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Evaluation of oil palm (*Elaeis guineensis* Jacq.) productivity on peatlands based on DRIS analysis of leaf nutrient content in Siak District of Indonesia

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Abstract: Indonesia is the largest producer of oil palm in the world, with Riau Province particularly Siak District being the major contributor. The study focused on oil palm plantations within Siak District, characterized by a tropical rainforest climate of high humidity. The soil type in this area was a peatland with sapric and hemic maturity. The planting material used primarily consists of the DxP Marihat variety, which was planted between 1995-2005, with an average potential fresh fruit bunch productivity of 29.00 tons/ha/year. Variations in nutrient contents in oil palm leaf were observed across each block of the study location. Diagnosis and recommendation integrated system (DRIS) analysis was conducted on found number 17 to determine the key nutrients required to increase oil palm productivity. This method consists of several stages, including norm analysis, DRIS index, nutrient balance index (NBI), optimum leaf nutrient value, and leaf nutrient interval. Data was obtained from 312 leaf nutrient analyses and fresh fruit bunch productivity across 39 blocks for the period between 2015 and 2022. A value of 26.33 tons/ha/year, derived from DRIS norm calculation, indicated the border between high and low productivity blocks. The results showed that the order of macronutrient and micronutrient requirements in high productivity blocks was N>P>K>Ca>Mg and B>Cu>Zn, while in low productivity blocks, it was Ca>Mg>N>K>P and B>Cu>Zn. Regression of DRIS index and leaf nutrient content obtained optimum nutrient values of 2.78%, 0.16%, 1.02%, 0.66%, 0.35%, 29.51 ppm, 3.65 ppm, and 15.37 ppm for N, P, K, Ca, Mg, B, Cu, and Zn, respectively. Therefore, nutrients Ca and B were prioritized to increase the achievement of oil palm fresh fruit bunch productivity.

Keywords: Fertilization, Oil palm, Optimum nutrients, Production.
Abbreviations: N_nitrogen; P_phosphorus; K_potassium; Ca_calcium; Mg_magnesium; B_boron; Cu_copper; Zn_zinc; C_carbon; Fe_ferrum.

Introduction

Indonesia is the largest producer of oil palm in the world, with 14.90 million hectares of plantations (BPS, 2023), of which 1.70 million are situated on peatlands (Gunarso et al., 2013). According to USDA (2023), crude palm oil production in the country reached 47.00 million metric tons or 59% of the total yield in the world, where the contribution of Riau Province was 20%.

Crude palm oil is produced from the extraction of fresh fruit bunches, and the extraction reaches 24% for the Tenera variety (Sugianto et al., 2023). The bunches are harvested at a regular frequency of 7-15 days and sent to yield crude palm oil (Monzon et al., 2022). Productivity of oil palm fresh fruit bunches is influenced by nutrient availability, variety, soil type, and environmental conditions (Monzon et al., 2021; Arifin et al., 2022; Lim et al., 2023; Sugianto et al., 2023). In Indonesia, it reaches 53%-62% of potential productivity (Monzon et al., 2021). Oil palm productivity is classified as high approaching potential productivity and low when further away (Essono et al., 2023; Monzon et al., 2023).

The low nutrient content of peatlands is a limiting factor for oil palm productivity (Sabiham and Sukarman, 2012). These lands are typified by high acidity, high levels of total C and N, and deficiencies in P, K, Ca, Mg, B, Cu, and Zn (Noor et al., 2014; Parish et al., 2019). To counteract the limitations, regular application of oil palm fertilizers is essential (Sabiham and Sukarman, 2012). Intensive fertilizer application maintains productivity and contributes to 50% of productivity (Behera et al., 2018; Essono et al., 2023). The costs contribute 25%-45% of oil palm fresh fruit bunch productivity (Azahari and Sukarman, 2020; Haron et al., 2015).

Fertilizers should be applied effectively by conducting leaf nutrient analysis as a stage in determining the dose. Leaf samples used for this analysis were obtained from frond number 17 (Corley and Tinker, 2016), and nutrient values were interpreted and correctly transformed into fertilizer recommendations (Fairhurst and Mutert, 1999). The several methods adopted in formulating the recommendations include nutrient critical value, optimum nutrient ratio, yield response function, and nutrient balance (Goh et al., 2011).

DRIS is a method for analyzing leaf nutrient content to determine fertilizer recommendations. The level of effectiveness is the same as nutrient critical value method and nutrient sufficiency interval (Bangroo et al., 2010). DRIS method is preferable due to the potential to analyze the relationship between nutrients, compare with DRIS norms, and identify nutrient imbalances, deficiencies, and excesses (Manorama et al., 2021; Behera et al., 2022).

Previous DRIS conducted in several oil palm plantation locations showed differences in the order of nutrient requirements as a limiting factor for fresh fruit bunch productivity. Kamireddy et al. (2023) reported that N and B were nutrient priorities for oil palms in the Andhra Pradesh location of India. Meanwhile, according to Behera et al. (2022), N and Ca nutrients were prioritized in high and low-productivity blocks in southern India. In the state of Pará Brazil, Matos et al. (2017) stated that Ca and Mn were nutrient priorities for oil palms older than 6 years. In the eastern Brazilian Amazon, Matos et al. (2018) identified N and B as critical nutrients. According to Herrera-Peña et al. (2023), Fe and Zn nutrients in the central location of Colombia are nutrient-limiting factors.

The objective of this study is to analyze nutrient composition of oil palm leaf on peatlands based on DRIS index value, nutrient balance index (NBI), nutrient optimum value, and leaf nutrient interval. In the process, the order of foliar nutrient requirements was determined, to increase oil palm fresh fruit bunch productivity against potential productivity.

Result

Productivity of oil palm

Oil palm productivity consists of the weight and number of fresh fruit bunches, thereby obtaining annual productivity (yield). The analysis was conducted in the form of a box plot graph, supplemented with t-test analysis at the α = 5% level, as shown in Figure 1. High and low productivity blocks had oil palm bunches ranging from 11.14 to 22.13 and 6.85-19.15 bunches/plant/year, respectively. The bunch weight of high and low productivity blocks ranged from 10.48 to 19.06 and 8.59 to 20.73 kg. Annual oil palm productivity (yield) of high and low productivity blocks ranged from 26.63-33.49 and 13.71-26.61 tons/ha/year, respectively. The productivity is influenced by the number of bunches due to sufficient nutrients and water (Rhebergen et al., 2019), with optimal application of P and K nutrients playing a crucial role (Purwanto and Sudradjat, 2019; Viégas et al., 2023).

Regression and correlation analysis of plant age with oil palm productivity were conducted to generate predicted productivity values, provided that the coefficient of determination was strong and the p-value was < 5%. Based on the regression analysis in Figure 2, the resulting coefficient of determination was weak, with a value of R^2 = 0.02% and a p-value of 0.788. Plant age was observed to have a low effect on productivity because each study block possessed different peat characteristics. Veloo et al. (2015) reported that oil palm productivity in peatlands was influenced by peat maturity (sapric and hemic), substratum, and material, while peat depth had no significant effect.

Norms of leaf nutrients

Stages of DRIS index calculation include the determination of norm value based on leaf nutrients of high productivity blocks, as stated by Beaufils and Sumner (1976). Based on the calculation in Table 1, the norm values of macronutrients N, P, K, Ca, and Mg were 8.11, 4.55, 1.87, 2.03, and 3.3,

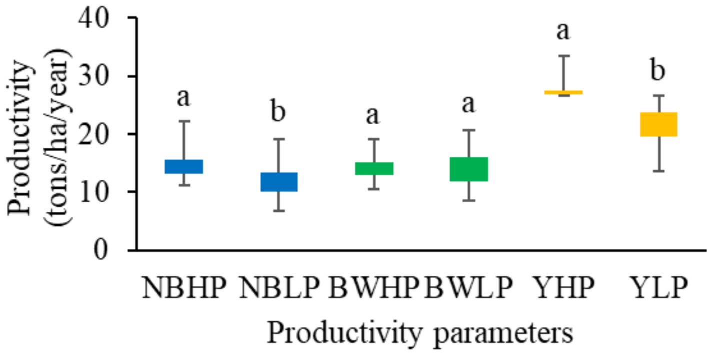

Figure 1. Comparison of oil palm fresh fruit bunch productivity parameters. Notes: NBHP (number of bunches high productivity), NBLP (number of bunches low productivity), BWHP (bunch weight of high productivity), BWLP (bunch weight of low productivity), YHP (yield of high productivity), and YLP (yield of low productivity). Box plots with the same color and followed by different letters indicate significant differences (p-value < 5%) in the t-test.

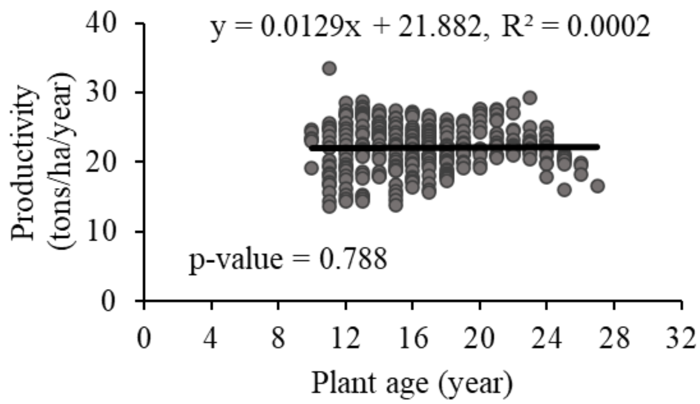

Figure 2. Effect of plant age on oil palm fresh fruit bunch productivity. Regression and correlation of plant age on oil palm fresh fruit bunch productivity has a coefficient of determination of R^2=0.02% and p-value > 5% which indicates that the relationship is not significant.

while micronutrients B, Cu, and Zn had values of 4.39, 3.89, and 0.68, respectively. The coefficient of variation (CV) of N, P, K, Ca, and Mg were 21.58, 20.27, 23.69, 30.01, and 21.38, respectively, while B, Cu, and Zn had values of 53.10, 47.92, and 39.98. Matos et al. (2017) stated that micronutrients had a higher CV.

DRIS index of leaf nutrients

DRIS index leaf nutrient of high productivity blocks approached 0 compared to the low productivity counterpart, as shown in Table 2. This indicated that high productivity blocks had a closer approach to nutrient optimum level. The order of macronutrient requirements of these blocks was N>P>K>Ca>Mg. Pardon et al. (2017) stated that high-productivity oil palm required higher N, while Lim et al. (2023) reported a positive relationship between productivity and nutrients such as N, P, K, and Mg. According to Essono et al. (2023), the ratio of N and K nutrients determines oil palm productivity.

Low-productivity blocks have a macronutrient requirement order of Ca>Mg>N>K>P. Lee et al. (2014) reported that Ca and Mg affect the low productivity of oil palm. According to

Table 1. Calculation of the norm values of macronutrients and micronutrients of leaf.

Variable	Macronutrient norms					Micronutrient norms		
	N	P	K	Ca	Mg	B	Cu	Zn
Norm	8.11	4.55	1.87	2.03	3.30	4.39	3.89	0.68
STDEV	1.62	0.80	0.45	0.62	0.71	2.59	2.35	0.30
CV (%)	21.58	20.27	23.69	30.10	21.38	53.10	47.92	39.98

Table 2. Comparison of DRIS index, leaf nutrients and NBI based on oil palm productivity

Nutrient	Unit	High productivity block			Low productivity block		
		DRIS index	Leaf nutrients	NBI	DRIS index	Leaf nutrients	NBI
N	%	-0.87	2.81	5.63 a	-0.36	2.75	5.56 a
P	%	-0.78	0.17	5.19 a	3.50	0.17	6.45 a
K	%	-0.68	1.03	7.03 a	2.04	1.06	7.48 a
Ca	%	0.63	0.69	6.97 a	-4.25	0.60	8.94 a
Mg	%	1.70	0.37	6.42 a	-0.94	0.34	8.33 a
B	ppm	-6.06	26.42	10.28 b	-14.72	20.53	16.44 a
Cu	ppm	0.26	4.02	9.50 a	-2.27	3.76	15.56 a
Zn	ppm	2.49	22.51	5.68 b	9.27	23.46	10.92 a

Notes: NBI (nutrient balance index) values followed by the same letter are not significantly different between high and low productivity blocks in the t-test (α = 0.05).

Table 3. Optimum value of leaf nutrients based on regression equation.

Nutrient	Unit	Regression equation	R^2	Optimum value
N	%	y = 20.783x – 57.772	R^2 = 0.5071	2.78
P	%	y = 310.1x – 48.851	R^2 = 0.5564	0.16
K	%	y = 47.264x – 47.994	R^2 = 0.7985	1.02
Ca	%	y = 71.071x – 46.76	R^2 = 0.8627	0.66
Mg	%	y = 143.74x – 49.681	R^2 = 0.8600	0.35
B	ppm	y = 32.509ln(x) – 110.03	R^2 = 0.4668	29.51
Cu	ppm	y = 42.185ln(x) – 54.667	R^2 = 0.5251	3.65
Zn	ppm	y = 1.0741x – 16.513	R^2 = 0.4651	15.37

Mirande-Ney et al. (2020), K affects the balance of Ca and Mg cations. Jamaludin et al. (2022) attributed the low Ca content to the low pH of the soil, a condition mitigated by the application of lime fertilizer. Haron et al. (2015) stated that increasing soil pH enhances nutrient availability and optimizes fertilizer use.

Based on DRIS index calculation, micronutrients had an order of B>Cu>Zn nutrient requirements in high and low productivity blocks. Zakaria and Tarmizi (2007); and Behera et al. (2022) reported that B and Ca had a synergistic relationship, while the concentration of N and B under plant-available conditions tends to decrease in high soil acidity. According to Tohirudin et al. (2010), N decreased Cu as well as Zn, P decreased Cu, and K decreased Zn. The effects of N, P, and K on B were inconsistent.

Nutrient balance index of leaf nutrients

Balanced fertilization recommendations provide the best results for oil palm productivity (Rhebergen et al., 2020). NBI on macronutrients and micronutrients presented in Table 2 shows that high productivity blocks have lower values, indicative of a more balanced nutrient content. Matos et al. (2018) reported a negative correlation between productivity and NBI in oil palm.

The value of NBI for micronutrients was greater than for macronutrients. This implied that micronutrients have a significant influence on nutrient imbalance in oil palms situated on peatlands. According to the results of the t-test analysis with a probability of 5%, the values of the B and Zn NBI were significantly different between high and low productivity blocks. Herrera-Peňa et al. (2023) reported that DRIS method identified nutrient balance towards variations in productivity coefficients.

Optimum and interval values of leaf nutrients

The optimum values of nutrients N, P, K, Ca, Mg, and Zn were obtained from linear regression equations, while nutrients B and Cu were obtained from natural logarithm regression equations, as shown in Figure 3. Reis Junior and Monnerat (2003) analyzed linear regression and natural logarithm in determining the optimum value. Based on the regression equation, as shown in Table 3, optimum nutrient values of N, P, K, Ca, Mg, B, Cu, and Zn were 2.78%, 0.16%, 1.02%, 0.66%, 0.35%, 29.51 ppm, 3.65 ppm, and 15.37 ppm, respectively. These values were obtained to calculate fertilizer recommendations. Given the variation in leaf nutrient contents across oil palm blocks, it is crucial to establish nutrient intervals to interpret nutrient sufficiency. Nutrient intervals of oil palm leaf in peatlands determined through DRIS index calculation are shown in Table 4.

Discussion

The comparison was conducted between the optimum nutrient range interval, determined through DRIS index calculation in Table 4, and the corresponding range derived from Von Uexkull and Fairhurst (1991) reference, used for fertilizer recommendations at the study location. The difference in the values for macronutrients N, P, K, Ca, and Mg, as calculated by DRIS index, compared to the reference value, shows a negligible variance, ranging from -0.01 to -0.06. However, for micronutrients B, Cu, and Zn, there is a significant variation between the optimum ranges. DRIS index indicated a greater value than the reference, with differences ranging from -0.95 to 4.35. The large difference in the optimum range of micronutrients can be influenced by the different soil types at the study location. Noor et al.

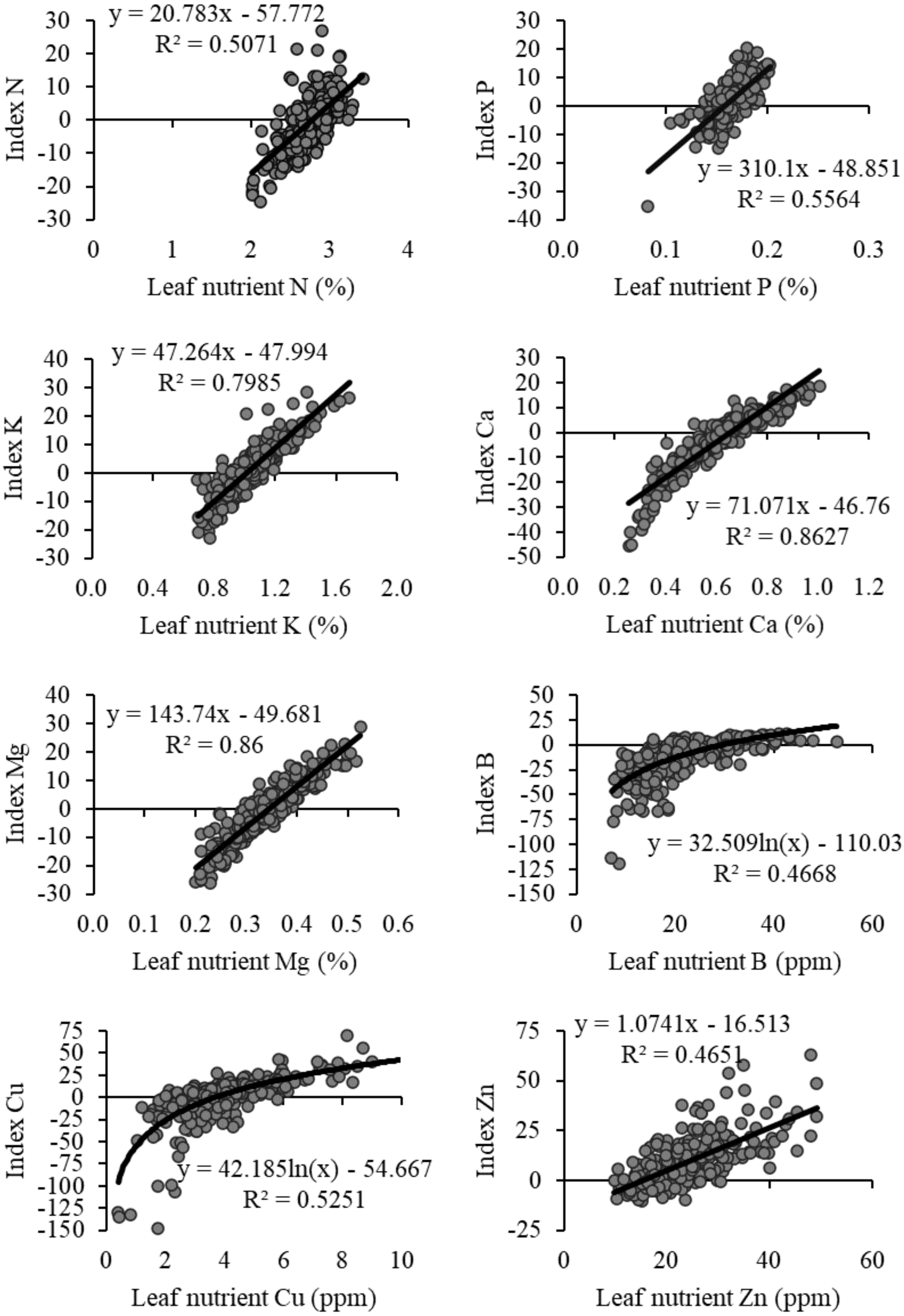

Figure 3. Regression equation of DRIS index and leaf nutrient content in N, P, K, Ca, Mg, B, Cu, and Zn nutrients.

(2014) reported that nutrient content of B, Cu, and Zn in peatland was lower than in mineral soil. According to Tohirudin et al. (2010), B, Cu, and Zn nutrients are influenced by N, P and K nutrients. Additionally, Matos et al. (2017) stated that micronutrients were more unbalanced than macronutrients.

Comparison of leaf nutrient intervals in high and low productivity blocks, based on nutrient content in Table 2, will be interpreted by referencing leaf nutrient intervals, calculated by reference and DRIS index. The macronutrient intervals of N, P, K, Ca, and Mg in the high and low productivity blocks were not different, and are in the optimum range of both nutrient intervals. Behera et al. (2022) reported that the optimum value of oil palm macronutrients in high and low-productivity locations was not different, with the difference being in the order of nutrient requirements.

The micronutrient content of B, Cu, and Zn in the high and low productivity blocks have different nutrient interval ranges. Hashim et al. (1993); and Mutert et al. (1999) stated

Table 4. Leaf nutrient content interval based on DRIS index calculation.

Nutrient	Unit	Deficiency	Deficiency alert	Optimum	Excess alert	Excess
N	%	<2.44	2.44 – 2.61	2.61 – 2.95	2.95 – 3.12	>3.12
P	%	<0.13	0.13 – 0.15	0.15 – 0.17	0.17 – 0.18	>0.18
K	%	<0.78	0.78 – 0.90	0.90 – 1.14	1.14 – 1.25	>1.25
Ca	%	<0.46	0.46 – 0.56	0.56 – 0.76	0.76 – 0.86	>0.86
Mg	%	<0.26	0.26 – 0.30	0.30 – 0.39	0.39 – 0.43	>0.43
B	ppm	<17.92	17.92 – 23.71	23.71 – 35.30	35.30 – 41.09	>41.09
Cu	ppm	<1.60	1.60 – 2.63	2.63 – 4.68	4.68 – 5.70	>5.70
Zn	ppm	<5.02	5.02 – 10.20	10.20 – 20.55	20.55 – 25.73	>25.73

Table 5. Comparison of optimum range value between leaf nutrient reference and DRIS index calculation.

Nutrient	Unit	Optimum		Optimum range		Difference range
		Reference	DRIS	Reference	DRIS	(DRIS-Reference)
N	%	2.40 – 2.80	2.61-2.95	0.40	0.34	-0.06
P	%	0.15 – 0.18	0.15-0.17	0.03	0.02	-0.01
K	%	0.90 – 1.20	0.90-1.14	0.30	0.24	-0.06
Ca	%	0.50 – 0.75	0.56-0.76	0.25	0.20	-0.05
Mg	%	0.25 – 0.40	0.30-0.39	0.15	0.09	-0.06
B	ppm	15.00 – 25.00	23.71-35.30	10.00	11.59	1.59
Cu	ppm	5.00 – 8.00	2.63-4.68	3.00	2.05	-0.95
Zn	ppm	12.00 – 18.00	10.20 – 20.55	6.00	10.35	4.35

Table 6. Comparison of leaf micronutrient content based on leaf nutrient content interval.

Nutrient	DRIS index		Reference	
	High productivity	Low productivity	High productivity	Low productivity
B	Optimum	Deficiency alert	Optimum-excess	Optimum
Cu	Optimum	Optimum	Optimum-deficiency	Optimum-deficiency
Zn	Excess alert	Excess alert	Optimum-excess	Optimum-excess

that oil palm productivity on peatlands was influenced by micronutrients, with low content of Cu and Zn nutrients being attributed to high solubility in water. Gutiérrez-Soto and Torres-Acuña (2013) reported that B nutrient deficiency in plants occured in locations with high rainfall and lack of clay minerals.

Micronutrients B, Cu, and Zn were further analyzed to determine nutrient sufficiency range based on the reference nutrient interval and the interval, calculated by DRIS index, as shown in Table 6. Based on nutrient sufficiency range analysis, B can describe the difference in oil palm productivity compared to Cu and Zn. Von Uexkull and Fairhurst (1991) reported that the micronutrient B was more essential for oil palms than Cu and Zn. The range of B nutrient sufficiency in nutrient interval calculated by DRIS index has a difference in the range in high and low productivity blocks. In high productivity blocks, B nutrient sufficiency falls in the optimum range, while in low productivity blocks, it indicates a deficiency alert. Behera et al. (2022) reported that there were differences in B nutrients between high and low-productivity oil palm locations. According to Lindolfo et al. (2020), the optimum nutrient content will increase oil palm productivity. Wu et al. (2019); and Sutarta and Syarovy (2019) reported that nutrient deficiency in oil palm resulted in low chlorophyll content, photosynthesis, as well as cellulose and pectin biosynthesis. In the study conducted by Rajaratnam and Lowry (1974); and Ginting and Pane (2023), B deficiency leads to low leaf location index, resulting in low productivity and quality of fresh fruit oil palm bunches.

The sufficiency range of B nutrient at the reference leaf nutrient interval was not significantly different. The high productivity block fell in the optimum to surplus nutrient sufficiency range, while the low productivity block remained in the optimum range. Leaf nutrient interval based on DRIS index calculation better describes the range of micronutrient sufficiency for oil palm productivity. It is important to note that site-specific fertilization recommendations will be more effective and environmentally friendly (Tarmizi and Tayeb, 2006).

Materials and Methods

Description of the study location

DRIS analysis was conducted from April 2023 to October 2023 at IPB University. Data on oil palm fresh fruit bunch productivity and leaf nutrients for the period 2015-2022 were obtained from oil palm plantations on peatlands in Siak District, Riau Province, Indonesia, with the study location map shown in Figure 4. This study consisted of 39 different sample blocks (oil palm cultivation management units) in a single oil palm plantation location. The location of one block ranges from 8-34 ha, taking a rectangular shape with a width of 80-340 m and length of 1000 m, making the total location of 930.85 ha.

Plant material and soil type

Oil palm variety was the DxP Marihat variety, planted during the period 1995-2005. Plant ages during the study period ranged from 10-27 years old and were classified as production oil palm over 6 years old. Oil palm productivity, categorized by plant age range and land suitability class, was deemed very suitable (S1), with average potential productivity of fresh fruit bunches of 29.00 tons/ha/year (IOPRI, 2023).

The soil type used was peatland which was divided into sapric, hemic, and fibric based on maturity level. Sapric peat is blackish-brown decomposed peat with a fiber content of

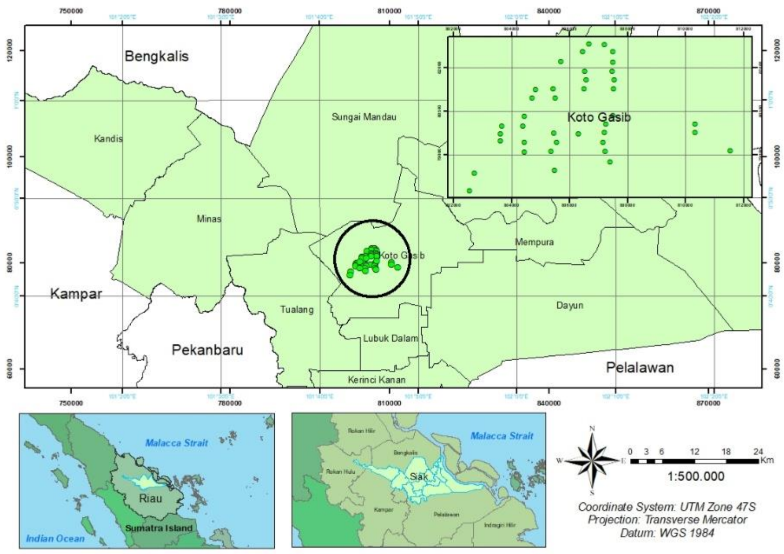

Figure 4. The study location in Siak District, Riau Province, Sumatra Island, Indonesia.

less than 15%. Hemic peat is a brownish decomposed peat with fiber content of 15-75%, while fibric peat is a incompletely decomposed peat with fiber content of more than 75% (Agus and Subiksa, 2008). According to Iskandar et al. (2020), DRIS analysis showed that a depth of 0-30 cm was sapric peat, while 30-50 cm was hemic and sapric peat.

Meteorology of the study location

Between 2015-2022, data obtained from an automatic weather station (AWS) situated at the plantation location, indicated an air temperature ranging from 23-33^{0}C with rainfall of 1.737-2.569 mm/year and rainy days of 72-154 days/year, as shown in Figure 5. Based on the Schmid and Ferguson (1951) climate classification, the study location from 2015-2022 had average wet (RF>100 mm/month), dry (RF<60 mm/month), and humid months (60<RF<100 mm/month) of 9, 1.13, and 1.88, respectively. Therefore, the location belongs to climate type A, which is a very wet tropical rainforest (Lakitan, 2002).

Recapitulation of DRIS study data

DRIS analysis data consisted of leaf nutrients and oil palm fresh fruit bunch productivity. Oil palm leaf nutrient data were sourced from the primary annual investigation, comprising macronutrients such as N, P, K, Ca, and Mg, as well as micronutrients including B, Cu, and Zn. Furthermore, the analysis was conducted once a year on frond number 17. Leaf samples taken were cleaned with cotton and distilled water, chopped and composited for each block, oven-dried at 70^{0}C, as well as analyzed in the laboratory for nutrients. The method of analyzing leaf samples in the laboratory adhered to the protocol outlined by Eviati and Sulaeman (2009) for N, P, K, Ca, Mg, B, Cu, and Zn. The dried samples were ground to a fineness of 2 mm and placed into plastic bottles. Macronutrients K, Ca, and Mg and micronutrients Cu and Zn were determined using HNO_3 and $HClO_4$ solutions and measured by an atomic absorption spectrophotometer (AAS). N nutrient content was determined using H_2SO_4 concentrated solution and Se catalyst and measured by a continuous flow analyzer. Similarly, the determination of P and B includes using HNO_3 and $HClO_4$ solutions, followed by measurement by a spectrophotometer.

Fresh fruit bunch productivity data were derived from secondary sources obtained from the harvest operations department. Oil palm fresh fruit bunches were harvested with a frequency of 7-15 days, counted in the field, and sent to the mill for weighing and processing. Monzon et al. (2022) stated that oil palm productivity was determined by both the number and weight of bunches.

Analysis of oil palm productivity

Analysis of oil palm fresh fruit bunch productivity compared to the potential productivity of the DxP Marihat variety of 29.00 tons/ha/year, was conducted. Productivity in blocks approaching or exceeding potential productivity was categorized as high. This is in line with the stages of DRIS analysis conducted by Walworth and Sumner (1987); and Behera et al. (2022), where the criteria for achieving crop productivity were divided. The border between high and low productivity blocks was 26.33 tons/ha/year, based on the value used as the norm.

Oil palm productivity analysis was conducted by comparing high and low productivity blocks with the parameters of bunch weight, number of bunches, and annual productivity, analyzed using box plot analysis and t-test with a probability of 5%. The age of the plant on the annual productivity of oil palm was examined using correlation and regression analysis. A strong coefficient of determination and p-value < 5%, is in accordance with the study of Sutandi and Barus (2007).

Calculation of leaf nutrient norm values

Leaf nutrient norm values were obtained by sorting 312 data on oil palm fresh fruit bunch productivity and leaf nutrients for the period between 2015-2022. The productivity at that period ranged from 13.71-33.49 tons/ha/year, with a potential of 29.00 tons/ha/year. The data were sorted from highest to lowest, based on Beaufils and Sumner's (1976) grouping by crop productivity. Following the approach proposed by Letzsch and Sumner (1984) for determining norm data size, the top 10% of entries based on the highest productivity were designated as norm values. Therefore, 31 data points representing the highest fresh fruit bunch productivity and corresponding leaf nutrient levels were identified as the norm. The threshold for distinguishing between high and low productivity was set at 26.63 tons/ha/year, in line with the methodology adopted by Bangroo et al. (2010). A total of 312 blocks of data were

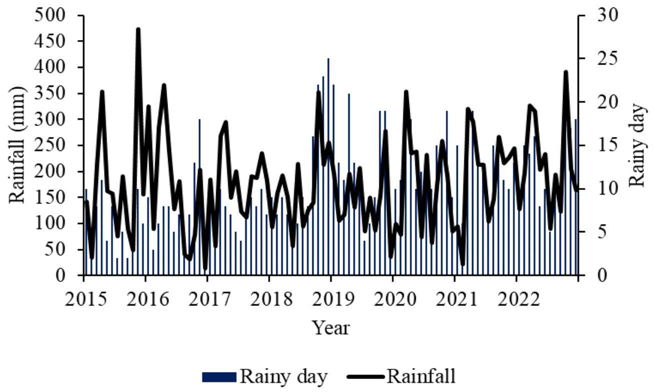

Figure 5. Rainfall and rainy days at the study location for the period 2015-2022.

divided into 31 high and 281 low-productivity blocks data. High productivity blocks had annual bunch productivity (yield) ranging from 26.63-33.49 tons/ha/year, while low productivity blocks ranged from 13.71-26.61 tons/ha/year. The border values of macronutrients and micronutrients N, P, K, Ca, Mg, B, Cu, and Zn in high and low productivity blocks followed fresh fruit bunch productivity blocks data, in line with the study of Behera et al. (2015) in determining nutrient norms.

Calculation of leaf nutrient DRIS index

DRIS index of macronutrients N, P, K, Ca, and Mg and micronutrients B, Cu, and Zn were computed separately based on the deviation from optimum percentage method proposed by Pereira et al. (2011). Since the units of measurement for macronutrients and micronutrients were in the form of percentage (%) and parts per million (ppm), respectively, CV will be high when combined. Furthermore, separating the calculation of macronutrients and micronutrients DRIS indices facilitated a more specific determination of the respective requirements. The computation of leaf nutrient DRIS index adhered to the equation outlined by Walworth and Sumner (1987).

A nutrient index = (f(A/B) + f(A/C) ..... + f(A/N))/t
B nutrient index = (-f(A/B) + f(B/C) ..... + f(B/N))/t
C nutrient index = (-f(A/C) - f(B/C) ..... + f(C/N))/t
N nutrient index = (-f(A/N) - f(B/N) - f(C/N) ..... - f(M/N))/t

The formula used in the calculation of DRIS index was determined based on the provisions of value comparison A/B and a/b. In cases where A/B > a/b, then f(A/B) = ((A/B)/(a/b) - 1) x 1000/CV, and when A/B < a/b, f(A/B) = (1 - (a/b)/(A/B)) x 1000/CV. Where A/B is the ratio of nutrients A and B in the analyzed sample, a/b is the norm value, CV is the coefficient of variation of the norm value, f is a function, and t is the sum of functions.

Calculation of nutrient balance index of leaf nutrients

NBI was calculated following DRIS index value to identify nutrient balance of oil palm leaf (Matos et al., 2018). The value was obtained by summing the absolute value of leaf nutrient DRIS index and was used to analyze the production of oil palm plants. The calculation was conducted following the procedures and equation of Matos et al. (2017).

NBI = [A nutrient index] + [B nutrient index] + [C nutrient index] + ... + [N nutrient index]

Calculation of optimum values and leaf nutrient intervals

The calculation of the optimum value of leaf nutrients followed the procedures of Serra et al. (2013). This comprised the intersection of the regression equation line between leaf nutrient DRIS index and content on the x-axis. The values obtained were divided into the interval categories of nutrient deficiency (optimum leaf nutrient - 4/3 standard deviation), deficiency alert (optimum leaf nutrient - 4/3 standard deviation) to (optimum leaf nutrient - 2/3 standard deviation), optimum (optimum leaf nutrients - 2/3 standard deviation) to (optimum leaf nutrients + 2/3 standard deviation), excess alert (optimum leaf nutrients + 2/3 standard deviation) to (optimum leaf nutrients + 4/3 standard deviation), and excess (optimum leaf nutrients + 4/3 standard deviation).

The position of DRIS in making fertilization recommendations for oil palm plant aged more than 6 years adopted the reference leaf nutrient sufficiency interval based on Von Uexkull and Fairhurst (1991).

Statistical analysis

The initial step included conducting DRIS analysis alongside box plot analysis, t-test, regression, and correlation, using a significance level of 5%. The aim was to determine the distribution of oil palm fresh fruit bunch productivity data. Subsequently, the effect of the number of bunches, bunch weight, and plant age on productivity, was analyzed. Norms were calculated based on the highest 10% of oil palm productivity. The value of NBI was analyzed using a t-test with a probability of 5% to determine the difference. Finally, the optimum leaf nutrient values obtained were further developed to calculate the sufficiency intervals.

Conclusion

In conclusion, the high cost of fertilization in peatlands required a location-specific method for calculating fertilizer recommendations. The selected method, DRIS, allowed the determination of leaf nutrient sufficiency intervals, thereby facilitating recommendations by considering the order of nutrient requirements and nutrient balance. Analysis showed that the prioritized order of macronutrient and micronutrient requirements for achieving high oil palm fresh fruit bunch productivity was N>P>K>Ca>Mg and B>Cu>Zn. Conversely, in scenarios of low oil palm fresh fruit bunch productivity, the order changed to Ca>Mg>N>K>P and B>Cu>Zn. Considering the results, Ca and B were prioritized to increase productivity, while N and B maintained the productivity of oil palm fresh fruit bunches. Based on the priority scale of nutrient needs, fertilizer application costs were expected to reduce.

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