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Distribution of macronutrients (N, P, K, Mg) from single-nutrient and compound fertilizers application in oil palm seedlings (*Elaeis guineensis* Jacq.)

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Abstract

Nutrients availability and plant's ability to absorb nutrients are essential factors in supporting plant performance. There are two forms of fertilizer as a source of nutrients for oil palm, which are single-nutrient fertilizer (SNF) and briquette compound-nutrient fertilizer (BCNF). This study observed the concentration, uptake, distribution, and efficiency of macronutrients in plant organs of oil palm seedlings with two different fertilizer types. An experiment using oil palm seedlings was arranged in non-factorial complete randomized design (CRD) with three treatments, namely control, NPK in the form of briquettes, and single nutrient fertilizer consisting of urea, TSP, MOP, and kieserite with doses adjusting the composition of the slow-release BCNF (16-10-24-0.75) in three replications with a total of 27 seedlings. The results showed that the concentration, uptake, and distribution of nutrients between treatments and control were not significantly different. The order of nutrient uptake in leaves and stems of plants was N > K > Mg and P, while in roots was K > N > Mg > P. In BCNF and SNF treatments, the biomass accumulation in the stems, roots, and leaves were at percentage of 41 %, 30 %, and 29 %, while in the control, the biomass accumulation in the roots, stems, and leaves were at percentage of 39 %, 33 %, and 28 %, respectively. BCNF treatment had a greater efficiency indicated by a higher nutrient use efficiency (NUE) value compared to SNF or control.

INTRODUCTION

Plants are autotropic organisms that utilize the energy of solar radiation, carbon dioxide (CO_2), water, and nutrients to produce carbohydrates as the essential ingredients of their biomass (Demura & Ye, 2010). Most of the nutrients are absorbed from the soil in the form of minerals by plant roots then transported and used for photosynthesis (N), potassium (K), and magnesium (Mg) have an essential role in plant growth and development. Therefore, these elements are always required to be sufficiently available in an equilibrium state in the soil to be absorbed and used by the plant to support their growth and development (López-Arredondo et al., 2013).

Each type of nutrient has specific function and behavior in plant metabolic system. Nitrogen (N) is generally needed by plants to form amino groups, phosphorus (P) is required to form ATP and ADP, and potassium (K) regularly plays a role in regulating turgor pressure and homeostatic water in plants. At the same time, magnesium (Mg) is utilized in the formation of chlorophyll (Maathuis, 2009). The function and mobility of each nutrient in the plant organs are specific. Therefore, its distribution and accumulation varies. There are several factors that influence the nutrient uptake, distribution, and accumulation of each nutrient such as climate, soil type, and management or agricultural practices including fertilization (Backes et al., 2018).

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In oil palm (*Elaeis guineensis* Jacq.) plantations, a genetically good quality seedling is also known as a defining factor of crop performance after transferred to the field. Fertilization presents an essential role in producing superior seedlings because generally, the nutrient content in the growing media is not sufficient enough to support crop needs during the nursery growth. The fertilizer type commonly applied to oil palm seedlings is a single-nutrient fertilizer.

As the technology of fertilizer production becomes more developed, nowadays a variety of mixed-nutrient (compound) fertilizers are produced, offering various advantages. One of which is the slow-release property. The previous study stated that the utilization of slow release fertilizer showed better results compared to a single-nutrient fertilizer, especially in terms of increasing its effectiveness and efficiency, along with reducing nutrient losses from the soil ecosystem (Trenkel, 2013). This research had been carried out with objectives to find out the effect of single-nutrient and briquette compound fertilizers on oil palm seedlings by comparing the macro nutrient uptake (N, P, K, and Mg) acquired from both type of fertilizers and nutrients (N, P, K, and Mg) distribution in roots, stems and leaves of oil palm seedlings.

MATERIALS AND METHODS

Study sites

This research was conducted at seedlings site, Laboratory of Soil Physics of Indonesian Oil Palm Research Institute (IOPRI) Medan, North Sumatra. The observations were held for six months from January to June 2015 on the nursery seedlings (three months old). The growing media used were sub-soil of 20 cm to 40 cm depth from Aek Pancur Experiment Field (IOPRI), Deli Serdang, North Sumatra. The single-nutrient and briquette compound fertilizer were applied once after transplanting seedlings from pre-nursery stage to main nursery stage. Rainfall during sixth months of experiment was 196 mm, 89 mm, 32 mm, 59 mm, 199 mm, and 34 mm, respectively. Meanwhile, the rain day was 16 days, 9 days, 7 days, 12 days, 18 days, and 7 days, respectively. Average rainfall during the study was 101 mm per month. The maximum, minimum and average air temperature were 33.98 °C, 28.11 °C, and 24.19 °C, respectively, and the relative humidity in the site during the study was 79.25 %. Furthermore, average solar radiation was 18.35 $MJ.m^{-2}$.

Table 1. Initial analysis of soil samples used as planting media

Soil characteristic	Value
Sand (%)	63
Silt (%)	27
Clay (%)	10
pH H_2O (1:2.5)	5.7
Organic-C (%)	0.48
Total N (%)	0.05
C/N	9.6
P (ppm bray-2)	5.71
K (me.100 g^{-1})	0.22
Ca (me.100 g^{-1})	0.43
Na (me.100 g^{-1})	0.03
Mg (me.100 g^{-1})	20
∑ exchangeable cations (me.100 g^{-1})	1.49
Cation exchange capacity (CEC) (me.100 g^{-1})	7.52
Exchangeable-Al (me.100 g^{-1})	0.17
Base saturation (%)	20

Sampling and measurements

Soil samples had sandy clay loam texture with sand, silt, and clay of 62 %, 27 % and 10 %, respectively. The soil was classified as acid soil with pH of 5.7 and relatively low organic C content of about 0.48 %. The high content of sand and low cation exchange capacity (CEC) indicated the low level of soil fertility as a planting medium in this study. The characteristics of the soil samples are presented in Table 1.

The soil weight for planting media per pot was 20 kg. This research was arranged in a non-factorial complete randomized design (CRD) with three treatments and three replications with a total of nine experimental units. One experimental unit consisted of three seedlings, and the total pot used in the study was 27 pots. The treatments applied were control (P0/without fertilizer), NPK compound fertilizers in briquette form (P1), and single-nutrient fertilizer (P2) such as Urea, TSP, MOP, and kieserite. The dose for single-nutrient fertilizer was accordance with the fertilization standard in the main nursery (14 weeks – 24 weeks) recommended by Indonesian Oil Palm Research Institute (2014). The dose for single-nutrient fertilizer used was 8.26 g Urea, 4.98 g TSP, 9.49 g MOP, and 0.74 g kieserite. The compound fertilizer composition was 16-10-24-0.75 (N-P-K-Mg). The compound fertilizer dose was calculated based on N nutrient. Thus, the compound dose applied was 24 g.

The fertilizer treatments were applied after the seedlings were planted in the pot. The method of fertilizer application followed the real application in the oil palm plantation. The compound fertilizer was applied with placement method by burying the fertilizer at a depth of with ± 3 cm. Meanwhile, the single-nutrient fertilizer was applied by spreading it on the soil's surface. The observed variables were nutrient content in oil palm organs (roots, stems, and leaves), nutrient uptake, nutrient use efficiency (NUE), and dry biomass for each treatment (Figure 1). Nutrient uptake by crop illustrates the amount of nutrient absorbed by crop from the soil source. In this study, the value of nutrient uptake was a multiplication result between nutrient levels in plant tissue with plant dry weight.

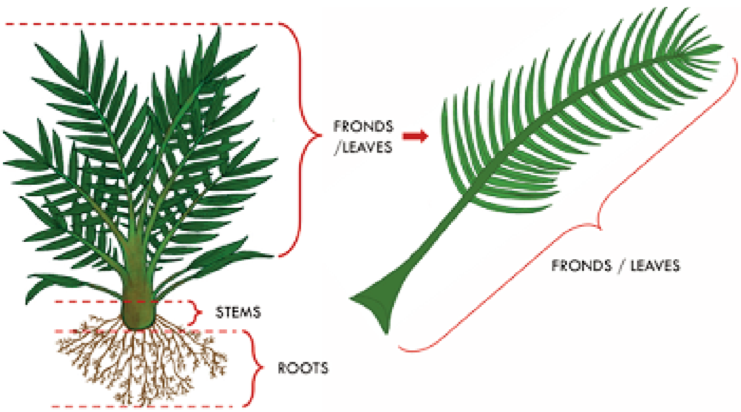


Figure 1. Part of oil palm at main nursery stage (Source: Document of IOPRI)

Nutrient use efficiency (NUE) is a concept for evaluating crop production systems, which is strongly influenced by fertilizer management (Fixen et al., 2015). Many equations were developed to express NUE in agricultural systems, but in this study, NUE was counted based on two approaches, namely Agronomic Efficiency (AE) and Apparent Recovery Efficiency (ARE). AE is an indicator that portrays the amount of nutrient efficiency absorbed by plant from several nutrients given through fertilizer. Both variables were used to determine the best treatment, showing the highest NUE value. The equation used for NUE is as follows (Dobermann, 2007):

$$AE = (Y - Y_0)/F \quad (1)$$

$$ARE = (U - U_0)/F \quad (2)$$

Note:

AE : Agronomic Efficiency

Y : Dry mass of treated plant

Y_0 : Dry weight of control plant (without fertilizer)

F : The amount of applied nutrient
ARE : Apparent Recovery Efficiency
U : the amount of nutrients absorbed by plants with fertilizer treatment
U_0 : The amount of nutrients absorbed by plants in control treatment.

Data analysis

One-way ANOVA and multiple comparisons were used to test nutrient levels, nutrient uptake, biomass dry matter in roots, stems and leaves, agronomic efficiency (AE), and apparent recovery efficiency (ARE) as affected by three treatments applied in this study. The analysis was then continued to Duncan test (with α = 5%) to compare the means between treatments using SPSS software.

RESULTS AND DISCUSSION

Nutrient concentration in oil palm organs

Nutrient levels of N, P, K, and Mg in each plant organ for each treatment are presented in Table 2. Overall, the significant difference of nutrient levels was shown in K content in stems, in which P1 treatment resulted in significantly lower value than P0 and P2. Meanwhile, magnesium (Mg) content in P0 was considerably higher than in P1 and P2. On the other side, there was no significant difference in other nutrient content in roots, stems, and leaves. The intriguing finding showed that there was tendency of higher P, K, and Mg content in the control treatment (P0) compared to in the fertilization treatment (P1 and P2). The above mentioned was considered as one of the results of dilution effect, in which concentrations in control plants without any treatment became higher than nutrient concentration in plants with treatments (fertilization). Jarrell & Beverly (1981) explained that the nutrient concentration in plant tissue is the resultant of two dynamic processes, namely nutrient uptake and accumulation of dry biomass. Furthermore, under optimal environment (without any growth limiting factors), the rate of dry matter accumulation in plants increases faster than the rate of nutrient accumulation. As the results, the nutrient concentrations become lower than before. On the other hand, in control plants growing on planting media with growth limiting factors, the rate of dry matter accumulation is suspected to be slower than nutrient accumulation. Thus, the nutrient concentration in plant tissue becomes higher. Furthermore, Riedell (2010) also expound that the level of some nutrients could decrease due to an increase of dry weight of plant shoots. Imo (2012)

Table 2. Nutrients level (N, P, K, and Mg) in each plant organ as affected by fertilizing treatments

Treatments	Nutrient levels in leaves (%)			
	N	P	K	Mg
P0	1.657 a	0.142 a	1.511 a	0.290 a
P1	1.690 a	0.130 a	1.577 a	0.229 a
P2	1.766 a	0.142 a	1.542 a	0.226 a
Treatments	Nutrient levels in stem (%)			
	N	P	K	Mg
P0	0.583 a	0.131 a	1.572 a	0.257 a
P1	0.628 a	0.106 a	1.223 b	0.220 b
P2	0.590 a	0.095 a	1.531 a	0.224 b
Treatments	Nutrient levels in roots (%)			
	N	P	K	Mg
P0	0.657 a	0.072 a	1.362 a	0.228 a
P1	0.638 a	0.057 a	1.263 a	0.221 a
P2	0.754 a	0.082 a	1.388 a	0.226 a

Remarks: Means denoted by different letters within the same column indicate significant differences between treatments according to Duncan test (α = 5%), P0= control; P1= briquette compound fertilizer; P2= single nutrient fertilizer.

added that the dilution effect needs to be considered clearly to determine the actual condition and interpret the data from the active uptake of the plants given several distinct treatments.

Further results showed that the nutrient levels in leaves tended to be higher compared to those in stems and roots. Particularly in stems and roots, nutrients with the highest level included potassium (K), followed by nitrogen (N), magnesium (Mg), and phosphorus (P). The different finding was observed in leaves, in which N showed the highest level, followed by K, Mg, and P (Figure 2).

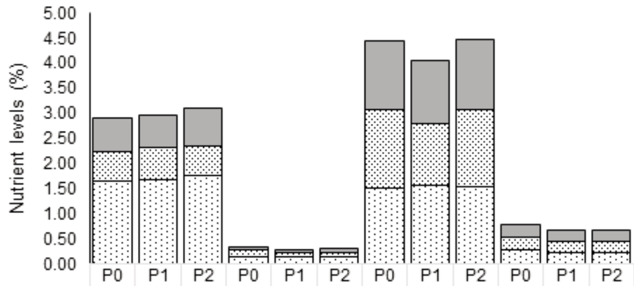
Figure 2 illustrates the average nutrient distribution in plant organs (roots, stems, and leaves) as affected by control (P0) and fertilizing (P1 and P2) treatments. All treatments resulted in similar nutrient distribution pattern. The higher nutrient level in leaves were due to their function as plant active organs conducting the photosynthesis process. While the photosynthesis occurred, the nutrients from the soil accumulated more to plant tissue to be synthesized into carbohydrates and redistributed back to all parts of the plants. This result was also supported by He et al. (2015), reporting that the accumulation of N was higher in leaves, stems, and roots, respectively. Nitrogen accumulation that is more dominant in leaves is a form of plant strategy in nutrient storage and redistribution. For example, in limited N and P conditions, stems and roots tend to act as nutrient sinks that provide various nutrients during the plant growth. It is also known as plant effort to allocat more nutrient partitions in photosynthetic plant organs such as leaves, to maintain regular Carbon (C) assimilation and support its growth (He et al., 2015). In conjunction with that, Imo (2012) added that the higher nutrient concentrations in young tissue of plant was approach to allocate nutrients for higher productivity.

Additionally, part of the leaves has more sensitivity towards nutrient dynamics in its surface during the climate and environment change compared to roots and stems. The higher nutrient level in leaves is an indication of the stoichiometric mechanism within plant organs. Each plant organ (root, stem, leaf) has diverse capacity in receiving, distributing and storing nutrients, which is also influenced by changes in pedo-agro-climate condition, nutrient limitations, and reduction in plant metabolite activity (He and Djikstra, 2014; He et al., 2015).

Oil palm dry biomass

Dry matter weight is the proportion of total plant components such as fiber, protein, carbohydrates, and lipids, which are soluble in water or other compounds, yet remain the same after water is removed. It is also used as an indicator to describe the mechanism of nutrient absorption by plants and its physiological function for growth and development. The amount of dry matter is generally associated with plant nutrient uptake, in which the higher the nutrient uptake, the higher the dry matter weight, and vice versa.

The result showed that the highest total dry matter weight was obtained in P1 (84.70 g), while the lowest dry weight was in P0 (29.59 g) (Figure 3). Meanwhile, there was no difference in the dry weight of seedlings (total and each organ) treated with briquette compound (P1) or single-nutrient (P2) fertilizers. Moreover, in P1



	P0	P1	P2	P0	P1	P2	P0	P1	P2	P0	P1	P2
		N			P			K			Mg	
Roots	.65	.63	.75	.07	.05	.08	1.3	1.2	1.3	.22	.22	.22
Stems	.58	.62	.59	.13	.10	.09	1.5	1.2	1.5	.25	.22	.22
Leaves	1.6	1.6	1.7	.14	.12	.14	1.5	1.5	1.5	.29	.22	.22

Figure 2. Nutrients levels (N, P, K, and Mg) in each plant organ as affected by control and fertilizing treatments; (P0= control ; P1= application of briquette compound fertilizer; P2= application of single nutrient fertilizer).

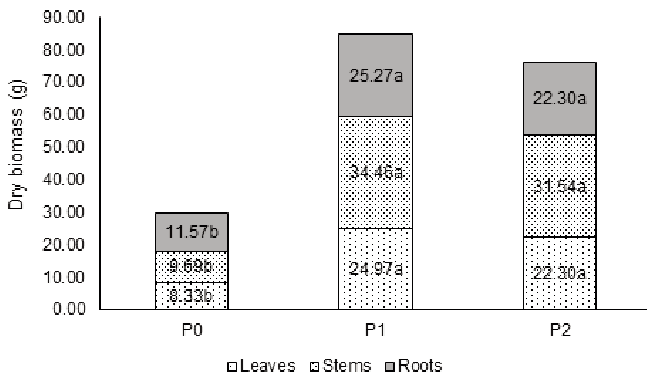


Figure 3. Biomass dry matter as affected by P0= control; P1= application of briquette compound fertilizer; P2= application of single nutrient fertilizer).

Remark: Means denoted by different letters within the similar pattern of histogram indicate significant differences between treatments according to Duncan test (α = 5%).

and P2, the highest biomass accumulation was relatively the same. The highest biomass accumulation was found in stems, followed by that in roots and leaves at 41 %, 30 %, and 29 %, respectively. This finding is in line with the study by Ofusu et al. (2018), which explained that the highest biomass was allocated to the stems, followed by roots and leaves.

This study also discovered that fertilization using both single-nutrient and compound fertilizers significantly increased dry biomass weight. It is seen from the lower dry weight in the control treatment (P0). The low value of biomass dry matter in P0 was induced by low soil fertility of the growing media without additional nutrients input from fertilization. Consequently, plant nutrient requirement was not fulfilled, thereby inhibiting biomass accumulation process.

In P0 treatment, the highest biomass accumulation was found in roots, followed by that in stems and leaves with the proportions of 39 %, 33 %, and 28 %, respectively. The higher percentage of biomass in roots is one of the evidences showing that limited nutrient affects the plant growth. Plant has various adaptation mechanisms towards low soil fertility condition. One of which is by changing its root structure to be longer, affecting the production of lateral roots and expanding the roots surface to increase nutrient uptake or other new nutrient resources in soil (Etienne et al., 2018; López-Arredondo et al., 2013; White et al., 2013). The modification of root structure requires more nutrients allocation; in furtherance, it affects the increasing amount of roots biomass. Previous studies have also suggested that when soil fertility declines, plants tend to allocate relatively more biomass to the roots than to the upper part of the plant (Kleyer and Minden, 2015).

The proportion of dry matter biomass of plant organs in P1 and P2 was relatively the same, which was around 30 % for roots, 40 % for stems, and 30 % for leaves. It depicts that unlike in control (P0), the proportion of plant biomass in the upper part (stems and leaves) of oil palm seedlings treated with P1 and P2 is relatively higher than in the roots. In the previous study, Ashraf et al. (2017) reported that in better soil fertility with adequate N supplies, the ratio of roots to shoot biomass of oil palm seedlings was lower due to an increase in N adequacy affecting leaves biomass and assimilate partitions on stems and roots. The root to shoot ratio is potentially affected by plant performance, especially under water stress and limited nutrient condition.

Oil palm nutrient uptake

This study indicated that the total nutrient uptake in control (P0) was significantly lower than in fertilization treatment using briquette compound (P1) or single-nutrient fertilizer (P2) for N, P, K, and Mg (Table 3). Similar pattern was found in leaves and stems. However, in roots zone, fertilization with single-nutrient or compound fertilizer only increased nutrient uptake of P and Mg.

In this study, potassium (K) was absorbed more by oil palm seedlings than other nutrients (nitrogen, phosphorus, and magnesium). It indicates the importance of large amounts of K to support the growth of oil palm. K plays a role in various important

Table 3. Nutrients uptake (N, P, K, and Mg) in each plant organ as affected by fertilizing treatments

Treatments	Nutrient uptake by leaves (g)			
	N	P	K	Mg
P0	0.137 b	0.012 b	0.126 b	0.024 b
P1	0.416 a	0.032 a	0.394 a	0.057 a
P2	0.392 a	0.032 a	0.344 a	0.050 a
Treatments	Nutrient uptake by stems (g)			
	N	P	K	Mg
P0	0.056 b	0.013 b	0.152 b	0.025 b
P1	0.216 a	0.036 a	0.423 a	0.076 a
P2	0.186 a	0.030 a	0.482 a	0.070 a
Treatments	Nutrient uptake by roots (g)			
	N	P	K	Mg
P0	0.076 a	0.008 b	0.159 a	0.026 b
P1	0.162 a	0.014 ab	0.318 a	0.056 a
P2	0.170 a	0.018 a	0.312 a	0.051 a
Treatmens	Total nutrient uptake (g)			
	N	P	K	Mg
P0	0.285 b	0.034 b	0.438 b	0.076 b
P1	0.828 a	0.082 a	1.146 a	0.189 a
P2	0.788 a	0.081 a	1.134 a	0.172 a

Remark: Means denoted by different letters within the same column indicate significant differences between treatments according to Duncan test (α = 0.05), P0= control; P1= briquette compound fertilizer; P2= single nutrient fertilizer.

metabolic processes in plant, plant growth, and plant adaptation under stress condition (Wang et al., 2013). Prajavati and Modi (2012) mention that potassium (K) acts as an enzyme activator and stabilizer of protein and starch synthesis, which is involved in osmoregulation, stomatal activity, photosynthesis rate, transport of sugars, and water-nutrient transport.

The nitrogen uptake was higher than P, K, and Mg specifically in leaves. The accumulation of high N concentration in leaves is due to the role of N as the main constituent of chlorophyll (> 75 %) in mesophyll tissue (Hanum et al., 2017; Mitra, 2015). The decrease in concentration of nitrogen will be followed by the decrease in leaf production, total leaf surface area, and interception area to carry out photosynthesis (Toth et al., 2002). Nitrogen is also a highly mobile nutrient generally stored in plants in the form of organic compounds, especially in leaves. This is in contrast to other nutrients such as P, K, S, Mg and micronutrients, which have varied mobility and are generally found in inorganic or organic molecular form (Etienne et al., 2018).

Figure 4 showed the average proportion of the nutrient uptake of N, P, K, and Mg in each organ of the plant as affected by single and compound fertilizer application (P2 and P3). It could be seen that N nutrients were mostly accumulated in the leaves, while P, K, and Mg nutrients were dominantly accumulated in the stem of the plant. Overall, stems and leaves had a sequence of nutrient uptake levels of N > K > Mg > P. Meanwhile, roots had a different sequence, which was K > N > Mg > P. The accumulation of high N concentration in leaves is due to the role of N as the main constituent of chlorophyll (> 75 %) in mesophyll tissue (Hanum et al., 2017; Mitra, 2015). If the concentration of N is decreased, there will be a decrease in the production of leaves, total leaf surface area, and sunlight interception area for the process of photosynthesis (Toth et al., 2002).

This result is reinforced by previous research denoting that nitrogen (N) is a highly mobile nutrient

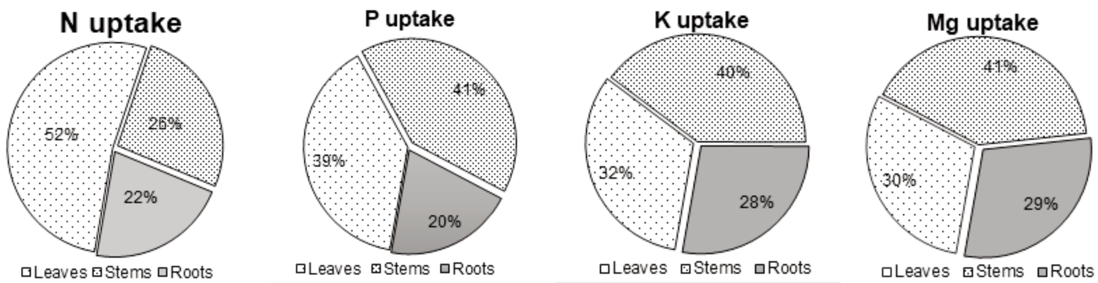


Figure 4. Nutrients uptake composition (N, P, K, and Mg) in each plant organ as affected by fertilizing treatments

Table 4. Agriculture efficiency and apparent recovery efficiency of each nutrient as affected by fertilizing treatments

Treatments	Agriculture Efficency (AE) ($g.g^{-1}$)			
	N	P	K	Mg
P1	14.50 a	23.96 a	9.67 a	275.58 a
P2	12.25 a	20.24 a	8.03 a	155.16 a
	Apparent Recovery Efficiency (ARE) (%)			
	N	P	K	Mg
P1	14.30 % a	2.07 % a	12.40 % a	56.40 % a
P2	13.24 % a	2.04 % a	11.99 % a	31.73 % a

Remark: Means denoted by different letters within the same column indicate significant differences between treatments according to Duncan test (α = 0.05), P1= briquette compound fertilizer; P2= single nutrient fertilizer.

generally stored by plants in the form of organic compound, especially protein substantially stored in leaves. Meanwhile, other nutrients such as P, K, S, Mg and micronutrients have more diverse mobility and usually found in the form of inorganic molecules or associated with the organic molecules (Etienne et al., 2018).

Ashraf et al. (2017) defined that the high supply of N will have an impact on the low value of root to shoot ratio of oil palm seedlings. Consequently, the nitrogen concentration will affect leaves biomass, thereby affecting assimilate partitioning in stems and roots. This ratio potentially affects plant performance, particularly under water stress and limited nutrient conditions.

Nutrient Use Efficiency (NUE)

Nutrient Use Efficiency (NUE) estimation results using Agronomic Efficiency (AE) and Apparent Recovery Efficiency (ARE) parameters are presented in Table 4. The results indicated that there was no significant difference between AE and ARE value as affected by P1 (application of briquette compound fertilizer) and P2 (application of single-nutrient fertilizer) treatments. Nonetheless, P1 treatment consistently produced higher AE and ARE values for macronutrients (N, P, K, and Mg) compared to P2 treatment. This finding indicated P1 resulted in a higher NUE value than P2 treatment.

The average ARE value, which was under 100 %, showed that the fertilization was not fully efficient. ARE value of nitrogen (N) was between 13 % to 14 %, meaning that most of the nitrogen (N) input from fertilizer highly vanished through run-off, leaching or evaporation. Elliot and Fox (2014) emphasized that the loss of nitrogen (N) from fertilization was in a range between 10% to 50%. The low ARE value in phosphorus (P) was allegedly affected by phosphorus fixation. Acid soils, in which the solubility of aluminum (Al) is quite high, can induce an increase in phosphorus fixation (P) which in furtherance will decrease P availability levels in soil (Chikowo et al., 2010).

The low ARE value of potassium (K) likely occurred due to the high amount of nutrients leached. According to Wu and Liu (2008), potassium (K) losses due to leaching ranged between 50 % to 70 %. In soil with a high content of sand, like the growing media for this study, the potassium (K) leaching potentially reaches 13 times higher than in clay soil (with about 40 % clay content) (Mendes et al., 2016). As for magnesium (Mg), the ARE value is relatively higher than other nutrients. The loss of magnesium was also caused by leaching. According to Senbayram et al. (2015) study, magnesium leaching can reach to 30%, depending on the soil type, source of magnesium inputs, and rainfall in the site.

CONCLUSIONS

The application of briquette compound (P1) and single-nutrient (P2) fertilizers produced higher biomass and nutrient uptake compared to control. Nutrient uptake in leaves and stems showed the same trend between the treatments, meanwhile in roots, the treatment of P1 or P2 significantly increased the nutrient uptake of P and Mg only. The distribution order in leaves and stems was N > K > Mg > P, while in roots was K > N > Mg > P. The seedlings treated by P1 tended to show greater nutrient efficiency compared to those with other treatments.

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