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DRIS Analysis of Nutrient Balance for High–Yielding Oil Palm Plantations in Peatlands

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ABSTRACT

This study was conducted using an exploratory survey method to collect annual production data and analyze oil palm leaf samples from peatlands in several private oil palm plantations in West Kalimantan Province. The data obtained were analyzed using the *Diagnosis Recommendation Integrated System (*DRIS). The results showed that to achieve optimal production of 23.81–30.33 tons ha $^{-1}$ year $^{-1}$, the optimal nutrient ranges in the oil palm leaf tissue on peatland were N 2.20–3.03%; P 0.14–0.18%; K 0.52–1.03%; Mg 0.16–0.30%; Ca 0.31–0.65%; B 7.05–18.06 ppm; Zn 2.44–14.26 ppm; Cu 2.76–6.37 ppm; Mn 18.36–315.28 ppm; and Fe 38.90–92.40 ppm. The nutrient balance ratios in the oil palm leaves on peatland showed optimal ratios for N/P 14.72–19.11; N/K 1.88–5.42; N/Mg 8.25–15.75; N/Ca 3.89–7.77; K/P 3.51–6.46; Mg/P 1.08–1.85; Ca/P 1.94–4.24; K/Ca 1.07–2.31; K/Mg 2.33–4.63; Ca/Mg 1.54–2.69; B/N 2.70–7.05; B/Fe 47.16–116.26; B/K 11.93–32.65; B/Ca 18.73–34.48; and B/Mg 32.54–80.43. Oil palm plants cultivated on peatlands with high production groups (>25 tons ha $^{-1}$ year $^{-1}$) had average nutrient indices of N (–1.5), P (1.6), K (0.9), Ca (0.2), Mg (0.0), and B (–1.4), with nutrient requirements in the order of N > B > Mg > Ca > K > P. In contrast, plants in the low–production groups (<25 tons ha $^{-1}$ year $^{-1}$) had average nutrient indices of N (–8.3), P (–3.9), K (1.1), Ca (6.8), Mg (0.7), and B (2.9), with nutrient requirements in the order of N > P > Mg > K > B > Ca.

Keywords: nutrient balance, oil palm, peatland

INTRODUCTION

Oil palm is one of the leading commodities that contributes to important foreign exchange in Indonesia. In 2023, the area of oil palm plantations in Indonesia was recorded at 16.83 million ha (Ditjenbun 2023). West Kalimantan, one of the main producing regions, ranks third in crude palm oil (CPO) production, with a total of 5.8 million tons in 2021 (Sipayung 2023). Most oil palm plantations in Indonesia, especially in Kalimantan, are located on peatlands, which have special characteristics that affect plant growth. Peatlands in Indonesia currently reach about 14.9 million ha, spread across the islands of Sumatra, Kalimantan, and Papua, with West Kalimantan having 1.68 million ha of peatland (Ritung *et al*. 2011). Peatlands tend to have low fertility rates, characterized by a highly acidic pH, as well as a lack of macro–and micronutrients that are essential for plant growth. Oil palm plants planted in peatlands often face obstacles in their growth and development due to these conditions. In addition, the presence of toxic organic acids is an inhibitory factor.

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To overcome these challenges, proper fertilization is indispensable to increase the availability of nutrients in peatlands. However, unbalanced fertilization, or not considering the interactions between various nutrients, can lead to nutrient imbalances in the soil (Las *et al.* 2016). This will interfere with the absorption of nutrients by oil palm plants and potentially lead to considerable waste of fertilization costs, considering that peat soils require more nutrient input than mineral soils. Improper determination of the type and dosage of fertilizer results in nutrient imbalances, which in turn affect crop productivity.

Analytical methods commonly used to determine nutrient adequacy and balance include the critical nutrient concentration (CNC) and nutrient sufficiency range (NSR). Although both methods are often used, they have drawbacks, especially when it comes to a single assessment that cannot describe the interactions between nutrients that affect each other. Therefore, a more comprehensive approach is needed to analyze nutrient balance, one of which is the Diagnosis and Recommendation Integrated System (DRIS) method, which can provide a more in–depth picture of nutrient balance in peatlands and oil palm plant tissues. This study aims to determine the range of efficient nutrient balance in oil palm plant tissues on peatlands, using the DRIS method.

METHODS

Research Location

This research was carried out in several private plantations located in the regencies of Sintang, Sekadau, and Sanggau, West Kalimantan Province. Leaf samples and palm oil production data were obtained from oil palm plantations spread across the region. To ensure uniformity of the factors affecting the results of the analysis, leaf samples were taken from plants of uniform age. If there was a difference in the age of the plants between the samples, the age factor of the plants was controlled and 'eliminated' through statistical analysis before further data processing. This study was conducted from December 2022 to October 2023, for field data collection, data inventory, laboratory analysis, data processing and analysis.

Procedures

This research was conducted using an exploration survey approach focused on oil palm plantations planted on peatlands. The plantation was divided into several sample blocks with an area ranging from 30 to 60 ha, with a total sample of 800 blocks and oil palm production data collected specifically from oil palm plants planted on peatlands.

Leaf samples were taken from the 17th fronds of the plant and analyzed in the Nutrient Chemistry Laboratory to determine the nutrient levels of N, P, K, Ca, Mg, B, Mn, Cu, Zn, and Fe. Data analysis was carried out using DRIS Norm as a basis for determining the nutrient status of the plants. The data analysis steps were arranged sequentially and interrelated to obtain a comprehensive understanding of the nutrient status of the plants and their impact on production yields. The following is the sequence of data analysis steps used in this study, along with the relationship between these steps.

DRIS Standard.

The first stage of DRIS implementation involves determining the standard value or norm. The DRIS norm is the average ratio of the nutrient pairs of the high–growth population, which is characterized by n/p, n/k, n/ca, n/mg, b/n, k/p, ca/p, m/p, k/ca, k/mg, ca/mg, b/k, b/ca, b/mg, where n, p, k, ca, mg, and b, are N, P, K, Ca, Mg, and B, respectively. The number of examples used as the norm is at least 5‒10% of the total population with blocks that have a production of at least 25 tons ha^{-1} because blocks that reach or exceed these numbers are considered to have high production, which is relevant for further analysis. The next calculation was the calculation of the standard deviation (SD), diversity coefficient (CV), and minimum and maximum range values of each nutrient analysis in the block of the high production group. The determination of these norm values is the basis for subsequent steps, including the grouping of leaf nutrient ranges, calculation of the DRIS index, and analysis of the nutrient relationship with production. This norm was used in all subsequent stages of the analysis.

The range of leaf nutrients or leaf nutrient standards in the high–production group can be grouped using norms or averages and standard deviations with the criteria of *Deficient*, *Low*, Sufficient, *High*, and *Excessive*) on each nutrient. For the optimal nutrient range, the values are taken from "Norms ‒4/3 SD to Norm +4/3 SD". The low range was calculated from "Norms ‒4/3 SD" to "Norms ‒8/3 SD." Furthermore, under "norms ‒8/3 SD" is included in the category of deficiency. Numbers from "norms +4/3 SD" to "Norms +8/3 SD" are in the high category. Values over "Norms +8/3 SD" were categorized as excessive (Savita *et al.* 2016). This grouping provides an overview of the nutrient status of plants and provides preliminary information regarding whether the nutrients present in the plant are sufficient or excessive, which will later affect the analysis of the relationship between nutrients and plant production.

Analysis of the Relationship Between Oil Palm Leaf Nutrients and Oil Palm Production

The relationship analysis can be performed using correlation and regression analyses. The relationship between nutrients as a dependent variable, actual production, and predicted production of palm oil as independent variables. A graph of the nutrient relationship between oil palm leaves and oil palm production was made, and line equations and regression lines were produced. This analysis will provide information on how much nutrient status affects production results. The results of this analysis will be useful for understanding the relationship between nutrient adequacy levels and the results achieved, which is an important step before moving on to DRIS index analysis.

DRIS Index.

The next stage was the DRIS analysis by determining the DRIS indices. A mathematical analysis of DRIS can be performed for many nutrient pairs. After the standard value or norm was determined, the norm was then used to produce DRIS indices with the following mathematical model (in this study the nutrients to be evaluated are N, P, K, Ca, Mg, and B).

$$\text{N index} = (f(N/P) + f(N/K) + f(N/Ca) + f(N/Mg) - f(B/N))/5$$
$$\text{P index} = (-f(N/P) - f(K/P) - f(Ca/P) - f(Mg/P) - f(B/P))/5$$
$$\text{K index} = (-f(N/K) + f(K/P) + f(K/Ca) + f(K/Mg) - f(B/K))/5$$
$$\text{Ca index} = (-f(N/Ca) + f(Ca/P) - f(K/Ca) + f(Ca/Mg) + f(B/Ca))/5$$
$$\text{Mg index} = (-f(N/Mg) + f(Mg/P) - f(K/Mg) - f(Ca/Mg) - f(B/Mg))/5$$
$$\text{B index} = (f(B/N) + f(B/P) + f(B/K) + f(B/Ca) + f(B/Mg))/5$$

If N/P ≥ n/p, then f(N/P) = [(N/P)/(n/p)−1]1000/cv; if N/P < n/p, then the nutrient function f(N/P) = [1–(n/p)/(N/P)]1000/cv, where N/P is the ratio of N and P in the sample tissue being diagnosed, n/p is the norm, and cv is the coefficient of diversity associated with the norm. Other function values, such as f(N/K) and f(N/Ca), were calculated in the same way as f(N/P), using the corresponding norm and cv (Walworth and Sumner 1987). The calculated DRIS index provides more in–depth information regarding the lack or excess of nutrients in plants. The DRIS index value was used to establish the nutrient status and determine if there were any nutrient imbalances that need to be corrected to increase production.

The next step, after determining the value of the nutrient index, namely the N nutrient index, the P nutrient index, the K nutrient index, the Ca nutrient index, the Mg nutrient index, and the B nutrient index, was to determine the DRIS nutrient index interpretation criteria. If the DRIS nutrient index was close to 0 or equal to 0, then the nutrients in the plant were sufficiently met. If the DRIS nutrient index value <0 has a deficiency category, the value of the DRIS nutrient index = 0 had a sufficient category; if the value of the DRIS nutrient index >0 was in the excessive category (Wadt *et al*. 1998).

Nutrient Balance Index (NBI)

Using the DRIS method, the nutrient balance in plant tissues could be measured relative to the value of the nutrient balance index or NBI. NBI is the absolute sum of each DRIS index for each diagnosed nutrient. In this study, NBI was the absolute sum of the nutrient DRIS index values for N, P, K, Ca, Mg, and B. The smaller the NBI value (close to zero), the more balanced the nutrient composition of the sample being diagnosed is. The NBI value was calculated as follows (Walworth and Sumner 1987):

NBI = [N nutrient index] + [P nutrient index] + [K nutrient index] + [Ca nutrient index] + [Mg nutrient index] + [B nutrient index]

Generally, crop production decreases with higher NBI values. The relationship between the NBI value and crop production was illustrated in a scatter chart to determine the distribution of NBI values for production. The value of NBI that was considered optimal is determined by using the boundary line method with a production barrier of 25 tons ha^{-1} year^{-1}, as explained at the time of determining the norms. NBI provides a measure of the balance of nutrient content in the plant tissue. The relationship between NBI and production output can be analyzed to identify the optimal NBI values, which could be used to improve fertilization management and production yields.

Determination of optimal nutrient levels

Optimal leaf nutrient levels could be determined by capitalizing the correlation regression between the nutrient content of oil palm leaves and the DRIS index, based on the equation of Walworth and Sumner (1987). In general, regression equation analysis is needed to model the relationship between nutrient content and the DRIS index of each nutrient, where the nutrient content is an independent variable and the DRIS index is an independent variable. To determine the best model, the selection between the logarithmic and linear models was based on the value of the largest coefficient of determination. The optimal nutrient level was when the DRIS index value was 0 (zero). The assumption that the DRIS index value is zero means that the nutrient content of plants is in a balanced or optimal condition, so that nutrients are not a limiting factor in the achievement of production (Wadt *et al*. 1998). The determination of optimal leaf nutrient levels will provide practical guidance for achieving nutrient balance conditions that support optimal crop production.

RESULTS AND DISCUSSION

Norm DRIS

DRIS is obtained from the ratio of plant nutrients to the optimal value of the high–production crop group (DRIS Norms) (Saputra and Mulyawan 2021). DRIS displays the average of the simultaneously identifying imbalances. deficiency or deficiency, excess plant nutrients, and the ranking of essential nutrients that plants need (Serra *et al.* 2013). The main advantage of this approach lies in its ability to minimize the effects of tissue age on diagnosis, thus allowing one to sample over a wider range of tissue ages than would be possible using conventional critical value approaches (Bangroo *et al*. 2010).

The DRIS norms of the oil palm plants analyzed are shown in Table 1. It was shown that the norms of N, P, K, Mg, Ca, B, Zn, Cu, Mn, and Fe were 2.60%, 0,16%; 0,77%; 0,23%; 0,48%; 12.62 ppm; 8.38 ppm; 4.58 ppm; 200.13 ppm; 66.33 ppm, repectively. N/P norm values were 16.92; N/A 3.65; N/Mg 12.00; N/Ca 5.83; B/N 4.87; K/P 4.98; Mg/P 1.47; CA/P 3.09; B/P 81.71; K/Ca 1.69; K/Mg 3.48; ca/mg 2.11; B/K 17.79; B/Ca 26.61; and B/Mg 56.48. Ginting *et al.* (2013) stated that regarding the diagnosis of nutrient balance N, P, K, Ca, and Mg in oil palm leaves taken from soil samples under various conditions showed significant differences in nutrient content and crop production. The average oil palm production in this study was 18.94 tons ha^{-1}, with the lowest production was 2.82 tons ha^{-1} and the highest was 36.77 tons ha^{-1}.

The nutrient content in the oil palm leaves showed clear differences: nitrogen (N) ranged from 1.59% to

Table 1 Nutrient norms of the 17th fronds of oil palm planted on peatlands

Nutritional expression	High production population groups					
	Mean/ Norms	Variance	SD	CV	Min	Max
N (%)	2.60	0.10	0.31	12.02	1.83	3.05
P (%)	0.16	0.00	0.02	13.26	0.09	0.19
K (%)	0.77	0.04	0.19	25.31	0.29	1.12
Mg (%)	0.23	0.00	0.05	24.04	0.12	0.35
Ca (%)	0.48	0.02	0.13	27.81	0.30	0.85
B (ppm)	12.62	16.91	4.11	32.59	6.57	22.41
Zn (ppm)	8.38	19.31	4.39	52.45	1.33	14.74
Cu (ppm)	4.58	1.82	1.35	29.45	2.63	8.34
Mn (ppm)	200.13	7676.48	87.62	43.78	61.38	381.39
Fe (ppm)	66.33	419.61	20.48	30.88	27.89	100.88
N/P	16.92	2.71	1.65	9.73	12.69	20.61
N/K	3.65	1.33	1.76	48.27	2.12	9.75
N/Mg	12.00	2.81	7.90	65.80	8.10	21.37
N/Ca	5.83	1.46	2.12	36.43	2.66	7.98
B/N	4.87	1.63	2.66	54.51	2.86	8.94
K/P	4.98	1.11	1.22	24.56	1.78	7.07
Mg/P	1.47	0.29	0.08	5.66	0.73	2.27
Ca/P	3.09	0.86	0.75	24.14	2.04	5.70
B/P	81.71	25.91	671.53	821.88	48.41	140.63
K/Ca	1.69	0.46	0.21	12.64	0.50	2.70
K/Mg	3.48	0.86	0.74	21.36	1.35	5.90
Ca/Mg	2.11	0.43	0.18	8.66	1.52	3.20
B/K	17.79	11.14	124.21	698.09	9.92	71.47
B/Ca	26.61	5.91	34.87	131.07	21.27	43.87
B/Mg	56.48	17.96	322.52	570.99	36.75	107.76

2.99%, with an average of 2.52%; phosphorus (P) was 0.07% to 0.33%, with an average of 0.16%; potassium (K) from 0.41% to 2.33%, with an average of 1.01%; calcium (Ca) from 0.21% to 1.23%, with an average of 0.66%; and magnesium (Mg) between 0.11% and 0.68%, with an average of 0.27%. The results of this study confirm that the nutrient content of leaves is influenced by factors such as soil conditions and production levels, which can vary over a wide range.

A diagnosis of nutrient balance in oil palm plant tissues in Indonesia using the DRIS method was reported by Ginting *et al.* (2013). In his study, the nutrient ratio norms of N/P, N/K, N/Ca, N/Mg, K/P, Ca/P, Mg/P, K/Ca, K/Mg, and Ca/Mg were 15.92; 2.53; 3.87; 10.12; 6.35; 4.17; 1.62; 1.55; 4.05; 2.65, respectively. The range of nutrient balance in the oil palm network for N/P was 14.87–16.98; N/K was 2.31–2.76; N/Ca was 3.52–4.21; N/Mg was 8.97–11.28; K/P was 5.86–6.84; Ca/P was 3.81–4.53; Mg/P was 1.42–1.81; K/Ca was 1.36–1.75; K/Mg was 3.52–4.57; and Ca/Mg was 2.31–2.99.

The range of nutrients in the 17th fronds of oil palm on peatlands was grouped into the categories of deficient, low, optimum (sufficient), high, and excessive. Oil palms planted on peatlands had optimal production criteria between 23.81 to 30.33 tons ha^{-1} $year^{-1}$. For the optimal category, nutrient values that were considered adequate included N 2.20–3.03%, P 0.14–0.18%, K 0.52–1.03%, Mg 0.16–0.30%, Ca 0.31–0.65%, B 7.05–18.06 ppm, Zn 2.44–14.26 ppm, Cu 2.76–6.37 ppm, Mn 81.36–315.28 ppm, and Fe 38.90–92.40 ppm. The optimal range of nutrients found in this study, for both macro– and microelements, tended to be wider than the existing standard leaf nutrient criteria. This could be explained by several factors. First, the distinctive characteristics of peatlands, such as high organic matter content and low pH, can affect the availability and absorption of nutrients by plants; therefore, a wider range of nutrients is needed to reflect the variability of land conditions. Second, diverse plant genetic and physiological factors as well as different responses between oil palm varieties or individuals can lead to variations in nutrient requirements. Third, various environmental conditions such as humidity, temperature, and light intensity also play a role in influencing the ability of plants to absorb nutrients. Fourth, differences in the methodology and standards of leaf nutrient testing used in this study may account for the natural variability that exists in the field. Finally, nutrient management practices, including varied fertilizer applications, could produce different responses to nutrient availability, expanding the range of optimal values. Thus, the wider range of nutrients in this study reflects the adaptation to variability in peatland conditions and diverse plant needs.

Relationship of Macro– and Micronutrients to Oil Palm Production in Peatlands

This study analyzed the relationship between macro–and micronutrient levels on the 17th fronds of oil palm and oil palm production in peatlands. The results of the linear regression analysis showed that all observed nutrients, both macro (N, P, K, Mg, Ca) and micro (B, Cu, Zn, Mn, Fe), had a significant positive relationship with oil palm production, which was reflected in the high value of the determination coefficient (R^2).

The regression line equation for each nutrient affecting palm oil production in peatlands can be explained as follows: For nitrogen (N), the equation is $y = 6.0744x$ with $R^2 = 0.965$, indicating a strong relationship between nitrogen levels and palm oil production. Similarly, for phosphorus (P), the equation was $y = 99.307x$ with $R^2 = 0.965$, which also has a significant influence. The element potassium (K) had an equation of $y = 17.739x$ with $R^2 = 0.9223$, which signifies a considerable influence, although it was slightly lower than that of N and P. Magnesium (Mg) showed an equation of $y = 55.521x$ with $R^2 = 0.8573$, while calcium (Ca) had an equation of $y = 23.81x$ with $R^2 = 0.84$, both of which also contributed significantly to production. Boron (B), copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) had equations of $y = 0.8241x$ ($R^2 = 0.7738$); $y = 1.8492x$ ($R^2 = 0.6111$), $y = 1.3084x$ ($R^2 = 0.7058$), $y = 0.0584x$ ($R^2 = 0.8437$), and $y = 0.1306x$ ($R^2 = 0.6447$), respectively. Overall, the high R^2 values for most of these nutrients indicate that the nutrient levels in the 17th fronds played a major role in determining oil palm production in peatlands.

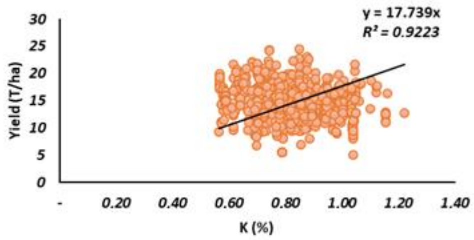
Although the regression analysis showed a positive relationship between nutrient levels and oil palm production, these results need to be understood in the context of the nutrient criteria in Table 2. The table classifies nutrient levels into five categories: "Deficient," "Low," "Optimum/Sufficient", "High," and "Excessive." Nutrient levels in the "High" or "Excessive" category indicated that very high nutrient levels have the potential to pose a negative risk to palm oil production. Even though linear correlations suggest that increased nutrient levels at a given range can support increased production, nutrient levels that fall into the "Excessive" category can have negative effects on plants. For example, N levels exceeding 3.45% are considered excessive and have the potential to disrupt plant metabolism, which can decrease production. The same is true for other nutrients such as K, Mg, and Ca. Therefore, even if the results of the regression analysis showed a positive relationship between nutrient levels and production, it is important to note that this relationship applies to the range of nutrient levels in the "Optimum" to "High" category (without falling into the "Excessive" category).

In this study, high R^2 values for some nutrients (such as N, P, and K) showed that increased nutrient levels in the range of "Low" to "Optimum" could indeed support increased production yields. However, at excessive levels, as described in Table 2, such positive effects can be reduced or even reversed, potentially inhibiting plant growth and lowering production yields. In line with these findings, previous research by (Ginting *et al* 2013) showed that very high levels of nutrients can disrupt the nutrient balance of plants and lead to a decrease in production yields. The results of the regression analysis show that the relationship between nutrients and palm oil production does not always follow a linear pattern. A fairly clear linear pattern was only indicated for nutrients N (a) and P (b), with a relatively high determination value (R^2), indicating a strong relationship. However, for other nutrients (K, Mg, Ca, B, Cu, Zn, Mn, and Fe), the relationship with palm oil production appears to be more widespread and does not form a clear linear pattern. This indicates that linear models may not be the best approach for all the nutrients. Therefore, further evaluation is required to determine the most appropriate regression model to improve the accuracy of oil palm production predictions based on the nutrient content of the leaves.

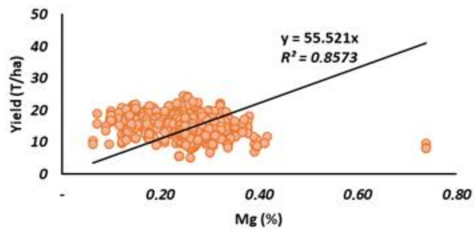
This study showed that nutrient levels in oil palm leaves have a linear relationship with peatland production, with a stronger correlation between N and P elements. These findings are in line with those of Ginting and Sutarta (2015), regarding the optimal levels of N, P, K, Ca, and Mg using the DRIS approach. The difference lies in the focus of the study, which emphasized the direct relationship between nutrient levels in leaves and oil palm production, whereas Ginting and Sutarta (2015) examined the relationship between nutrient levels and the DRIS index, which described the balance of nutrients in plant tissues. This difference in relationship patterns can be explained by differences in analytical approaches, where the DRIS

Table 2 Nutrient range in the 17th fronds of oil palm on peatlands

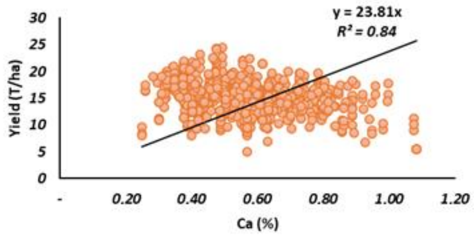
Nutrient expressions	Deficient	Low	Optimum/ Sufficient	High	Excessive
N (%)	<1.78	1.78–2.19	2.20–3.03	3.04–3.45	>3.45
P (%)	<0.10	0.10–0.13	0.14–0.18	0.19–0.21	>0.21
K (%)	<0.24	0.24–0.51	0.52–1.03	1.04–1.29	>1.29
Mg (%)	<0.08	0.08–0.15	0.16–0.30	0.31–0.37	>0.37
Ca (%)	<0.12	0.12–0.30	0.31–0.65	0.66–0.83	>0.83
B (ppm)	<1.53	1.53–7.04	7.05–18.06	18.07–23.57	>23.57
Zn (ppm)	<0.49	0.49–2.43	2.44–14.26	14.27–20.17	>20.17
Cu (ppm)	<0.94	0.94–2.75	2.76–6.37	6.38–8.17	>8.17
Mn (ppm)	<35.62	35.62–81.35	81.36–315.28	315.29–432.24	>432.24
Fe (ppm)	<12.00	12.00–38.80	38.90–92.40	92.41–119.20	>119.20
Production (T ha^{-1} $year^{-1}$)	<20.53	20.53–23.80	23.81–30.33	30.34–33.59	>33.59



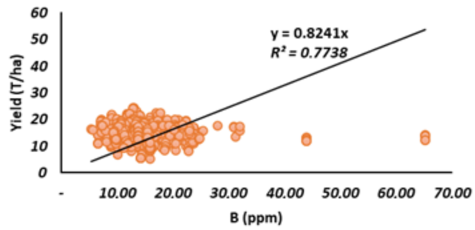
(c) Relationship between K nutrients in oil palm leaves and predicted yield.



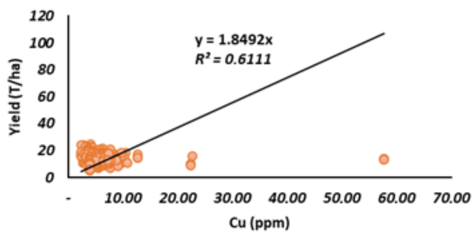
(d) Relationship between Mg nutrients in oil palm leaves and predicted yield.



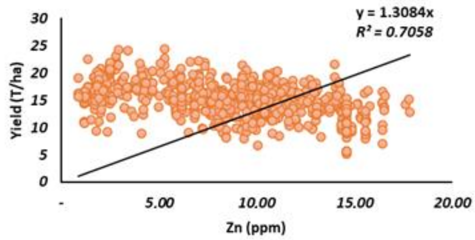
(e) Relationship between Ca nutrients in oil palm leaves and predicted yield.



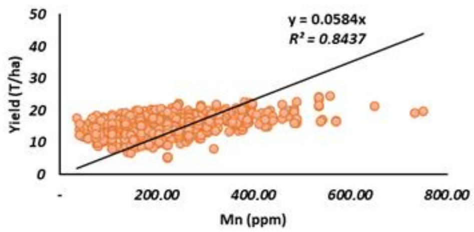
(f) Relationship between B nutrients in oil palm leaves and predicted yield.



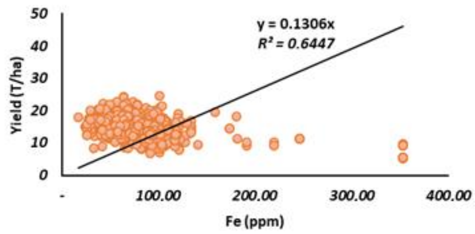
(g) Relationship between Cu nutrients in oil palm leaves and predicted yield.



(h) Relationship between Zn nutrients in oil palm leaves and predicted yield.



(i) Relationship between Mn nutrients in oil palm leaves and predicted yield.



(j) Relationship between Fe nutrients in oil palm leaves and predicted yield.

Figure 1 Distribution of macro nutrients: Nitrogen (a), Phosphor (b), Kalium (c), Magnesium (d), & Calcium (e) & micro nutrients: Boron (f), Cuprum (g), Zink (h), Mangan (j), & Ferrum (j) relationships with palm oil production in

index considers interactions between nutrients, whereas this study observed the direct impact of nutrient levels on crop yields. However, the optimum level set by Ginting and Sutarta (2015) remains an important reference for determining the range of nutrient adequacy required for optimal oil palm growth. This study underscored the importance of meeting nutrient levels in the optimum range to increase crop productivity, but the identified linear relationships need to be further investigated to understand the possibility of nonlinear relationships at more extreme nutrient levels.

DRIS Index

DRIS is one of the methods used to evaluate the nutrient status of plants using the ratio of leaf nutrients to a pair of nutrients through NBI. The DRIS indices describe the nutrient composition of plant tissues. The DRIS index describes the nutrient needs of existing plants. DRIS index of < 0 indicates a condition of nutrient deficiencies, indicating that the plant requires more additional nutrients than the amount previously provided to achieve optimal nutrient balance. The DRIS index = 0 describes the optimal conditions, where the nutrient level is sufficient for the needs of the plant, such that the dose of nutrient application given previously does not need to be changed. In contrast, a DRIS index > 0 signals excessive nutrients, which means that the plant does not require further nutrient addition, and the dose given earlier can be reduced. The response to the application of nutrients refers to adjusting the dose of fertilizer or nutrients applied to optimize nutrient conditions in plant tissues and achieve optimal results.

Based on the DRIS index calculation from 800 plant block samples, K, Ca, Mg, and B were the nutrients that have the most positive DRIS index numbers, which were 57%, 70%, 59%, and 56%, respectively. On the other hand, N and P had the most negative DRIS index numbers, namely 80% and 64%, respectively. The distribution of the DRIS nutrient index and its relationship with oil palm production in peatlands is shown in Table 3. N, P, K, Ca, Mg, and B were distributed over a range of negative and positive values, suggesting deficient, deficient, excessive, or excessive. The nutrient indices N, P, K, Ca, Mg, and B, which were close to zero, indicate that the nutrients were in a position and state that they are close to balanced or balanced.

The diagnosis results using the boundary line method with a limit of oil palm production in peatlands of 25 tons ha^{-1} year^{-1} (the production limit between the high–production subpopulation and the low–production subpopulation) yield the range of the minimum nutrient index and the maximum nutrient index presented in Figure 2.

Table 3 Total DRIS indices are positive and negative for each nutrient

Nutrient	DRIS index				Total	
	Positive		Negative			
N	163	20%	637	80%	800	100%
P	289	36%	511	64%	800	100%
K	458	57%	342	43%	800	100%
Ca	562	70%	238	30%	800	100%
Mg	469	59%	331	41%	800	100%
B	451	56%	349	44%	800	100%

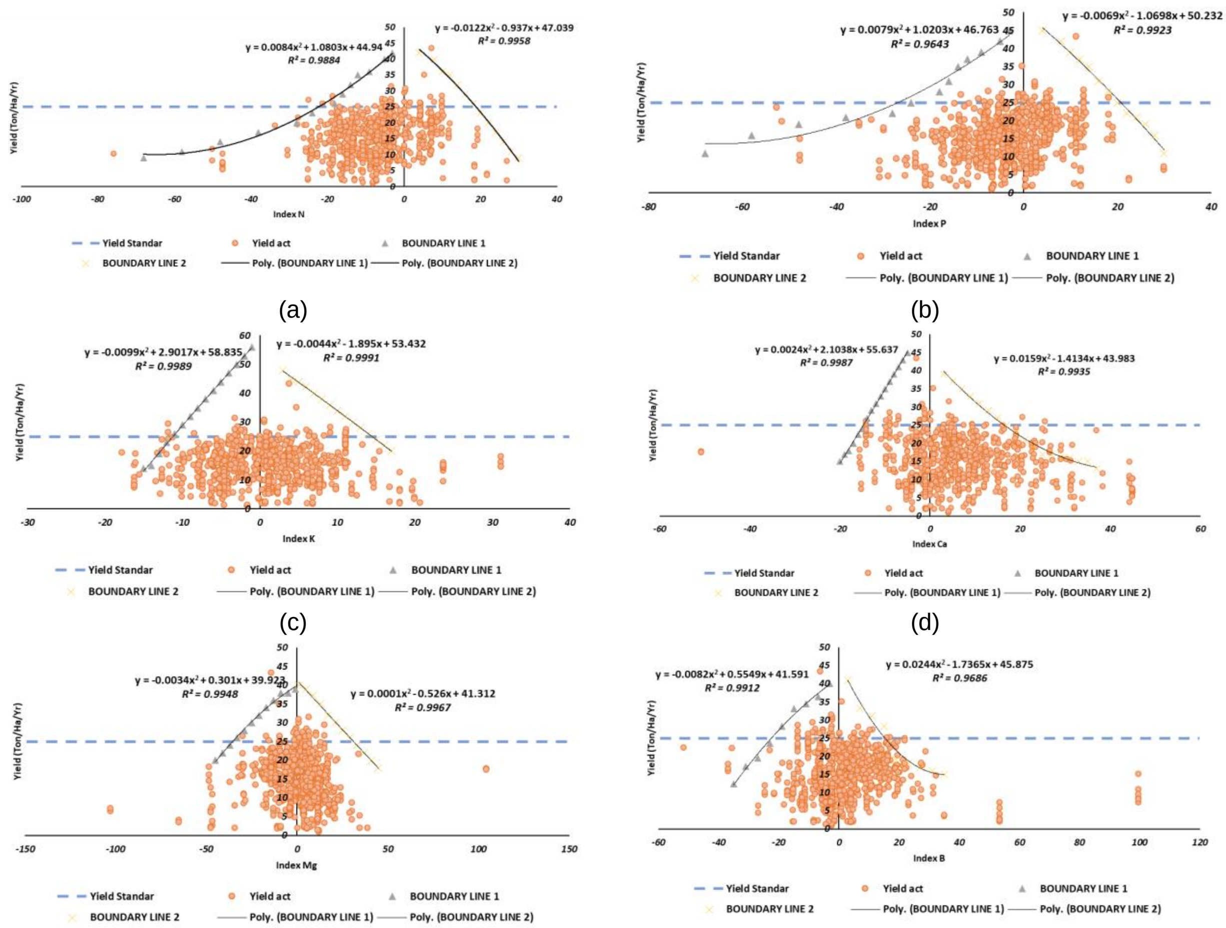


Figure 2 Distribution diagram of the relationship between oil palm production in peatlands and N (a), P (b), K (c), Ca (d), Mg (e), and B (f).

The results of the diagnosis of the nutrient index in the high–production subpopulation had Variability in Nutrient Levels consist of Nitrogen (N) and Magnesium (Mg) show the widest ranges (N: –25 to 10; Mg: –30 to 15), indicating high variability in these nutrients. Potassium (K) has the narrowest range (–12 to 11), suggesting more stable levels. Most nutrients (N, K, Ca, Mg, B) have means close to zero, implying balanced distributions. Phosphorus (P) has a slightly positive mean (2), suggesting a tendency toward higher values. Distribution Shape, Negative skewed: N (–0.79) and Mg (–1.07) have left–tailed distributions, meaning more frequent higher values. Positive skewed: Ca (0.77) and B (0.52) have right–tailed distributions, indicating more frequent lower values. Kurtosis: Mg (2.45) is leptokurtic (peaked with heavy tails), while P (–0.37) and K (–0.30) are platykurtic (flatter distributions). (Table 4).

On the other hand, the nutrient index in the low–production sub–population has a minimum and maximum nutrient index value, respectively, Mostnutrients (N, P, K, Ca, Mg, B) show negative minimum values, indicating severe deficiencies in some parts of the subpopulation. N and P have negative means (−8 and −4, respectively), suggesting overall deficiency in these nutrients. K, Ca, Mg, and B have positive means but very low values (close to zero), indicating marginal sufficiency or slight deficiency in some areas. Mg and B exhibit high variability (SD = 16 and 15, respectively), meaning their levels vary widely across the subpopulation. K has the lowest variability (SD = 7), suggesting more consistent levels. N, P, and Mg are left–skewed (negative skewness), meaning most values are clustered on the higher side but with extreme low outliers. K, Ca, and B are right–skewed (positive skewness), indicating clustering on the lower side with some extreme high values. B has a very high skewness (2.55), suggesting a strong right–tailed distribution (a few extreme high values). Mg and B have very high kurtosis (12.61 and 15.30), indicating heavy tails and potential outliers. N, P, and Ca have moderate kurtosis (>3), meaning distributions are more peaked than normal. K has near–normal kurtosis (1.31), suggesting a flatter distribution. Based on the results of the above diagnosis, the range of nutrient indices in the high–production subpopulation is more balanced when compared to the range of the nutrient index in the low–production subpopulation. This is shown by the range of DRIS nutrient index in the high–production subpopulation being narrower or shorter than those in the low–production subpopulation (Table 5).

Oil palm planted in peatlands has a high production group of >25 tons ha^{-1} $year^{-1}$. The average index of N (–1.5), P (1.6), K (0.9), Ca (0.2), Mg (0.0), and B (–1.4), meaning that it had a sequence of nutrient needs of N > B > Mg > Ca > K > P. In contrast, oil palm plants with a low production group of < 25 tons ha^{-1} $year^{-1}$ had an average nutrient index of N (–8.3), P (–3.9), K (1.1), Ca (6.8), Mg (0.7), and B (2.9), and had a sequence of nutrient needs of N > P > Mg > KB > Ca.

Each oil palm planted on a type of land has a relatively different DRIS and NBI. This is related to differences in climatic conditions. Origin of Mother Rock. factors in land formation. and of course, related to the cultivation practices in the field itself. Maharani (2009) examined the DRIS index for oil palm plants. Oil palm, which has a production of 33.76 tons ha^{-1} $year^{-1}$, had an index of N (–4.2), P (–2.1), K (4.5), Ca (8.0), and Mg (–6.2), and suggested a nutrient requirement sequence of Mg > N > P > K > Ca. On the other hand, in contrast to oil palm plants with a production of 17.93 tons ha–1 year–1 have a nutrient index of N (–4.9), P (–36.1), K (41.8), Ca (–2.4), and Mg (1.5) had the order of nutrient requirements P > N > Ca > Mg > K. According to Matos *et al*. (2017), oil palm grown in

Table 4 Range of oil palm nutrient indices in peatlands in high–production subpopulations

Nutrient index	High production subpopulation					
	Minimum	Maximum	Means	SD	Skewness	Kurtosis
N	–25	10	–1	9	–0.79	0.49
P	–15	18	2	8	0.01	–0.37
K	–12	11	1	6	–0.02	–0.30
Ca	–14	26	0	9	0.77	0.82
Mg	–30	15	0	9	–1.07	2.45
B	–14	22	–1	9	0.52	–0.23

Table 5 Range of oil palm nutrient index in peatlands in low–production subpopulations

Nutrient index	Low production subpopulation					
	Minimum	Maximum	Means	SD	Skewness	Kurtosis
N	–76	27	–8	11	–0,71	4.02
P	–53	30	–4	10	–0,83	3.14
K	–18	31	1	7	0,59	1.31
Ca	–51	45	7	12	0,47	2.84
Mg	–103	104	1	16	–0,34	12.61
B	–52	99	3	15	2,55	15.30

Brazil was identified using the DRIS method for the diagnosis of nutrient needs. The results showed that for young oil palm plants < 6 years after planting, the order of nutrient fulfillment was Ca > Fe > B > S > Mn > K > Mg = Cu > Zn > N > P In contrast to mature oil palm plants > 6 years after planting, the order of nutrient fulfillment was Ca > Mn > Zn > Fe > S = B > N = Cu > K > Mg > P.

Relationship of Nutrient Levels with Leaf DRIS Index

Regression analysis was used to determine the relationship between each nutrient and the DRIS index. The nutrient level became an independent variable (x), and the DRIS index became a dependent variable (y). The best model can be chosen between the linear and logarithmic models, which have the highest coefficients of determination. The nutrient content with the optimal criteria has a DRIS value of the nutrient DRIS index = 0 (zero). The regression analysis was carried out so that the regression equation for each type of nutrient is as follows: N nutrients with $y = 18.095x - 52.469$; P nutrients with $y = 218.21x - 36.513$; P with $y = 32.317x - 25.396$; Mg with $y = 193.65x - 47.107$; Ca with $y = 60.473x - 27.839$; B with $y = 1.9705x - 26.825$. When

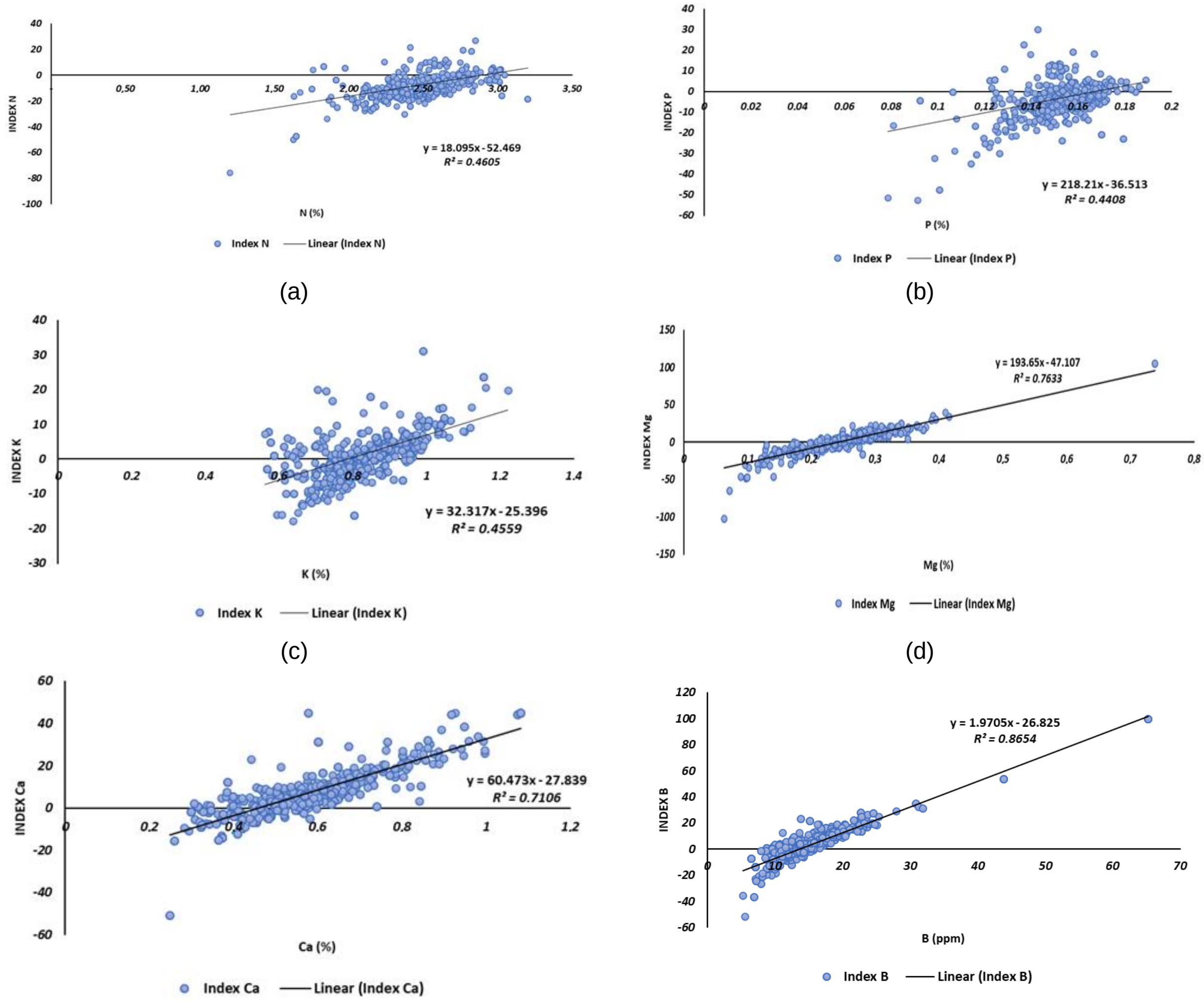


Figure 3 Relationship between the nutrient DRIS index N, P, K, Mg, Ca, and B with each nutrient level in oil palm leaves in peatlands.

Table 6 Optimum values of N, P, K, Mg, Ca, and B nutrients in oil palm leaves in peatlands based on the DRIS method

Nutrient	Regression line equation	R^2	Optimum nutrient levels
N (%)	$y = 18.095x – 52.469$	0.4605	2.90
P (%)	$y = 218.21x – 36.513$	0.4408	0.17
K (%)	$y = 32.317x – 25.396$	0.4559	0.79
Mg (%)	$y = 193.65x – 47.107$	0.7633	0.24
Ca (%)	$y = 60.473x – 27.839$	0.7106	0.46
B (ppm)	$y = 1.9705x – 26.825$	0.8654	13.61

each value of the nutrient index was replaced by 0 (zero) and with the calculation to obtain the optimal value of *x* (nutrient) then N, P, K, Mg, Ca, and B were 2.90%; 0,17%; 0,79%; 0,24%; 0,46%; and 13.61 ppm, respectively. The model of the relationship between the DRIS index and the optimal nutrient rate of the leaf, as well as the optimal nutrient rate per nutrient, is shown in Figure 3 and Table 6.

Nutrient Balance Index (NBI)

The relative nutrient balance indicator in oil palm can be determined using NBI. NBI is the sum of the total nutrient DRIS index of oil palm plants in absolute terms and is said to be balanced if the value of NBI is close or equal to zero. Higher NBI values indicate that the nutrient composition of oil palm plants is less balanced. The minimum and maximum values (means) of NBI in the high–production sub–population were 8 and 76, respectively, whereas the minimum and maximum values of NBI in the low–production subpopulation were 18 and 87, respectively. Based on a diagnosis using a limit line with a production limit of 25 tons ha^{-1} year^{-1}, an optimal NBI of approximately 38 was obtained (table 7). Figure 4 shows that production decreases with a larger NBI; on the other hand, high production is generally obtained by a lower NBI. Regression analysis showed the value of $R^2 = 0.5495$. NBI was calculated based on the ratio of available biomass to that required for production, adjusted to environmental conditions. These findings indicate that lower NBI is associated with higher production. The higher mean NBI in the low–production group might suggest differences in neurobehavioral traits affecting productivity. The skewness indicates that a few individuals in both groups have notably higher NBI scores. The kurtosis differences suggest variations in score clustering around the mean.

CONCLUSION

To achieve an optimum production of 23.81–30.33 tons ha^{-1} year^{-1}, the optimum nutrient range of oil palm leaf tissue in peatlands for nutrients N was 2.20–3.03% and P was 0.14–0.18%. The range of nutrient K is at 0.52–1.03%. The range of Mg nutrients was between 0.16–0.30%. Ca 0.31–0.65%. The range of micronutrients such as B is between 7.05–18.06 ppm, Zn nutrients are 2.44–14.26 ppm, Cu nutrients are between 2.76–6.37 ppm, Mn nutrients are between 18.36–315.28 ppm, and Fe are in the range of 38.90–92.40 ppm. Critical balance ratios were identified, such as N/P (14.72–19.11), K/Mg (2.33–4.63), and B/N (2.70–7.05), which are essential for maintaining nutrient harmony. High–yield plantations (>25 tons ha^{-1} year^{-1}) showed nutrient deficiencies in N and B, with requirements ordered as N > B > Mg > Ca > K > P. Low–yield plantations (<25 tons ha^{-1} year^{-1}) exhibited greater imbalances, with N and P being most deficient, followed by Mg, K, B, and Ca. A lower NBI (closer to zero) correlated with higher production, with an optimal NBI of ~38. High–yield plots had narrower NBI ranges (8–76) compared to low–yield plots (18–87), indicating better nutrient balance. The study provides precise nutrient targets and ratios for peatland oil palm cultivation, enabling optimized fertilization strategies to enhance productivity while reducing inefficient overfertilization. Achieving balanced nutrient management based on DRIS–derived norms can significantly improve oil palm yields on peatlands, addressing both nutrient deficiencies and excesses to support sustainable cultivation.

Table 7 Range of oil palm nutrient balance index in peatlands in high–production and low–production subpopulations

NBI	Minimum	Maximum	Means	SD	Skewness	Kurtosis
High production population	8	76	38	16	0.32	–0.08
Low production population	18	87	45	15	0.34	0.40

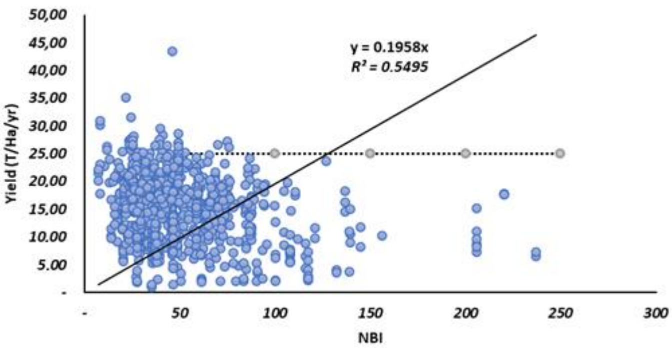


Figure 4 Distribution of the relationship between oil palm production on peatlands and NBI.

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