[a]
	0.042	7.925±0.495[a]	13.791±0.689[b]	8.574±0.549[a]	77.101±1.872[a]
	0.053	7.608±0.358[a]	13.153±0.623[b]	8.358±0.419[a]	76.683±2.234[a]
	0.063	8.720±0.581[a]	14.094±0.754[b]	9.480±0.628[a]	76.758±1.411[a]
Young mature (9 years)	0	6.755±0.455[a]	10.202±0.404[a]	6.965±0.482[a]	65.728±5.984[a]
	1	6.633±0.579[a]	10.105±0.553[a]	6.855±0.612[a]	68.502±5.087[a]
	2	6.108±0.396[a]	9.242±0.426[a]	6.280±0.441[a]	68.350±4.454[a]
Prime mature (12 years)	0	6.810±0.553[a]	10.510±0.517[a]	7.167±0.616[a]	60.862±2.970[a]
	1	6.968±0.746[a]	10.943±1.259[a]	7.585±1.051[a]	61.970±2.460[a]
	2	5.820±0.232[a]	9.083±0.268[a]	6.123±0.321[a]	60.953±2.180[a]
		$Blue_{canopy}$ (%)*	$Green_{canopy}$ (%)*	Red_{canopy} (%)*	NIR_{canopy} (%)*
Young mature (9 years)	0	10.905±0.105[a]	2.615±0.224[a]	1.755±0.147[a]	32.287±2.881[a]
	1	10.997±0.063[a]	2.858±0.108[a]	1.890±0.018[a]	36.562±0.677[a]
	2	10.967±0.081[a]	2.817±0.160[a]	1.840±[a]0.060	35.562±1.573[a]
Prime mature (12 years)	0	11.277±0.056[a]	3.255±0.083[a]	2.308±0.112[a]	35.337±0.927[a]
	1	11.240±0.068[a]	3.220±0.121[a]	2.277±0.058[a]	35.508±0.849[a]
	2	11.232±0.034[a]	3.152±0.092[a]	2.330±0.058[a]	34.347±0.984[a]

*Data with significant interactions between N treatments and listed parameters. Means with different alphabets in the same column according to age are significantly different at $p<0.05$ (±SE)

Spectral parameters: With the exception to the immature palm, no significant response was reflected by spectral reflectance in blue, green, red and NIR wavelengths either at the leaf or canopy level (Table 2). While NIR_{leaf} reflectance were reciprocally related to the age of palms, visible reflectance at the canopy level, $blue_{canopy}$, $green_{canopy}$ and red_{canopy} were linearly increased with palms age.

$Green_{leaf}$ reflectance of immature palm demonstrated a nonlinear response to the N treatments as the SPAD readings. In young mature palms, the visible ($blue_{leaf}$, $green_{leaf}$ and red_{leaf}) reflectance responded well to the N treatments, although the reflectance failed to depict a significant response. In prime mature palms, the optimum N rate yielded the highest reflectance in all spectral regions, followed by the control and excessive rates. A similar observation also was made on the NIR_{canopy} reflectance for both mature palms. On the contrary, the pattern reflectance of the NIR_{leaf} as affected by the N fertilisation was less consistent for the immature palms.

In assessing the magnitude of spectral reflectance at the leaf and canopy levels, an inconsistent pattern was observed. For instance, while the $blue_{canopy}$ was greater than the $blue_{leaf}$, the $green_{leaf}$, red_{leaf} and NIR_{leaf} were greater than their counterparts. Additionally, the visible reflectance made at the canopy level for the young mature palms were consistently smaller than for the prime mature palms.

Correlations among plant nitrogen indicators with growth and spectral parameters

Growth parameters: Among the palm ages, foliar N had a significant moderate positive correlation only with diameter of prime mature palms ($r = 0.55$, $p = 0.05$), while no relationship between the growth parameters and SPAD readings was observed (data is not shown).

Spectral parameters: Both foliar N content and SPAD readings in immature palm had negative correlations with $green_{leaf}$ reflectance (Table 3). Of all spectral parameters, NIR_{leaf} reflectance in mature oil palms showed strong negative correlations to both N indicators. As for the young mature palms, only $blue_{leaf}$ reflectance had a significant correlation ($p = 0.05$) with foliar N content. While the correlations between foliar N content with spectral parameters were more common in prime mature palms, SPAD readings of young mature palms had more correlations with spectral parameters made at the canopy level. As for the pooled palm ages correlation as presented in Table 4, SPAD readings produced moderate to strong relationships to all spectral parameters. The highest correlation with SPAD readings were obtained for $green_{leaf}$, followed by red_{leaf}, NIR_{leaf} and lastly $blue_{leaf}$. On the other hand, foliar N had fewer correlations with spectral reflectance; $green_{leaf}$ and NIR_{leaf} reflectance. As opposed to the leaf spectral measurement, foliar N content had more significant correlations ($p = 0.05$) with spectral parameters;

Table 3: Pearson correlation between plant N indicators (foliar N content and SPAD readings) with blue, green, red and NIR for immature and mature oil palm stands

	Foliar N content (%)				SPAD readings (SPAD Unit)			
Maturity stages	$Blue_{leaf}$ (%)	$Green_{leaf}$ (%)	Red_{leaf} (%)	NIR_{leaf} (%)	$Blue_{leaf}$ (%)	$Green_{leaf}$ (%)	Red_{leaf} (%)	NIR_{leaf} (%)
Immature (13 months)		-0.484****				-0.565****		
Young mature (9 years)	-0.492*			-0.644**				-0.787****
Prime mature (12 years)				-0.491*				
	$Blue_{canopy}$ (%)	$Green_{canopy}$ (%)	Red_{canopy} (%)	NIR_{canopy} (%)	$Blue_{canopy}$ (%)	$Green_{canopy}$ (%)	Red_{canopy} (%)	NIR_{canopy} (%)
Young mature (9 years)	-0.641**	-0.535*			0.746***	0.686**		0.480*
Prime mature (12 years)		-0.545*	0.521*	-0.617**			-0.494*	0.556*

*,**,***,****Denote significant levels (p-value) at 0.05, 0.01, 0.001, and 0.0001, respectively

$blue_{canopy}$, $green_{canopy}$ and NIR_{canopy} while, SPAD readings displayed positive correlation only with NIR_{canopy}.

DISCUSSION

Growth and spectral parameters were affected by N treatments and palm maturity. Nitrogen treatments resulted in significantly increased (p = 0.05) foliar N contents, growth and spectral characteristics of oil palms only at the immature stage. The foliar N contents for immature palms, while significantly different for different N rates, for instance, fell under the deficient N class, which is below 2.5%, except for the 0.063 kg N/palm rate[5]. Nevertheless, based on the growth parameters that depicted decrement for N rates more than 0.042 kg N/palm, it was perceived that this critical nutrient level might be higher than ours due to the fact that the oil palm planting materials might have changed over the years. Likewise, the foliar N contents of mature palms were also considered deficient, where they were below 2.3%. Irrespective of significant differences (p = 0.05) in mature palms, the applications of N fertilizer tended to increase the foliar N level and growth parameters compared to the control treatment. The insignificant differences might be attributed to the high N reserve within the palm trunk itself. A negative response in growth parameters can only be observed when nutrient reserve in palm is exhausted.

Similarly, N treatments also significantly affected (p = 0.05) plant growth parameters of immature palms only. This may be accredited to the active growing stage of immature palms, further applied N promoted the faster vegetative growth. Meanwhile, there was insignificant response of N treatments to the mature palm's growth parameters. It was hypothesized that the nutrient reserve in mature palms should be exhausted first before any differences in growth parameters could be detected, however, results have shown a lower N fertilizer application resulted in lower yield. Additionally, the insignificant response could be attributed to the different allocations of N according to the palm's organs such as leaflets, rachis, spear and cabbage and trunk. While leaflets are the most dominant N-sink at the early age of palm, the amount of N allocation to this organ decreases gradually as the age of the palm increases[10]. On the contrary, the N distribution to the trunk increases with the maturity of palms since a considerable amount of N which could up to 250 kg N ha^{-1}/year along with other macro plant nutrients such as P, K and Mg are stored in palm trunk[23,24]. This high nutrient reserve may be viable to clarify the lack of foliar N response in mature palms and significant correlation between diameter and foliar N in prime mature palms. Also, it

Table 4: Pearson correlation between plant N indicators (foliar N content and SPAD readings) with blue, green, red and NIR for pool data across palm ages

Plant N indicators	$Blue_{leaf}$ (%)	$Green_{leaf}$ (%)	Red_{leaf} (%)	NIR_{leaf} (%)
Foliar N content (%)		-0.480****		-0.348**
SPAD readings (SPAD Unit)	-0.395**	-0.829****	-0.548****	-0.461****
	$Blue_{canopy}$ (%)	$Green_{canopy}$ (%)	Red_{canopy} (%)	NIR_{canopy} (%)
Foliar N content (%)	-0.368*	-0.404**		-0.349*
SPAD readings (SPAD Unit)				0.409**

*,**,***,****Denote significant levels (p-value) at 0.05, 0.01, 0.001 and 0.0001, respectively

is hypothesized that the growth and spectral responses of mature oil palms could also be similarly delayed due to this complex N partitioning and climate. Besides, a longer time frame is required for young palms to show a stabilized fertilizer response on foliar nutrition status and yield which could take at least four years or more as addressed by Soon and Hoong[25] and Corley and Tinker[4].

In general as the palms grow, in particular immature palms, the growth parameters, such as height, diameter and LAI reflected an increase in size. However, the increase ceased after the 0.042 kg N/palm rate. According to the management of the oil palm nursery that we adopted, the 0.042 kg N/palm is the standard practice that the planters used and deemed as the optimum rate. The increase of the mentioned parameters was not observed after this rate can be attributed to a few factors such as higher rate of ammonium chloride in soil resulted in higher salinity in soil and plant uptake competition of other essential plant cations in soils. While the effects of age and N fertilization on these growth measurements were inseparable, Afandi *et al.*[3], Moradi *et al.*[26] and Moradi *et al.*[27], showed that the N fertilization positively increased palms trunk measurements and leaf area. As noted previously, the prime mature palms depicted higher increments of growth parameters compared to the young palms. Since soil available N was probably depleted in both mature fields and the soil type of both fields is also similar, factors that include micro-topography, leaf number, fruiting cycle and palm density[10] can influence different growth rates of these two mature palm stages.

$Green_{leaf}$ reflectance of immature palms was found to have negative, moderate relationships to foliar N and SPAD readings whereas NIR_{leaf} of mature palms showed negative, though stronger relationships to both plant N indicators. While the direction of these relationships was true for the $green_{leaf}$ reflectance, the N treatments were found to produce inconsistent NIR_{leaf} reflectance responses. The inconsistency could be caused by a reciprocal effect on the number of air spaces due to the smaller and fewer cells within the stressed leaves that was reported by many researchers for various types of crops, including Fridgen and Varco[28] (cotton), Castro and Sanchez-Azofeifa[29] (hardwood trees), Slaton *et al.*[30] (shrub trees), Carter and Estep[31] and Schlemmer *et al.*[32] (corn). These results also may suggest that the effects of N treatments in immature palms were more pronounced in the visible region, particularly green, which is an indicator of pigment absorption. For the mature palms, NIR reflectance that reflects information related to the leaf cell structure should be assessed. Also of importance is the thicker leaves of mature palms noted visually may be related to the age factor rather than the N treatments. The leaf thickness of the immature palms was similar among N treatments. While responses of N treatments were markedly age-dependent, pooled correlations analysis across palm age categories illustrated a strong relationship of $green_{leaf}$ and NIR_{leaf} to foliar N and SPAD readings. This finding suggests the potential of green and NIR reflectance to be an indicator of oil palm N status through spectral indices. Gitelson *et al.*[33] and Li and He[34] reported that these spectral bands were sensitive to the chlorophyll content of many crop species, such as beech, wild vine, maple, chestnut and tea.

Young mature palms depicted a moderate to strong relationship of $blue_{canopy}$ and $green_{canopy}$ to foliar N and SPAD readings while prime mature palms had the red_{canopy} and NIR_{canopy} moderately correlated to foliar N and SPAD readings. However, the direction of this relationship was less consistent as for the leaf measurement, where foliar N decreased with increasing spectral reflectance while SPAD readings increased as the spectral reflectance increased, especially for the visible region. While the SPAD-visible reflectance relationship was hypothesised to be negative, a positive relationship found from this study was also reported by Tewari *et al.*[35] and Stone *et al.*[36]. However, the factors that might contribute to this positive relationship remain unknown. For the prime mature palms, besides chlorophyll-sensitive absorption bands, NIR reflectance that is an indicator of leaf arrangement and LAI in the canopy is also an essential spectral parameter related to N palm status[37].

Pooled correlation analysis illustrated that the spectral reflectance at the canopy level was better correlated to foliar N than the SPAD readings. Additionally, there were more spectral parameters that attained significant relationships with the plant N indicators from the canopy measurements compared to the leaf measurements. This is not surprising considering that Chapman and Gray[38] and Rajaratnam *et al.*[39] reported that frond number 17, which was used for the foliar N analysis, was highly correlated to fruit bunch yield and thus representative of the canopy characteristics of oil palm. Also, the fact that LAI increases with age indicated that the canopy parameters became an important N sink as the palms mature because more leaf area is available to intercept light in the chlorophyll absorption regions. This finding is valuable because oil palms are often cultivated in large plantation areas and thus canopy measurements can be further employed for the estimation of N status, however, the estimation of N is still subject to factors that can confound the N signals, such as soil background reflectance, canopy orientation, angle of sensors and atmospheric interference as summarised by and Hatfield *et al.*[40].

In assessing plant N status indicators, foliar N was less influenced by oil palm age compared to the SPAD readings that were sensitive to both N and age factors as depicted by the broad range values spanning from 37-74 across the palm growth stages. Although the SPAD readings values more than 50 may turn out to be less accurate[41], it is worth noting that such high values were common in perennial crops, such as coffee[42] and citrus[43]. While it was emphasised by Loh *et al.*[44] that extending SPAD meter application in predicting N for perennial crop can be difficult due to many factors, such as leaf age, sampling time, complex sink-source relationships and interactions with other nutrients, this sensitivity can be advantageous in monitoring variations exhibited by age, for example yield[4].

Foliar N had better relationships with spectral parameters at the canopy level than SPAD readings, while SPAD readings was better than foliar N at the canopy level. While these moderate relationships can be supported by the association of frond number 17 to canopy characteristics, which is an exciting finding though tempered by the fact that frond number 17 is located slightly deeper in the canopy and such correlations despite being moderate, was not expected since canopy measurements made by optical satellites are commonly confined to the top part of the canopy[45]. In fact, the strong relationship between SPAD readings and spectral parameters at the leaf level can be explained by fact that they both acquired information related to the chlorophyll response in the same manner of spectral measurements.

CONCLUSION

Response of oil palm growth and spectral parameters to N fertilizer was strong at all growth stages. For immature palms, growth and spectral responses indicated that vegetative organs and particularly leaflets are the main N-sink. For mature palms, multiple N-sinks were observed, such as diameter and canopy spectra. In assessing foliar N content and SPAD readings as indicators of oil palm N status, the former is age-independent while the latter is confounded by the age factor where N responses should be assessed along palms maturity. The findings in this study also suggested that the spectral parameters have potential in predicting N nutrition status in oil palm.

SIGNIFICANCE STATEMENTS

This study discovered the possibility of utilizing growth and spectral parameters for predicting multi-ages oil palm's nitrogen (N) nutrition status under the field condition that can be beneficial for agronomists as well as planters in monitoring and managing the N status in vast oil palm plantation areas. This study will help the researchers to uncover the critical areas of spectral and growth parameters in monitoring N status of oil palm that many researchers were not able to explore. Thus this study provided a new insight on the utilization of spectral and growth parameters for predicting the N status of multi ages oil palm.

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