

# A COMPREHENSIVE ASSESSMENT OF COMPOSITION AND NUTRIENT CONTENT IN VARIOUS COMMERCIAL FERTILISERS USED IN INDONESIAN OIL PALM PLANTATIONS

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## ABSTRACT

*The objective of this study was to evaluate the composition and nutrient content of various types of commercial fertilisers used in oil palm plantations in Indonesia. The utilisation of non-conforming fertilisers harms soil fertility and health, leading to decreased plant productivity and affecting product quality. Combating non-conforming fertilisers is therefore crucial in supporting the sustainability of oil palm plantations. This study is classified as evaluative, with primary data comprising fertiliser analysis results, interviews, and field observations. Fertiliser samples were obtained from oil palm plantations in eight provinces in Indonesia, namely Central Kalimantan, South Kalimantan, West Kalimantan, East Kalimantan, South Sumatra, West Sumatra, Riau and North Sumatra. The results demonstrate that the quality of the tested fertilisers can be categorised into three criteria: Original fertilisers, adulterated fertilisers and counterfeit fertilisers. NPK fertiliser tends to be a target for counterfeiting due to its relatively high price, widespread usage across various agricultural commodities and ease of imitation with available technology. In conclusion, this comprehensive assessment sheds light on the varying compositions and nutrient content of fertilisers used in oil palm plantations. The findings can assist plantation managers in making informed decisions to enhance overall productivity and sustainability in oil palm cultivation.*

**Keywords:** adulterated, counterfeit fertilisers, non-conforming fertilisers, nutrient content, soil health.

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## INTRODUCTION

Oil palm plantations are a crucial agricultural sector for Indonesia's economy (Abdul-Hamid *et al.*, 2022; Dermawan *et al.*, 2022; Krishna *et al.*, 2017; Waudby & Zein, 2021). The cultivation of oil palm significantly contributes to palm oil production, one of Indonesia's primary export commodities (Afriyanti *et al.*, 2016; Lam *et al.*, 2019; Xin *et al.*, 2022). To support the sustainable and optimal productivity of oil palm plantations, proper fertilisation plays a crucial role (Essono *et al.*, 2023; Lim *et al.*, 2023; Zainuddin *et al.*, 2022). Fertilisers are essential sources of nutrients for plants, fulfilling their nutritional requirements for growth, development and optimal yields (Albuquerque *et al.*, 2022; Georgieva *et al.*, 2022; Wilson & Shakya, 2023). Selecting and using the right type of fertiliser directly influences the quality and

productivity of oil palm (Liu *et al.*, 2023; Morra *et al.*, 2021; Shahwar *et al.*, 2023). As a result, fertilisation becomes a key factor in enhancing productivity, with fertiliser costs accounting for approximately 37% of total production expenses, or around 60% of the total maintenance costs for oil palm cultivation (Aji *et al.*, 2021; Arifin *et al.*, 2022; Firmansyah *et al.*, 2021; Saprida & Saruksuk, 2021).

However, farmers and plantation managers often face numerous choices of fertiliser options, each with different nutrient compositions (Chen *et al.*, 2023; Hu *et al.*, 2024; Li *et al.*, 2018; Martin *et al.*, 2023). Given the variety of fertilisers available in the market, it is essential to evaluate the composition and nutrient content of each fertiliser (Dhankhar & Kumar, 2023; Nektarios *et al.*, 2022). This becomes more complex with the prevalence of counterfeit fertilisers, posing a serious threat in the agricultural sector (Khor & Zeller, 2014; Michelson *et al.*, 2021; Pujawati & Kurniati, 2021). This phenomenon arises due to the increased demand for fertilisers by farmers and plantation managers, leading to illegal practices in fertiliser production and distribution (Bold *et al.*, 2017). Many cases have been reported where counterfeit fertilisers are sold in the market with deceptive labels and packaging, raising concerns among farmers about the quality and safety of the fertilisers that they use (Jamilah *et al.*, 2022; Pujawati & Kurniati, 2021). These cases are not limited only to Indonesia but have also been reported in Malaysia (San, 2022), Nigeria (Dania, 2023), India (TNN, 2022), California (Fromartz, 2011), Tanzania (Michelson *et al.*, 2021; Norton *et al.*, 2020), Vietnam (Nam, 2008), Ghana (Beidou Company, 2019) and several other countries.

Such unethical practices can lead to potential financial losses and reduced production for farmers. The use of inappropriate fertilisers can negatively impact soil fertility and health, decrease crop yields, affect product quality and hamper overall agricultural productivity (Huang *et al.*, 2023; Li *et al.*, 2018; Liu *et al.*, 2022; Quemada *et al.*, 2019). From a cost perspective, it can result in significant financial burdens due to increased fertilisation expenses without proportional gains in production. The use of counterfeit fertilisers also renders the subsequent application of the 5R approach (right source, right method, right timing, right application site), ineffective. Cases of counterfeit fertiliser application typically occur among oil palm industry stakeholders who seldom or never conduct nutrient content identification and testing of the received fertilisers (Fitrya *et al.*, 2022; Wongmaneeroj *et al.*, 2019). Various reasons cited by farmers and plantation managers include lack of knowledge, expensive analysis costs, prolonged analysis results and inconsistent employee performance in fertiliser sampling (Rui *et al.*, 2012; Vuthy, 2020). Therefore, it is crucial to combat non-conforming fertilisers.

The use of counterfeit fertilisers can be considered to have the same effect as not fertilising at all, as only the fertiliser material is provided, without supplying the necessary nutrients for oil palm plants. This becomes even more severe when it occurs in the plantations of Indonesian farmers because almost 90% exhibit potassium (K) deficiency, 50% lack nitrogen (N) and 67% lack phosphorus (P) (Lim *et al.*, 2023). Rhebergen *et al.* (2016) explain that with poor nutrient management, the yield gap in oil palm production can reach 5 t ha<sup>-1</sup> yr<sup>-1</sup>. Continuous N fertilisation in oil palms can maintain yields above 30 t ha<sup>-1</sup> yr<sup>-1</sup>, but cessation can lead to a drastic decrease (Anuar *et al.*, 2008). However, excessive use of fertilisers in oil palm plantations can increase leaching processes and alter nutrient reserves in the soil without a significant increase in production compared to sufficient doses (Dubos *et al.*, 2016).

Earlier studies have focused on oil palm fertilisation, providing insights into fertiliser usage in general. However, specific data regarding the composition and nutrient content of commonly used fertilisers in oil palm plantations remain limited. The objective of this study was to evaluate the composition and nutrient content of various types of fertilisers commonly used in oil palm plantations. Analysing the nutrient content of different fertilisers is expected to provide in-depth information on the benefits and efficiency of each fertiliser for oil palm growth.

## MATERIALS AND METHODS

### Research Location

The research was conducted from March to June 2023 at PT. Mustika Sembuluh (PT. MS), located on Jl. Jenderal Sudirman Km 62 Sampit – P. Bun, Kab. Kotawaringin Timur, Central Kalimantan, Indonesia. This study was carried out in several oil palm plantations situated in different regions. The selection of these locations ensured a broader representation of fertiliser usage across various oil palm plantations. Samples were collected from eight provinces in Indonesia, namely Central Kalimantan, South Kalimantan, West Kalimantan, East Kalimantan, South Sumatra, West Sumatra, Riau, and North Sumatra (Figure 1).

### Research Method

This study belongs to the category of evaluative research, involving the assessment of the composition and nutrient content of various fertilisers in different oil palm plantations. The types of fertilisers used in the study include nitrogen phosphorus potassium (NPK), nitrogen

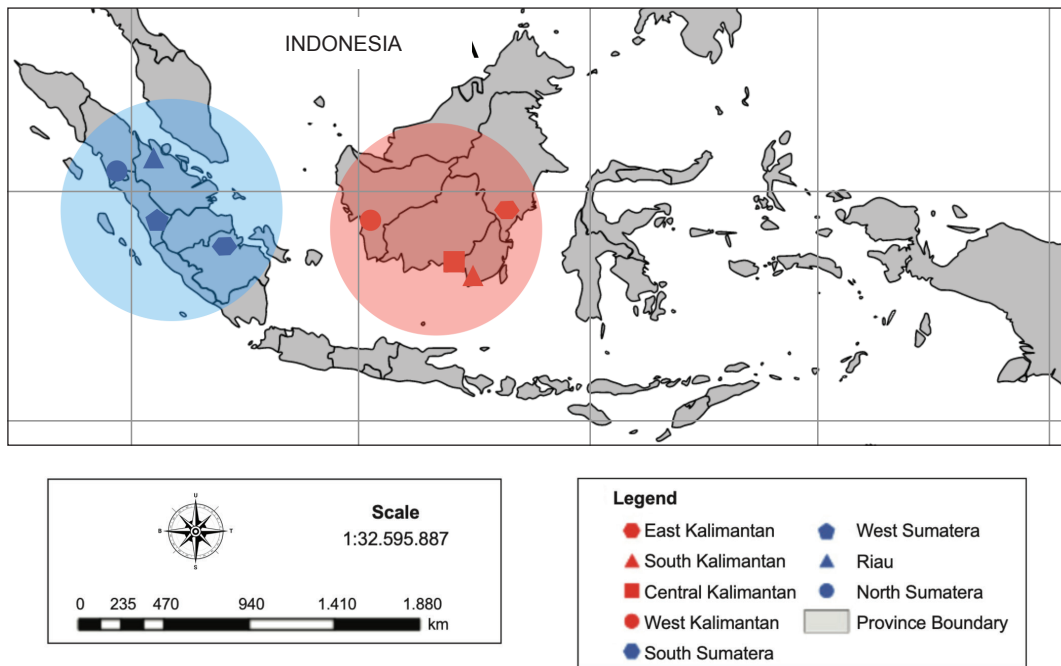


Figure 1. Locations where fertiliser samples were taken.

potassium (NK), rock phosphate Peru (RP Peru), dolomite, muriate of potash (MOP), kieserite, magnesium sulfate heptahydrate (MgSB), sulphuric acid (SOA), borate and urea. Primary data collection includes fertiliser analysis results, interviews, and field observations. Interviews were conducted with farmers, farmer groups and plantation staff or managers. Fertiliser samples were analysed in the laboratory to determine their composition and nutrient content. Direct observations were made in the oil palm plantations to understand the specifications of various fertiliser types, fertiliser sampling methods and how non-conforming fertilisers were handled. The secondary data consists of previous studies and reports, fertiliser product knowledge and relevant regulations and policies.

**Research Procedure**

Samples of various types and brands of fertilisers were collected from different oil palm plantations. The sampling of solid fertiliser in sack packaging followed the Indonesian National Standard (SNI) 19-0428-1998. Upon receiving the fertilisers, standard checks were performed on the packing and labels, including the condition of the sack thread, the condition of the inner plastic, the number of torn sacks, packaging labels, and the type and origin of the fertiliser. Each sampled sack was given a number using a marker to facilitate identification of the sack’s source truck and other relevant details. Each sample sack was weighed to assess the consistency of sack weights per arrival.

Sampling of fertiliser from the sacks was conducted using a probe. Each sack sample was sampled diagonally from the bottom left and right sides. The sack sample was laid horizontally and probed from the bottom to the top, or from two opposite corners, using a stainless-steel probe. The fertiliser obtained from the probe was mixed in a bucket to create a composite sample. When sampling from the fertiliser sack, the hole in the stainless-steel pipe should face downward. Once the pipe is fully inserted, it is rotated 180° until the hole faces upwards and is filled before removing the pipe. Each sample sack is referred to as a primary sample, and several sacks will be sampled as per SNI 19-0428-1998. All primary samples will be combined to create composite samples, totalling more than 750 g (Figure 2).

Interviews were conducted in a structured manner with farmers, members of farming groups, and staff/managers of oil palm plantations, who were selected through specific inclusion criteria to ensure sufficient knowledge about oil palm fertilisation. The interview questions, based on literature and research objectives, will explore respondents’ experiences with different types of fertilisers and their effectiveness, quality, and selection challenges. Interviews were conducted in an atmosphere that supported honesty, informed consent agreement, and accurate recording to ensure data reliability. Data analysis will use qualitative content methods with coding to identify the main themes and data triangulation to enhance the reliability and validity of the findings. This systematic and ethical approach aimed to

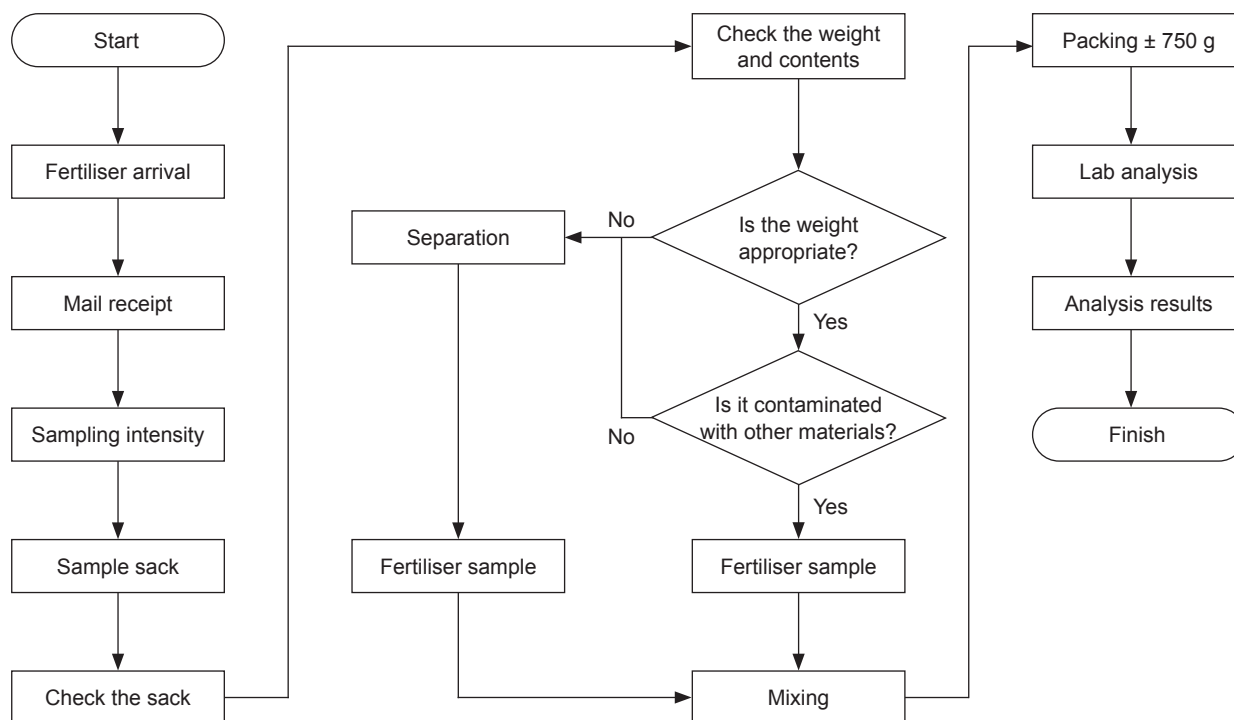


Figure 2. Flow diagram of fertiliser sampling.

produce valuable insights into the evaluation of fertiliser composition and nutrient levels in palm oil plantations, with reliable and credible findings.

### Data Analysis

Descriptive and comparative analysis methods were used to analyse the data. Descriptive analysis provides detailed insights into the composition and nutrient content of each evaluated fertiliser type. Descriptive and comparative analyses were used for data analysis. A descriptive analysis was used to provide a detailed overview of the composition and nutrient content of each type of fertiliser. The comparative analysis in this study utilised advanced statistical methods to objectively compare the composition and nutrient content of various types of fertilisers, identifying statistically significant differences through Analysis of Variance (ANOVA). *Post-hoc* Least Significant Difference (LSD) and independent t-test <5% analyses were used to determine specific differences between fertiliser groups. This approach was strengthened by correlation and regression analyses to uncover the relationship between fertiliser composition and its effects on oil palm growth. This study ensured reliability and validity by using a representative sample and accurate data processing using SPSS Statistics 29 software. The results are credible and offer evidence-based recommendations regarding the selection of the most effective fertilisers for oil palm plantations.

## RESULTS AND DISCUSSION

### Fertiliser Quality Criteria Analysis

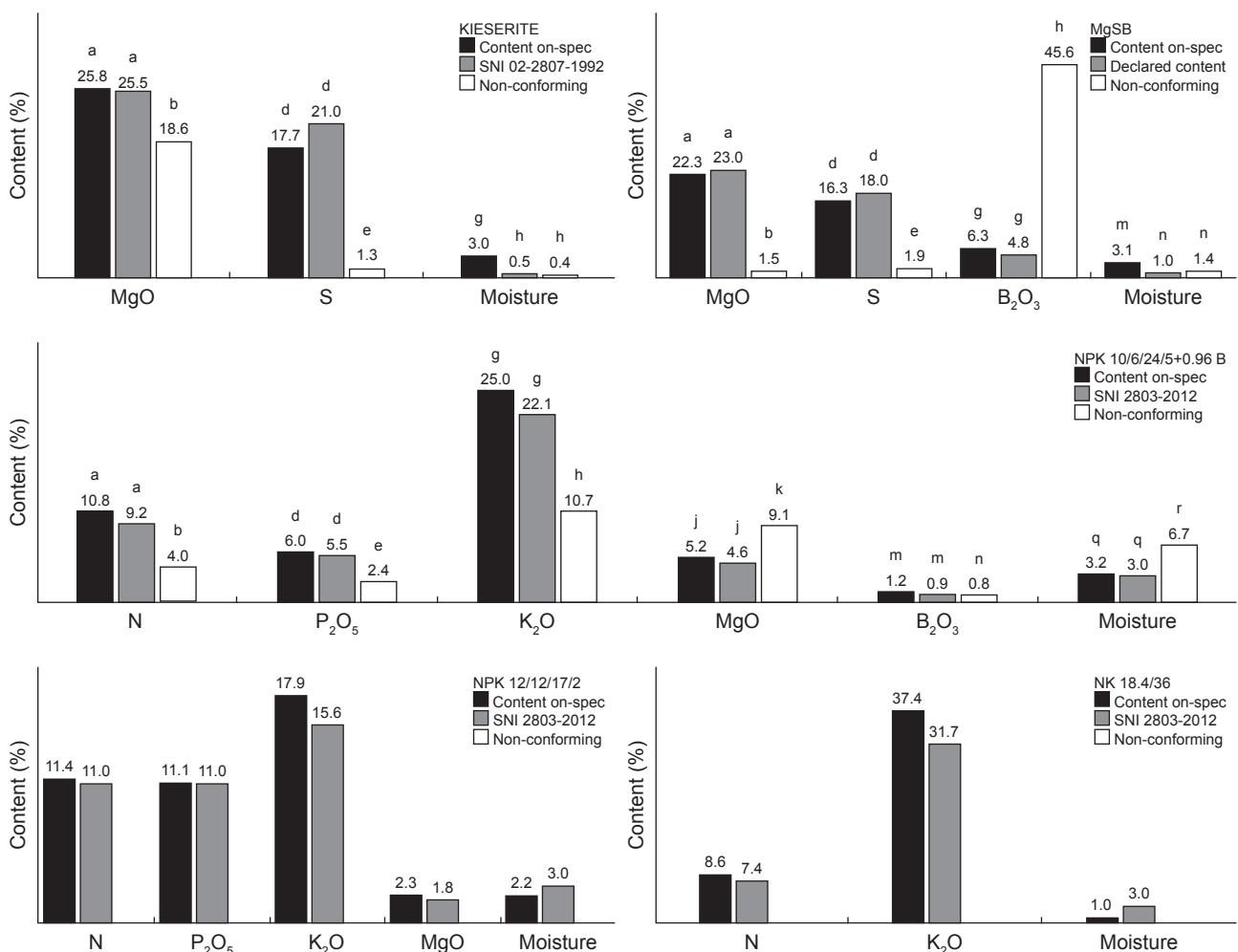
The laboratory analysis of composition and nutrient content showed that the presence of non-conforming fertilisers reached 2.8%. Among the tested samples throughout the year, NPK fertiliser had the highest percentage of non-conforming at 2.4%, followed by kieserite at 0.3% and MgSB at 0.1% from a total of 723 samples. No non-conforming fertilisers were found in the samples of NPK, NK, RP Peru, dolomite, MOP, SOA, borate, and urea during the year 2022. There are two types of NPK, namely NPK 10/6/24/5+0.96 B, which for convenience are referred to as NPK 10, and NPK 12/12/17/2, are referred to as NPK 12. Although MOP fertiliser was found to contain some other mixed materials, resulting in a non-conforming condition, its nutrient content still fell within the permissible tolerance range. The SNI has set the standard for the content of NPK and NK fertilisers (SNI 2803-2012), RP (SNI 02-3776-2005), dolomite (SNI 02-2804-2005), MOP (SNI 02-2805-2005), kieserite (SNI 02-2807-1992), SOA (SNI 02-1760-2005), borate (SNI 02-4959-1999), and urea (SNI 2801-2010). These standards regulate the quality criteria of the fertilisers concerning their composition and nutrient content that must be met.

Figure 3 and 4 compare the chemical compositions of various fertiliser samples, grouped according to the percentage of components that meet the specifications (content on-spec),

following the SNI, and those that did not meet the specifications (non-conforming). Each bar is labelled with lowercase letters below it (a, b, d, e, g, m, n), representing the notation from the LSD test at the 5% significance level; numbers with the same lowercase letter notation indicate no significant statistical difference.

Based on the mentioned standard, a tolerance of 8% SNI 2803-2012 is allowed for the nutrient content stated on the fertiliser NPK label. For example, NPK 10 fertiliser has a tolerance of N min 9.2%, phosphate (P<sub>2</sub>O<sub>5</sub>) min 5.5%, potassium oxide (K<sub>2</sub>O) min 22.1%, magnesium oxide (MgO) min 4.6%, boron oxide (B<sub>2</sub>O<sub>3</sub>) min 0.9% and maximum moisture of 3.0%. Other fertilisers such as NK, RP Peru, dolomite, MOP, kieserite, MgSB and SOA also have tolerance standards based on SNI, as shown in Figure 3. For the tested NPK 10 fertiliser, its nutrient content was found to be significantly below the standard specified on the label and SNI 2803-2012. The nutrient content

of this NPK fertiliser was only about 50% of the established standard. Specifically, the N content was 4.0% (min 9.92%), P<sub>2</sub>O<sub>5</sub> was 2.4% (min 5.5%), and K<sub>2</sub>O was 10.7% (min 22.1%). Furthermore, the B<sub>2</sub>O<sub>3</sub> content was low, at 0.8% (min 0.9%), while the MgO content was excessively high at 9.1% (min 4.6%). These significant discrepancies between the found nutrient contents and the standard indicate that the fertilisers can be categorised as non-conforming fertiliser. Such inconsistency points to potential errors or fraudulence in the production or distribution process, resulting in the received fertiliser not meeting the specified standards. Similar deviations were also observed for Kieserite (MgO 18.6% and S 1.3% below the standard) and MgSB (MgO 1.5% and S 1.9% below the standard), with B<sub>2</sub>O<sub>3</sub> exceeding the standard significantly. In the context of NK and NPK 12 fertilisers, no significant difference was found between these fertilisers and the SNI, thus, no non-conforming fertilisers were detected.



Note: Each bar labelled with the same lowercase letter notation indicates no statistically significant difference from the LSD test at the 5% significance level.

Figure 3. The average nutrient content of various types of fertilisers analysed in the laboratory (kieserite, MgSB, NPK and NK).

The results in *Figure 4* indicate that the nutrient content in RP Peru, Dolomite, MOP, SOA, Borate and Urea fertilisers generally comply with the applicable SNI. For RP Peru, the total  $P_2O_5$  (30.1% and min 28.0%) and moisture content (4.0% and max 5.0%) were very close to the SNI 02-3776-2005 standard. Meanwhile, Dolomite exhibited compliance with the SNI 02-2804-2005 for MgO (18.6% and min 18.0%), CaO (32.1% and min 29.0%), and moisture content (1.4% and max 3.0%). Similarly, MOP met the SNI 02-2805-2005 requirements for total  $K_2O$  (60.4% and min 60.0%) and moisture (0.4% and max 1.0%). For SOA, the N (20.9% and min 20.8%) and S content (23.3% and min 23.8%), as well as moisture (0.1% and max 1.0%), appeared to be in line with SNI 02-1760-2005. For Borate, the  $B_2O_3$  content (49.4% and min 45.0%) and moisture 2.3% complied with SNI 02-4959-1999. And finally, Urea adhered to the SNI 2801-2010 standard for N content (46.4% and min 46.0%) and moisture (0.3% and max 0.5%). Overall, there are no statistically significant differences in terms of nutrient content and moisture between the analysed samples and the SNI standards, with no fertilisers identified as non-conforming.

Based on field observations and the nutrient content results as shown in *Figure 3* and *4*, the fertiliser quality can be categorised into three criteria: On-spec fertilisers (original), adulterated fertilisers and counterfeit fertilisers. On-spec fertilisers maintain the nutrient content as specified on the label and comply with the SNI standards. It can be relied upon to provide the necessary nutrients for plant growth. Non-conforming adulterated fertilisers contain a nutrient content of only about 50% of the label and SNI. Its use may reduce productivity and harvest quality due to inadequate nutrient supply. Counterfeit fertilisers, on the other hand, contain nutrient content far below the label and SNI specifications for that fertiliser type, even less than 1%. This classification aids in identifying the different qualities of fertilisers available in the market and facilitates standardisation for fertiliser users, such as farmers and plantation managers.

*Figure 5* shows a series of scatter plots of the distribution of nutrient levels in the NPK 10 fertiliser samples. Each plot represents one type of nutrient, with red dots indicating samples with nutrient levels below the tolerance standard of

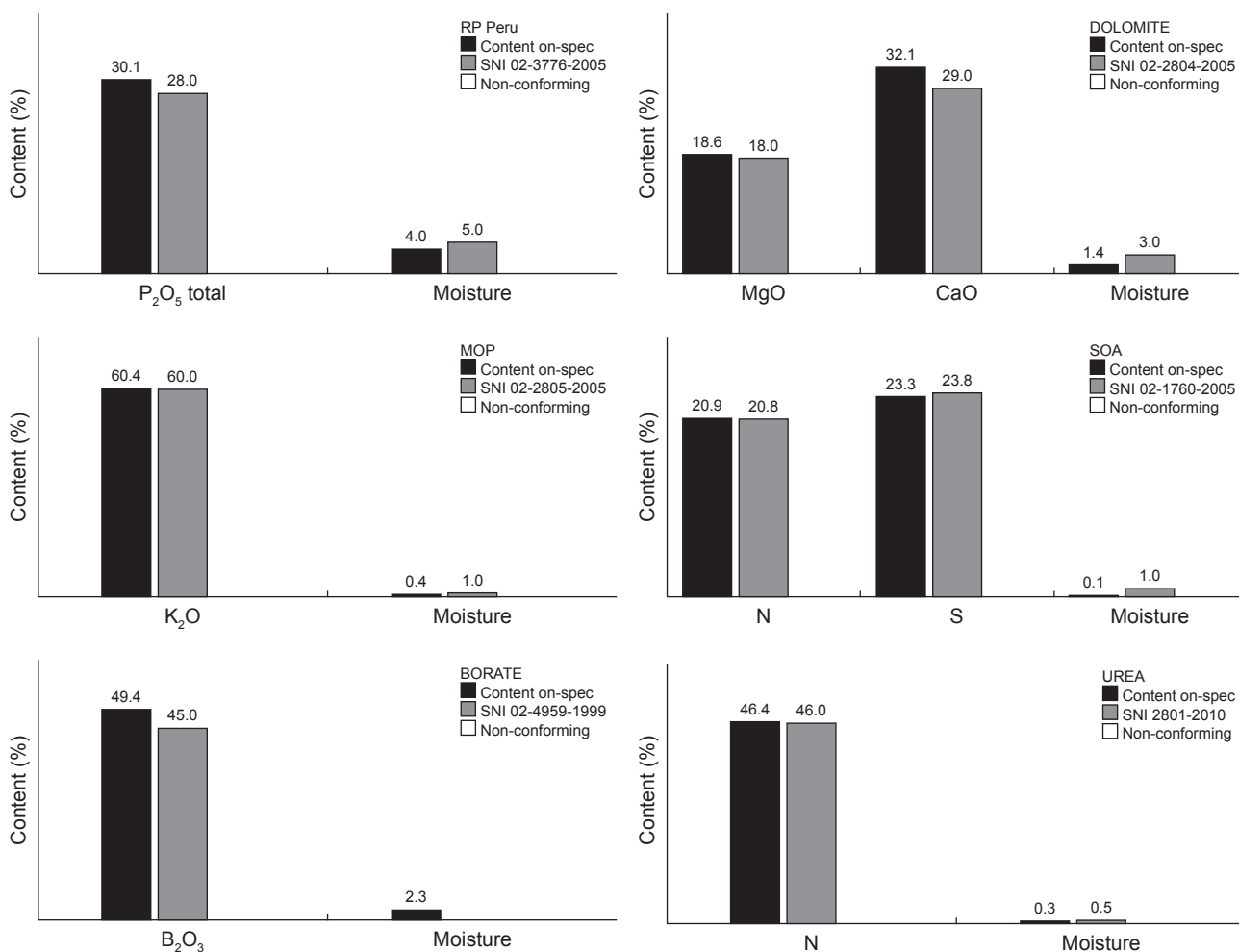


Figure 4. The average nutrient content of various types of fertilisers analysed in the laboratory (RP Peru, dolomite, MOP, SOA, borate, urea).

SNI 2803-2012 (non-conforming) and blue dots indicating samples with nutrient levels above the standard (original). The red and blue colours were also used to illustrate the significant difference between the original and non-conforming fertilisers, based on the results of the independent t-test  $<5\%$ . The results of the independent t-test at  $<5\%$  level indicate that the contents of N,  $P_2O_5$ ,  $K_2O$ , MgO and moisture showed significantly different results between the original NPK 10 and the non-conforming, with only  $B_2O_3$  not showing a significant difference. This figure assists in identifying fertiliser samples that meet or do not meet the specified requirements based on SNI standards and provides a visual representation of the variation in nutrient content among samples.

In *Figure 5*, N shows that most samples are above the 9.20% standard (blue), with a small portion below the standard (red).  $P_2O_5$  levels were displayed similarly, with a minimum standard of 5.52%, also showing a majority above the standard.  $K_2O$  samples exceeded the 22.08% threshold in large numbers. The MgO and  $B_2O_3$  plots followed the same pattern, with standards set at 4.60% and 0.96%, respectively. Moisture content is marked in red for levels above 3.00% and in blue for below. These plots clearly illustrate that most samples are above the nutrient standards; however, caution is advised, as there are samples below the standard for all NPK 10 nutrient contents tested.

In some cases, slight deviations below the minimum tolerance level set by SNI 2803-2012 may be found for one nutrient content in the on-spec fertiliser in *Figure 5*. However, the differences are not significant, and other nutrient contents remain at high levels. This indicates that although there is a slight discrepancy in one nutrient content, the fertiliser still maintains relatively good quality. Through this visualisation and comparison, the distribution of nutrient levels in NPK 10 fertiliser and its compliance with the established standard can be seen clearly.

*Figure 6* presents a visual comparison between original and adulterated NPK Mix 10 fertilisers. The original NPK Mix 10 is marked by the presence of dominant white and yellowish granules (such as urea, kieserite and borate) and the absence of dark brown granules. Furthermore, the original NPK 10 fertiliser exhibits richer colour variations, with around five different colours in the mixture. Conversely, the confirmed adulterated NPK fertiliser displays dark and dominant brown granules, even causing the white granules to fade. Additionally, only four colour variations are visible in the mixture, indicating an imbalance in fertiliser composition. This is further evidenced by the absence of urea granules (yellowish-white and round) and the difficulty in differentiating kieserite and borate granules due to their colour fading

caused by the adulterated granules. Other visual differences may also be observed in the quality of the fertilisers. The original fertilisers tend to have a uniform texture and do not contain foreign or additional materials that should not be present. On the other hand, counterfeit fertilisers often appear non-homogeneous, unevenly granulated, or even contain hazardous materials. These visual differences are crucial for farmers and fertiliser users as they can be an initial indication of the authenticity and quality of the purchased fertiliser.

The presence of non-conforming fertiliser with unsuitable nutrient content can also be due to the addition of other materials. There are some common examples of non-conforming fertilisers, such as adulterated fertilisers and counterfeit fertilisers. Firstly, adulterated fertiliser occurs when the original fertiliser is mixed with additional materials that should not be present in its composition. For instance, *Figure 7* shows MOP fertiliser mixed with materials like sand, brick, or laterite soil. This is done to increase the volume of the fertiliser, reduce production costs, or is deliberately carried out by irresponsible parties by reducing the amount of original fertiliser in the sack and refilling it with unsuitable materials. Secondly, non-conforming fertiliser refers to a situation where the original fertiliser is replaced with other materials that may appear to have similar characteristics but differ in their actual composition and nutrient content. For example, kieserite fertiliser is substituted with dolomite, which is, in fact, a different material (*Figure 7*). This can result in differences in nutrient content and composition that should be present in the original fertiliser.

### Prevalence of Counterfeit NPK Fertilisers in the Market

The field observations and *Figure 7* above provide valuable insights into the prevalence of counterfeit NPK fertilisers in the market. NPK fertilisers are more susceptible to counterfeiting, compared to other types of fertilisers, and several relevant factors explain this phenomenon. Firstly, it is crucial to note that the use of NPK fertilisers has become widespread and significantly increased across various agricultural commodities. NPK fertilisers are popular and extensively utilised in agriculture due to their combination of three essential nutrients: N, P and K. These elements play a crucial role in supporting plant growth and development. Given the high demand from farmers, NPK fertilisers have become an attractive target for counterfeiters.

This trend is also observed in the oil palm plantation industry, where the use of NPK 10 fertiliser has the highest average compared to other types of fertilisers (*Figure 8*). The high demand

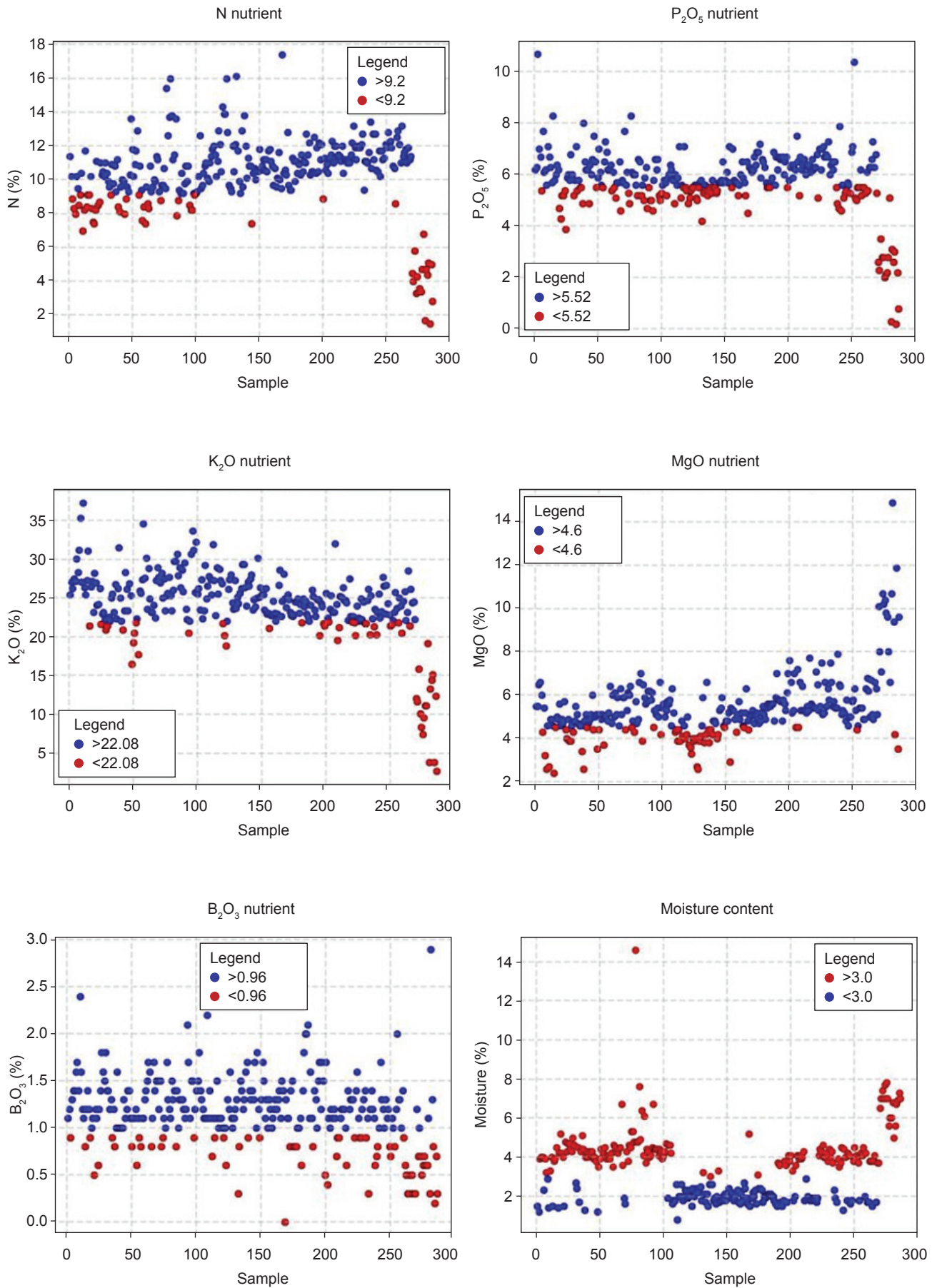


Figure 5. Distribution of nutrient content of NPK 10 from laboratory analysis compared to SNI 2803-2010 standard (tolerance 8%).

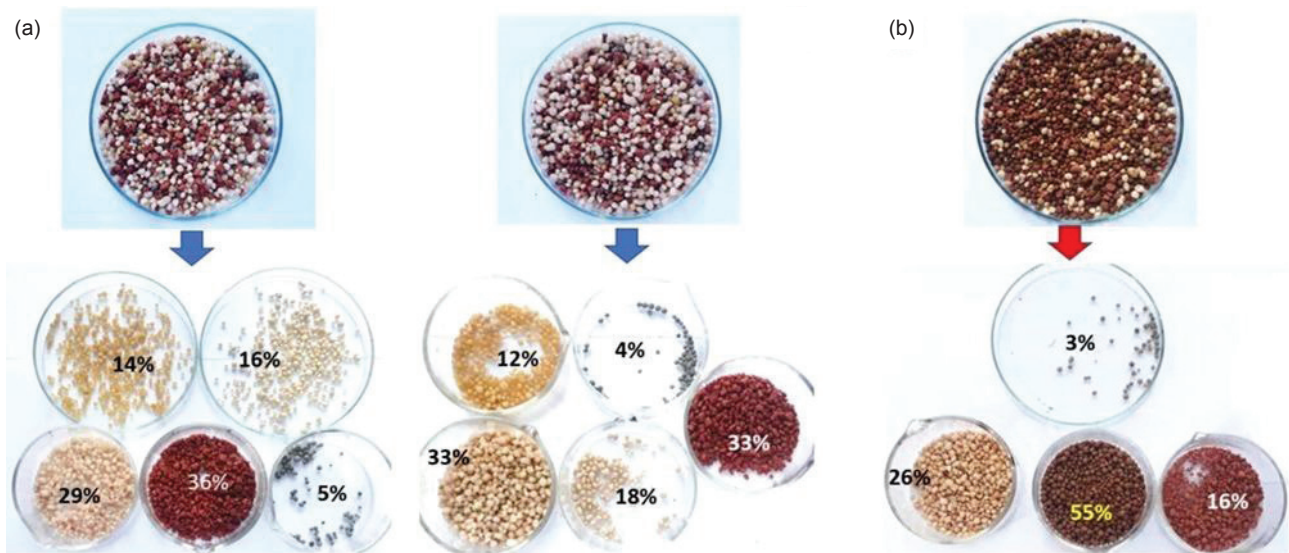


Figure 6. Visual comparison of NPK Mix 10; (a) original and (b) adulterated.

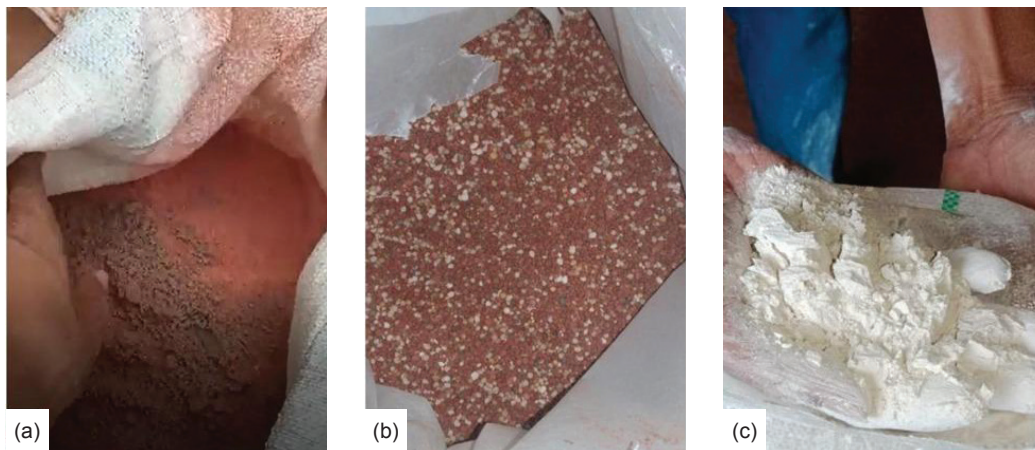


Figure 7. Mixed fertiliser; (a) MOP mixed with other materials such as sand, bricks, lattice soil, (b) NPK Mix mixed with granular clay and dolomite and non-conforming fertiliser (c) Kieserite replaced by Dolomite.

for NPK fertilisers creates a potential market for counterfeit manufacturers, as unscrupulous actors see an opportunity to exploit this demand. The large market size and high demand make the supervision of NPK fertilisers increasingly important. In such situations, the risk of counterfeit NPK fertilisers increases due to economic incentives to produce and market substandard fertilisers. Irresponsible actors may try to imitate popular NPK fertiliser brands and compositions, aiming to gain financial profit without considering the negative impact on plant growth and the environment.

Figure 8 shows that NPK fertiliser dominated the usage at 34%, followed by NK at 18%, dolomite at 10%, MOP, kieserite and urea at 7%, and RP and kieserbor at 5%. The borate had the lowest proportion (1%). The use of NPK fertiliser, reaching the largest proportion of 34%, signifies its

importance in oil palm plantations. If NK fertiliser is not used, the proportion of NPK usage could increase to over 50%. The chart presented is not a representation of the quantity of fertiliser given in one year but is the general dose of fertiliser per palm. In practice, the given fertiliser dose is adjusted based on various factors, such as soil classification, plant age, production targets, nutrient loss due to leaching, and other relevant agronomic factors. Because of these factors, the applied fertiliser dose can vary from location to location.

The second factor is the relatively high price of NPK fertilisers (Table 1). The high cost provides an incentive for unscrupulous actors to counterfeit NPK fertilisers and sell them at lower prices. Counterfeit fertilisers are often offered at a lower cost than original fertilisers, tempting farmers to choose the more financially accessible option. In situations

where farmers have limited finances, or the expected harvest profits are insufficient, they may be inclined to opt for cheaper counterfeit fertilisers as a more economical alternative. This is especially true if farmers lack adequate access to information or knowledge about the risks and consequences of using counterfeit fertilisers.

Based on the non-subsidised fertiliser price table, NPK 12 fertiliser has a maximum price of USD1.00 kg<sup>-1</sup>. Compared to other fertilisers, NPK 10 is sold at a lower maximum price of USD0.53, making NPK 10 47% cheaper than NPK 12. NK fertiliser (maximum USD0.80) was 20% cheaper than NPK 12. RP Peru and kieserite have the same maximum price of USD0.40, or 60% cheaper than NPK 12. Dolomite, with the lowest maximum price in Table 1 at USD0.10, is 90% cheaper than NPK 12, presenting a much more economical choice for buyers if they need MgO and CaO.

The MOP has a price almost identical to NPK 12 at USD0.93; thus, it is only 7% cheaper. However, MgSB with a maximum price of USD1.33, was 33% more expensive than NPK 12, indicating a significant additional cost for certain nutrients. SOA is sold at a maximum price of USD0.37 or 63% cheaper than NPK 12. Urea, with a maximum price of USD0.50, shows to be 50% cheaper than NPK 12, offering a

more affordable alternative for buyers in need of high N nutrients. Overall, these prices illustrate the cost spectrum that farmers may face when selecting fertilisers, with some options being much cheaper than NPK 12, while others, such as MgSB offer different nutrients at a higher cost.

Thirdly, it is essential to be vigilant about the relatively easy process of imitating NPK fertilisers using available technology. This provides opportunities for unscrupulous actors to produce and distribute counterfeit fertilisers in the market. Figure 9 shows two samples of NPK fertiliser taken from the field. Sample A is a fertiliser that meets the standards (original), whereas sample B is a fertiliser that is non-conforming. Although these two samples have differences in quality and composition based on laboratory tests, they appear to be visually very similar. This similarity poses a challenge for farmers and fertiliser users to distinguish between them, through visual inspection alone. This situation underscores the challenges present in the fertiliser industry, where the physical appearance of a fertiliser does not always reflect its nutrient content, and without more in-depth analysis, non-conforming products can easily be mistaken for those that meet the standards (original).

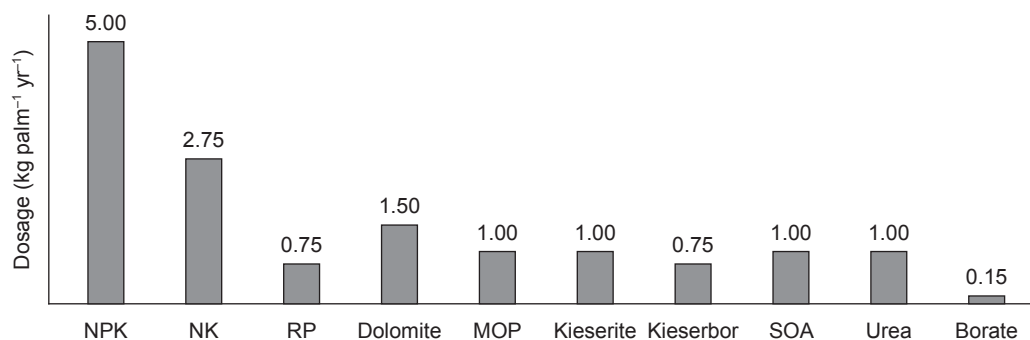


Figure 8. Average fertiliser usage during the TM phase in oil palm plantations.

TABLE 1. RANGE OF NON-SUBSIDISED FERTILISER PRICES AT AGRICULTURAL STORES (JUNE 2023)

No.	Fertiliser type	Composition	Price kg <sup>-1</sup> (USD)
1	NPK 12	N 12.00%, P <sub>2</sub> O <sub>5</sub> 12.00%, K <sub>2</sub> O 17.00%, MgO 2.00%	0.80 to 1.00
2	NPK 10	N 10.00%, P <sub>2</sub> O <sub>5</sub> 6.00%, K <sub>2</sub> O 24.00%, MgO 5.00%, B <sub>2</sub> O <sub>3</sub> 0.96%	0.43 to 0.53
3	NK 8.4/36	N 8.40%, K <sub>2</sub> O 36.00%	0.70 to 0.80
4	RP Peru	P <sub>2</sub> O <sub>5</sub> 28.00%	0.33 to 0.40
5	Dolomite	MgO 18.00%, CaO 29.00%	0.07 to 0.10
6	MOP	K <sub>2</sub> O 60.00%	0.83 to 0.93
7	Kieserite	MgO 25.50%, S 21.00%	0.33 to 0.40
8	MgSB	MgO 23.00%, S 18.00%, B <sub>2</sub> O <sub>3</sub> 4.80%	1.16 to 1.33
9	SOA	N 20.80%, S 23.80%	0.31 to 0.37
10	Urea	N 46.00%	0.43 to 0.50

Note: USD1.00 = IDR15,026.00 per 30 June 2023.

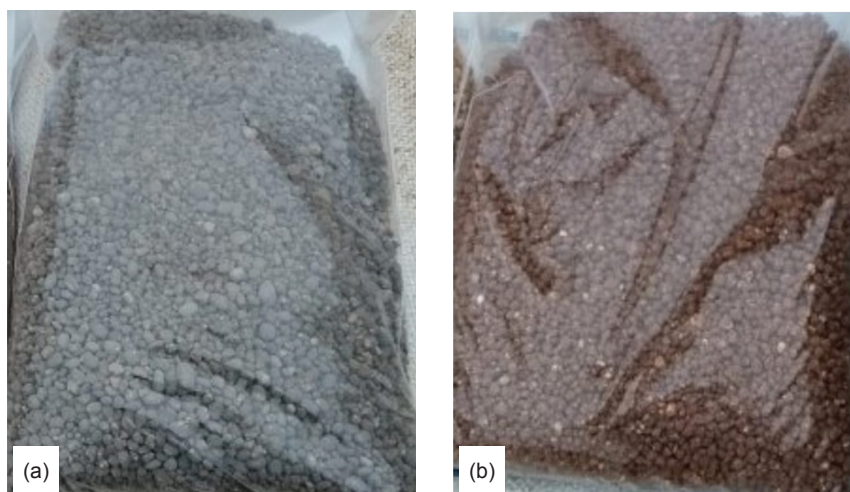


Figure 9. NPK 13/6/27 compound fertiliser (a) on-spec, and (b) non-conforming criteria found in the field are challenging to differentiate.

The above data reveals serious concerns regarding the presence of non-conforming fertilisers, especially counterfeit NPK fertilisers circulating in the field. The existence of non-conforming fertilisers has severe consequences for agriculture and farmers, including reduced productivity, nutrient imbalances, low harvest yields, poor product quality and environmental risks. Farmers also experience financial losses as non-conforming fertilisers do not yield the expected results. Therefore, it is essential to implement an effective fertiliser quality verification system and control the usage of non-conforming fertilisers in oil palm plantations to minimise the negative impacts and promote productive and sustainable agriculture. Identifying the most vulnerable types of fertilisers to becoming non-conforming provides valuable insights and enables targeted improvement actions focused on NPK fertilisers. This information forms a critical basis for formulating appropriate strategies and corrective actions to reduce the use of non-conforming fertilisers and enhance the efficiency and productivity of oil palm plantations.

### Negative Impact of Non-conforming Fertilisers on Oil Palm

The use of counterfeit fertilisers over the years had significant negative consequences for agriculture and the environment. The first impact of using counterfeit fertilisers is reduced soil fertility. Counterfeit fertilisers often have low and unbalanced nutrient content, leading to inadequate nutrient supply for plants (Pujawati & Kurniati, 2021). As a result, the soil becomes deficient in essential nutrients such as N, P, K and other micronutrients (Chen *et al.*, 2023). Soil fertility decline can hinder the growth of oil palm plants, reduce fruit production and ultimately decrease

the income of farmers and plantation managers (Loh *et al.*, 2019; Maity *et al.*, 2022; Zainuddin *et al.*, 2022).

Moreover, the use of counterfeit fertilisers can damage the overall health of the soil. Additional substances present in counterfeit fertilisers can disrupt soil structure and reduce its ability to retain nutrients. Unhealthy soil will struggle to provide optimal conditions for oil palm roots to absorb nutrients and water, negatively impacting overall plant growth and development (Pérez-Sato *et al.*, 2023; Romanyuk *et al.*, 2023; Salomon & Cavagnaro, 2022).

Furthermore, the use of counterfeit fertilisers can lead to reduced crop production. With inadequate nutrient content, oil palm plants will not thrive and produce optimally, resulting in a significant decline in oil palm fruit production, leading to economic losses for farmers and plantation managers (Chukwu *et al.*, 2023; Ganesapillai *et al.*, 2016). Additionally, reduced crop production affects the availability of palm oil, an essential commodity for food and industrial needs (Monzon *et al.*, 2023; Sugianto *et al.*, 2023; Zhao *et al.*, 2023).

Lastly, the use of counterfeit fertilisers also negatively impacts the quality of food and the final products of palm oil. Oil palm plants exposed to counterfeit fertilisers may have low nutrient content and contain harmful residue from these counterfeit fertilisers. Consequently, the resulting palm oil may have poor quality and lack essential nutrients, affecting the quality of food and the competitiveness of palm oil products in the international market (Dubey *et al.*, 2021; Milošević *et al.*, 2022; Nakayama & Matsuda, 2022).

To address the issue of counterfeit fertiliser use, it is crucial for farmers and plantation managers to always choose fertilisers that have been tested

for quality and comply with official standards (Pujawati & Kurniati, 2021). Strict government supervision and enforcement are also necessary to reduce the prevalence of counterfeit fertilisers in the market (Fitrya *et al.*, 2022; Nasrin *et al.*, 2019; Yang & Lin, 2020). Additionally, education and awareness regarding the importance of selecting and using appropriate fertilisers need to be enhanced to raise awareness of the negative impacts of counterfeit fertilisers and promote the use of quality and licensed fertilisers (Kautsar *et al.*, 2020; Kholis & Setiaji, 2020). With appropriate preventive and corrective measures, it is hoped that the agricultural and oil palm plantation sectors can operate more sustainably and produce high-quality products for the benefit of society and the environment.

### CONCLUSION

To facilitate plantation managers in determining fertiliser application policies in the field, fertiliser quality can be categorised into three criteria: Original fertiliser (composition and content in line with the label), diluted fertiliser (nutrient content around 50% of the label and standard) and counterfeit fertiliser (nutrient content significantly deviating from the label and standard, even less than 1%). Visual inspections can identify fertilisers with improper compositions (non-conforming), such as MOP mixed with other materials (sand, bricks, laterite soil), NPK granules mixed with clay and dolomite granules, and the substitution of kieserite with dolomite. Original NPK Mix fertiliser is characterised by dominant white and yellowish granules and a rich variety of colours with around five variations in the mixture, whereas counterfeit NPK Mix has dominant dark brown granules, only four variations in colours, and lacks the characteristic white to yellowish granules.

NPK fertilisers have the highest percentage of non-conforming at 2.4%, followed by kieserite at 0.3%, and MgSB at 0.1% out of 723 samples tested over a year. NPK fertilisers are more prone to counterfeiting due to their relatively high price, widespread use, increasing demand in various agricultural commodities, and their relatively easy production process to replicate with available technology. The use of non-conforming fertilisers negatively impacts the growth and development of oil palm plants.

In conclusion, it is essential to address the prevalence of counterfeit and non-conforming fertilisers in the market to ensure the productivity and sustainability of oil palm plantations. Plantation managers should prioritise the use of original and quality fertilisers, that comply with official

standards, to maximise the yield and quality of oil palm produce. Additionally, rigorous government supervision and strict law enforcement are crucial to reducing the circulation of counterfeit fertilisers. Raising awareness among farmers about the detrimental effects of counterfeit and non-conforming fertilisers can also contribute to making informed decisions regarding their fertiliser choices. By taking appropriate actions and implementing preventive measures, the oil palm plantation sector can achieve better outcomes, benefiting both the industry and the environment.

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