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Utilization of Mill Effluent for Growth, Availability and Uptake of Nutrients by Palm Oil Seedlings

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Abstract: A large amount of palm oil mill effluent is one of the issues faced by palm oil producers in Indonesia. To alleviate the environmental pollution, it is necessary to reduce the problem by using it as a liquid organic fertilizer. A pot experiment to determine the effects of mill effluent on growth of palm oil seedlings (*Elaeis guineensis* Jacq.), availability and uptake of macronutrients was conducted in Tandun Plantation Unit, province of Riau, Indonesia. The experiment used a randomized block design, consisting nine combinations of mill effluent doses (3.2, 6.4 and 9.6 L) and recommended fertilizer doses (100%, 75%, 50% NPKMg) in 20 kg soil and one control. The experiment was replicated three times. The results showed that plant height, stem diameter and number of fronds of palm oil seedlings at 26 weeks after planting (WAP) were significantly affected by application of 9.6 L mill effluent with 50%-75% NPKMg. The enhancement of soil organic C (C_{org}) content, soil pH and cation exchange capacity due to the application of 9.6 L mill effluent combined with 50% NPKMg caused the availability of soil P and total N (N_{tot}) increased significantly, while exchangeable K was affected by application of 6.4 L mill effluent combined with 100% NPKMg. All treatments did not affect soil exchangeable Mg. A positive correlation between availability of soil N, P, K and its uptake by palm oil seedlings at 26 WAP were indicated by r = 0.61, 0.63 and 0.57, respectively.

Key words: K, Mg, mill effluent, N, palm oil (*Elaeis guineensis* Jacq.), phosphate.

1. Introduction

Growth of commercial palm oil plantations in Indonesia has led to a growing call for the sustainable production of palm oil, driven to a large extent by concerns over the associated impacts of deforestation in Borneo and Sumatra islands. As the second largest palm oil producing country, approximately 0.65 tons of palm oil mill effluents are produced for every ton of fresh fruit bunches in Indonesia [1]. Because of high content of organic matter in forms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), as well as heavy metals, palm oil mill effluent is greatly polluting and its discharge to environment can be devastating to the ecosystem [2]. However, the mill effluent still contains high amount of nutrients, such as N, P and K [3], which makes it potential to be reused as liquid organic fertilizer.

In areas where plantation crops have been grown for two to three generations, most of the inherent soil nutrients and organic matter are exhausted. On the other hand, the production of high quality palm oil seedlings is dependent on good growing media. Organic inputs may increase soil fertility and crop production potential, possibly by changes in soils' physical and chemical properties. The physicochemical and biological properties of a growing medium will affect plant growth and directly influence root growth [4].

In a tropical region, soils are at acidic conditions for most soil series in the pH range of 4.5-5.5, but certain tropical soils are highly weathered, which have pH of about 4.0, such as Ultisols and Oxisols [5]. Highly weathered with low native fertility of majority soils

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has a major constraint to increase yield of oil palm plantation due to low organic C (C_{org}), pH, nutrients and exchangeable cations (Ca, K, Mg and Na), as a result of intensive leaching [6].

Mill effluent is a brown slurry, which is composed of 4%-5% solids (mainly organic), 0.5%-1.0% residual oil, about 95% water and high concentration of organic N [7]. This effluent is a serious land and aquatic pollutant when discharged immediately into the environment. Besides the presence of lipids and volatile compounds, the inhibitory effects of mill effluent on living tissues could also be due to presence of water-soluble phenolic compounds that caused low pH [8]. However, since no chemicals are added during the oil extraction process, mill effluent is non-toxic, even it also contains substantial amounts of P, K and Ca, which are vital nutrient elements for plant growth, source of carbon and energy for microbial activities [9]. The purpose of this research was to evaluate the effects of mill effluent in combination with inorganic fertilizer on the growth of palm oil seedlings and the changes of soil chemical properties.

2. Materials and Methods

2.1 Experimental Site

A pot experiment was conducted from April until October 2016 in Tandun Plantation Unit, province of Riau, Indonesia. The climate is classified as humid tropical, which the maximum temperature ranged from 30.0 °C to 34.7 °C, while the minimum temperature varied from 19.5 °C to 26.9 °C and the average relative humidity varied from 73.4% to 91.2%.

Pre-soil analysis was conducted on composite samples (0-30 cm), obtained from the experimental field in Tandun Plantation Unit. The soil was air dried and ground to pass through a 2 mm sieve. Chemical properties of all samples were conducted before and after treatments using the standard procedures described in methods of soils analysis in AOAC [10]. The experimental soil is composed by 36% sand, 10% silt and 54% clay in texture. The chemical properties of the soil had pH value of 5.09 (1:2.5 of soil:water), 13.6 g/kg C_{org}, 1.7 g/kg total N (N_{tot}, Kjeldahl), C/N was 8 and 7.0 mg/kg available P (Bray I), 0.15 $cmol_c$/kg exchangeable K, 0.49 $cmol_c$/kg exchangeable Mg, 1.95 $cmol_c$/kg exchangeable Ca, 0.61 $cmol_c$/kg exchangeable Na (1 N NH_4-acetate) and 7.84 $cmol_c$/kg cation exchange capacity (CEC).

Mill effluent sample was taken from the last reservoir pool of local palm oil mill plant and analyzed for COD, BOD, total suspended solid (TSS) according to a modified method explained in APHA [11]. The pH of mill effluent, N_{tot}, C_{org}, P, K, Mg, Ca, Na, electrical conductivity (EC) and sodium adsorption ratio (SAR) determinations were carried out using wet oxidation method as described in AOAC [10].

2.2 Experiment Design

The pot experiment used 20 kg soil in the randomly arranged polybags and set in an equilateral triangle system (70 × 70 × 70 cm) in the main nursery. The treatments were nine mill effluent doses combined with recommended NPKMg (15:15:15:7) fertilizer. The experiment used randomized block design, consisting of a control A (100% recommended fertilizer dose of 40 g NPKMg/polybag) and nine combinations of mill effluent doses: B (3.2 L mill effluent + 100% recommended fertilizer dose/polybag); C (6.4 L mill effluent + 100% recommended fertilizer dose/polybag); D (9.6 L mill effluent + 100% recommended fertilizer dose/polybag); E (3.2 L mill effluent + 75% recommended fertilizer dose/polybag); F (6.4 L mill effluent + 75% recommended fertilizer dose/polybag); G (9.6 L mill effluent + 75% recommended fertilizer dose/polybag); H (3.2 L mill effluent + 50% recommended fertilizer dose/polybag); I (6.4 L mill effluent + 50% recommended fertilizer dose/polybag); J (9.6 L mill effluent + 50% recommended fertilizer dose/polybag) with three replications. Seven days after the application of treatment combinations in the main nursery, the soils were planted with 12 weeks old palm oil seedling (four leaves) from local pre-nursery. Gradually, doses of mill effluent were given every two weeks, started at 14-24 weeks after planting (WAP), except in the control, and followed by daily watering until 26 WAP. Then, the seedlings would be ready to be transplanted in oil palm plantations as immature plants for 8-9 years according to its growth cycle.

2.3 Statistical Analysis

Weekly observations on the growth components of palm oil seedling (plant height, stem diameter and number of fronds) were conducted until 26 WAP. Parameters of soil C_{org}, pH, CEC, availability of N, P, K, Mg and their uptake by plants were also observed. The data were subjected to analysis of variance, using statistical software SPSS version 17.0. The means were separated using the Duncan multiple range test (p = 0.05). The correlation between the parameters for soil nutrient availability and their uptake by palm oil seedlings was established using the Pearson's correlation coefficient (r) method.

3. Results and Discussion

3.1 Mill Effluent and Soil Chemical Properties

The characteristics of mill effluent showed that palm oil mill effluent sample was acidic (pH 4.90) with high level of C_{org} (1,301 mg/L) and N_{tot} (220.0 mg/L), moderate levels of total P, K, Ca and Mg (176.0, 61.9, 95.2 and 491.1 mg/L, respectively) (Table 1). Level of Na content of mill effluent was 61.1 mg/L with the value of SAR 3.57 $cmol_c$/L, and moderate EC (0.29 dS/m) did not affect the permeability and stability of soil structure, because its SAR value was lower than 6.0 $cmol_c$/L [12]. BOD, COD and TSS were reasonably high as expected for effluent with high organic content. Therefore, palm oil mill effluent can create environmental problems because the discharge of effluents was found to consist of low pH and high TSS, BOD and COD.

Results of chemical and physical analysis of the pre-planting soil indicated that soil used in this experiment was classified as Ultisols as revealed by its low percentage base saturation (31.12%) and CEC (7.84 $cmol_c$/kg), acidic nature of the soil, low content of C_{org} and N_{tot}, and Al content was 1.07 $cmol_c$/kg. Analyses of particle size distribution in the top soil (0-30 cm) showed that the characteristic of soil was clay loam. The low content of soil exchangeable cations (K, Na, Ca and Mg) indicated that Ultisols constituted a highly weathered soil undergoing high leaching, so the content of exchangeable base cations was low, while its Al saturation (40.8%) was relatively dominant in exchangeable acidity.

3.2 Growth Components of Palm Oil Seedlings

At the end of the experiment, in the main nursery that lasted 12 weeks (from 14 WAP until 26 WAP), the applications of mill effluent combined with lower doses of inorganic fertilizer (50% NPKMg/polybag) significantly affected plant height, stem diameter and number of fronds compared to the control (Table 2). The lowest number of fronds in the control was probably

Table 1 Chemical characteristics of palm oil mill effluent.

Parameter	Concentration
pH (H_2O)	4.90
BOD (mg/L)	17,750.2
COD (mg/L)	18,552.0
TSS (mg/L)	10,461.1
Oil (mg/L)	7,360
C_{org} (mg/L)	1,301
N_{tot} (mg/L)	220.0
C/N	5.9
P (mg/L)	176.0
K (mg/L)	61.9
Ca (mg/L)	95.2
Mg (mg/L)	491.1
Na (mg/L)	61.1
SAR ($cmol_c$/L)	3.57
Ash (mg/L)	1,394.4
EC (dS/m)	0.29

Table 2 Effects of mill effluents and NPKMg combinations on plant height, stem diameter and number of fronds of palm oil seedling (*Elaeis guineensis* Jacq.) at 26 WAP.

Treatments	Plant height (cm)	Stem diameter (cm)	Number of fronds
A	31.57^{b}	1.49^{b}	6.41^{c}
B	34.03^{ab}	1.62^{ab}	7.88^{b}
C	34.08^{ab}	1.54^{ab}	7.75^{b}
D	33.13^{ab}	1.50^{b}	7.37^{bc}
E	32.25^{b}	1.49^{b}	7.39^{bc}
F	32.60^{b}	1.60^{ab}	7.88^{b}
G	35.10^{a}	1.64^{a}	8.33^{a}
H	33.29^{ab}	1.54^{ab}	7.59^{bc}
I	32.94^{b}	1.47^{b}	7.67^{bc}
J	36.31^{a}	1.64^{a}	8.12^{a}

Means within a column with the same letter are not significantly different according to Duncan multiple range test (p = 0.05).

Table 3 Effects of mill effluents and NPKMg combinations on soil C_{org}, pH and nutrients availability at 26 WAP.

Treatments	C_{org} (g/kg)	pH	CEC ($cmol_c$/kg)	Exchangeable Mg ($cmol_c$/kg)	Exchangeable K ($cmol_c$/kg)	N_{tot} (g/kg)	Available P (mg/kg)
A	13.8^{b}	5.09^{b}	9.21^{b}	1.44^{a}	0.49^{c}	0.90^{b}	7.0^{b}
B	17.6^{ab}	5.27^{b}	11.97^{ab}	1.45^{a}	0.78^{ab}	1.00^{ab}	7.0^{b}
C	14.8^{b}	5.46^{b}	11.93^{ab}	1.46^{a}	0.85^{a}	1.10^{ab}	8.0^{ab}
D	17.8^{ab}	5.69^{ab}	11.23^{ab}	1.52^{a}	0.79^{ab}	1.30^{a}	9.0^{ab}
E	15.7^{b}	5.24^{b}	11.26^{ab}	1.56^{a}	0.78^{ab}	1.10^{ab}	9.0^{ab}
F	14.5^{b}	5.48^{b}	10.41^{b}	1.63^{a}	0.73^{bc}	1.30^{a}	7.0^{b}
G	19.7^{ab}	5.71^{ab}	13.38^{ab}	1.69^{a}	0.81^{ab}	1.30^{a}	11.0^{a}
H	14.6^{b}	5.15^{b}	13.07^{ab}	1.54^{a}	0.68^{bc}	1.10^{ab}	7.0^{b}
I	18.2^{ab}	5.51^{b}	12.15^{ab}	1.67^{a}	0.68^{bc}	1.20^{ab}	9.0^{ab}
J	22.6^{a}	5.82^{a}	13.72^{a}	1.51^{a}	0.80^{ab}	1.30^{a}	10.0^{ab}

Means within a column with the same letter are not significantly different according to Duncan multiple range test (p = 0.05).

as a result of low content of soil C_{org}, so that nutrients became less available to plants, as well as low soil pH.

Applications of 9.6 L mill effluent combined with 50%-75% NPKMg/polybag at 26 WAP resulted in the tallest palm oil seedling (35.10-36.31 cm), which gave an increase of 8.8%-12.6% compared to control (31.57 cm). Increase of stem diameter (9.2%) and number of fronds (21.1%-23.0%) was also affected significantly by those treatments. As observed by Rosenani et al. [4], the increase was a result of many factors in changing soil microenvironment for better seedling root growth and development, including composition of solutes in the soil solution, C_{org} and N concentrations.

3.3 Soil Chemical Parameters

Table 3 showed that the treatments influenced soil nutrients availability at 26 WAP. Compared to the control, mill effluent applications in combination with NPKMg fertilizer significantly affected the increase of soil C_{org}, providing an evidence of better soil amendment to improve low content of C_{org} in Ultisols. Enhancement of C_{org} in the amount of 0.4%-0.9% (Table 3) was obtained as a result of 9.6 L mill effluent applications combined with 50%-75% NPKMg/polybag. Presumably, this was due to high levels of functional groups, such as R-COO-, R-C=O, R-COH, R-SH from TSS of palm oil mill effluent used in this study.

Ikbel et al. [13] reported that mill effluent amendment may have provided the needed microbes that stimulated soil C_{org} degradation. Consequently, mill effluent applications may be attributed to the ability of the waste to stimulate the decomposition of the original C in the subsisting soil-plant environment. Even at 26 WAP, application of 9.6 L mill effluent combined with 50% NPKMg/polybag resulted in a higher soil pH compared to the control. The invariable degree of ionizable H^+ and OH^- present in the soil suggests the activities of anion and cation limits to acidity and alkalinity aspects of the soil, especially in soil solution and exchange sites present in the soil [14].

Higher soil CEC (13.72 $cmol_c$/kg) was due to the application of 9.6 L mill effluent combined with 50% NPKMg/polybag, in particular due to the ability to retain the cations on soil colloids and their negative charge. Most likely that soils dominated by clays with a high specific surface area and numerous reaction sites, such as Ultisols, adsorb more organic substances than soils dominated by clays with a low specific surface area [15].

Meanwhile, combinations of mill effluents and NPKMg did not affect soil exchangeable Mg, but soil exchangeable K (39%-73%) and N_{tot} (11%-44%) increased significantly (Table 3). Hardie and Cotchin [16] reported that increasing the amount of waste applied to soils always lead to a greater amount of potentially available N and K present in the soil waste mixture. In addition, Ikbel et al. [13] proved that mineralization of organic matters releases inorganic N, P and other nutrients contained in organic matters of mill effluent.

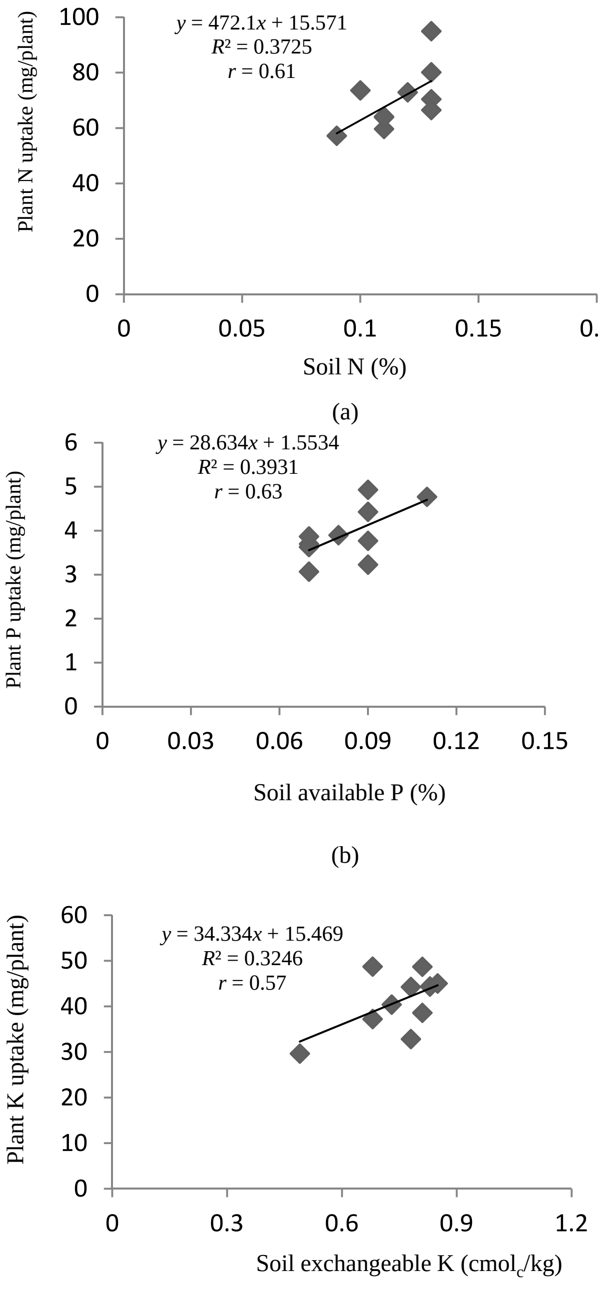
On the other hand, excess exchangeable Ca^{2+} on mill effluent is usually not compatible for the availability of other soil nutrient, such as P [17]. However, the highest availability of soil P in this study was obtained due to applications of 9.6 L of mill effluent combined with 50% NPKMg/polybag. The increase in the available P, according to Akinyele et al. [18], is a result of high adsorption in the soil or a possible precipitation of P in the soil, as well as the gradual biodegradation of mill effluent, which leads to a delay effect on the soil.

Incorporation of mill effluent and NPKMg combinations had an impact on nutrient uptake by palm oil seedlings at 26 WAP (Table 4). Compared to the control, higher doses of mill effluent (9.6 L) combined with 50% NPKMg significantly increased the uptake of N (11.7%-66.0%) and P (5.2%-60.6%) by palm oil seedlings, while the uptake of K increased 10.8%-64.2% due to the dose of 9.6 L mill effluent combined with 75% NPKMg. The correlation between soil nutrients availability and their uptake by palm oil seedlings (r = 0.61, 0.63 and 0.57, respectively) indicated a positive relationship to the quantity of those ions present in the soil matrix and soil solution (Fig. 1). Results of this study corresponded to the statement of Shenoy and Kalagudi [19] that the utilization of organic liquid enhanced the efficiency of inorganic fertilizer use.

Table 4 Effects of mill effluent and NPKMg combinations on nutrients uptake by palm oil seedlings (*Elaeis guineensis* Jacq.) at 26 WAP.

Treatments	N (mg/plant)	P (mg/plant)	K (mg/plant)	Mg (mg/plant)
A	57.20^{a}	3.07^{a}	29.67^{a}	7.13^{a}
B	73.57^{b}	3.70^{a}	44.30^{bc}	8.01^{a}
C	64.13^{a}	3.90^{a}	44.40^{bc}	8.53^{a}
D	80.13^{bc}	4.43^{ab}	48.73^{c}	8.10^{a}
E	59.67^{a}	3.23^{a}	32.87^{a}	7.67^{a}
F	70.40^{ab}	3.63^{a}	40.43^{bc}	8.06^{a}
G	66.47^{ab}	4.77^{ab}	48.77^{c}	7.43^{a}
H	63.90^{a}	3.87^{a}	37.27^{ab}	8.09^{a}
I	72.90^{b}	3.77^{a}	38.63^{ab}	8.10^{a}
J	94.97^{c}	4.93^{b}	45.07^{bc}	8.17^{a}

Means within a column with the same letter are not significantly different according to Duncan multiple range test (p = 0.05).



(c)

Fig. 1 Correlation between soil nutrients availability and uptake of N (a), P (b) and K (c) by palm oil seedlings (*Elaeis guineensis* Jacq.) at 26 WAP.

4. Conclusions

Application of 9.6 L mill effluent combined with 50%-75% NPKMg/polybag caused the increase of plant height (8.8%-12.6%), stem diameter (9.2%) and number of fronds (21.1%-23.0%) of palm oil seedlings at 26 WAP. The enhancement of soil C_{org} content (0.4%-0.9%), soil pH (12.5%), CEC (33.9%), availability of soil P (36.4%) and N_{tot} (11%-44%) occurred due to the application of 9.6 L mill effluent combined with 50% NPKMg/polybag, while increases of soil exchangeable K (39%-73%) were caused by the application of 6.4 L mill effluent combined with 100% NPKMg/polybag. Soil exchangeable Mg was not affected by all doses combinations of mill effluents and NPKMg. A positive correlation between availability of soil N, P and K and their uptake by palm oil seedlings at 26 WAP were indicated by *r* value 0.61, 0.63 and 0.57, respectively.

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