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Short Report

Utilizing Palm Oil Mill Effluent by Mixing with Dolomite and Chicken Manure to Increase Soybean Production on Tropical Ultisols

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Introduction

Indonesia is the world's largest producer of palm oil, and it currently contributes nearly half of all global palm oil production (FAO, 2016). In Indonesia, the land area of oil palm (*Elaeis guineensis* Jacq) plantations has expanded rapidly over the last few decades, having increased from 1 million ha in 1990 to 11 million ha in 2014 (IMOA, 2014). This rapid expansion of oil palm plantations has occurred with the encouragement of the Indonesian government, which aims to acquire foreign currency, in many cases at the cost of losing natural tropical forest, thus threatening natural ecosystems with some of the richest biodiversity in the world (Carlson *et al.*, 2012; Margono *et al.*, 2014). Indonesia is expected to double its palm oil production during 2010–2030 (Gilbert, 2012).

On the other hand, palm oil mills, which process fresh fruit bunches into crude palm oil through high-pressure steam sterilization, bunch stripping, digestion, and oil extraction and purification, generate various types of wastes including large quantities of liquid wastes (Setiadi, 2008). The generation of waste by palm oil mills represents another threat to the environment of the palm oil industry. The liquid waste from palm oil mills is often referred to as "palm oil mill effluent (POME)", which denotes the sum total of liquid waste including various kinds of liquids, residual oil and suspended solids from the palm oil processing (IMOE/JMOE, 2013). In most cases, POME cannot be easily or immediately reprocessed to extract useful products, and thus it is often drained to effluent pits for anaerobic digestion (Ugoji, 1997). However, the limited capacity of effluent pits is a major constraint in treating POME, and it often leads to the emission of incompletely treated POME that can cause environmental pollution (IMOE/JMOE, 2013). Usually, POME is strongly acidic (pH≈4); high in biological oxygen demand (≈25,000 mg L^{-1}), chemical oxygen demand (≈50,000 mg L^{-1}) and oils (≈6,000 mg L^{-1}); and contains certain amounts of nutrients such as N, P and K (IMOE/JMOE, 2013). These characteristics of POME represent environmental pollution risks but also indicate its potential as a fertilizer (Ugoji, 1997).

Considering the various nutrients included in POME and the limited capacity for waste water treatment in Indonesia (IMOE/JMOE, 2013), the application of POME to agricultural lands can aid in the recycling of bio-wastes, increase food production and reduce the environmental pollution risk related to palm oil processing. However, the strongly acidic nature of POME limits its use in agriculture because untreated or poorly treated POME may have adverse impacts on crop production and soil management. Thus, the use of POME in food crop production requires that the POME receive appropriate treatment, especially amelioration of its acidity, using locally available material and an affordable methodology. We have considered that liming POME's acidity with dolomite can provide a solution because: (i) dolomite that contains high amounts of Ca and Mg is very useful for liming acidic substances (Dierolf *et al.*, 2001); and (ii) dolomite is locally available at a relatively low price in Indonesia. Thus, dolomite can be advantageous when utilizing POME in agricultural production on Ultisols, soils which cover up to 46 million ha, about 25% of the total land area in Indonesia (Subagyo *et al.*, 2000). Ultisols are deeply weathered, red-colored soils which are formed from various types of parent materials and are inherently low in bases such as Ca and Mg but high in acidity as a result of the intensive chemical weathering of rocks and minerals in a tropical

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humid climate (Juo, 1980; Kang and Spain, 1986). Their poor fertility characteristics represent a significant soil constraint on the production of food crops in Indonesia (Subagyo *et al.*, 2000) such as soybeans, which are known to be sensitive to soil acidity (YAIAT, 2008).

Another constraint regarding the utilization of POME in agriculture is its physical state of matter. As stated earlier, POME is in a liquid state even after the addition of dolomite for deacidification, and it is not easy for farmers to transport/handle POME. To overcome this constraint, we added chicken manure to POME so that the POME transforms into a solid state after drying. Chicken manure was chosen because it can absorb high amounts of liquids, is available in local markets, and adds nutrients to POME that can be beneficial for crop production.

In this study, we processed acidic, liquid-state POME into neutral, solid-state POME by mixing it with dolomite and chicken manure (hereafter the mixture of POME with dolomite and chicken manure is referred to as POME+DC), and aimed to examine the effects of POME+DC on crop production and soil fertility characteristics in order to collect basic information on the utilization of POME in crop production. To this end, a pot experiment was conducted in a greenhouse using a POME+DC, Ultisol and soybeans.

Materials and Methods

POME (s.g., 1.2 g mL^{-1}; pH, 4.1; BOD, 24.7 g L^{-1}; COD, 51.3 g L^{-1}; total solid, 35.0 g L^{-1}; N, 660 mg L^{-1}; P, 112 mg L^{-1}; K, 1676 mg L^{-1}), which was obtained from PT. Bakrie Sumatra Plantations Tbk in West Pasaman, West Sumatra, Indonesia, was mixed with dolomite powder (CaO, 30%; MgO, 18%) at a ratio of 10:1 (w/w). This mixture was subsequently mixed with chicken manure (N, 21.6 g kg^{-1}; P, 12.3 g kg^{-1}; K, 19.7 g kg^{-1}) at a ratio of 3:1 (w/w) after its pH reached neutral (pH=7). The mixture of POME with dolomite and chicken manure was incubated for 30 days and was finely ground before use. The final product, so-called POME+DC, had a pH of 7.0 and contained 187 g kg^{-1} of total C, 16.5 g kg^{-1} of total N, 5.4 g kg^{-1} of available P, and 74.3, 46.1 and 85.1 mg kg^{-1} of 1 M neutral ammonium acetate extractable K, Ca and Mg, respectively. Here, the analytical methods used for POME+DC were the same as those used for the soil samples described in the following paragraph.

Soybeans (*Glycine max* (L.) cv. Willis), which are widely cultivated on Java Island, were used as a test plant. A highly weathered tropical red soil, classified as a Typic Kandiudult (Soil Survey Staff, 2014), was collected from an experimental farm (soil depth: 0–20 cm) at Andalas University (0°54’52”S; 100°27’45”E), Padang, West Sumatra, and was used as a culture soil in the pot experiment. This soil had a pH of 5.2 and contained 16.8 g kg^{-1} of organic C, 1.8 g kg^{-1} of total N, 1.2 mg kg^{-1} of available P (Bray-I P), 0.1 $cmol_c$ kg^{-1} of exchangeable K, 2.3 $cmol_c$ kg^{-1} of exchangeable Ca, 0.3 $cmol_c$ kg^{-1} of exchangeable Mg, 2.6 $cmol_c$ kg^{-1} of exchangeable acidity, 5.8 $cmol_c$ kg^{-1} of effective cation exchange capacity (CEC) and a base saturation of 55%. Here, the soil characteristics were analyzed according to routine methods. Briefly, the soil pH was measured using a glass electrode (9625-10D connected to D-55, Horiba, Ltd., Tokyo) in a solid:liquid ratio of 1:2.5. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1 M neutral ammonium acetate and determined by atomic absorption spectrometry (Z-2300, Hitachi Tech., Co., Tokyo). Organic C was determined by the Walkley-Black method, while total N was measured by the Kjeldahl method. Available P was extracted by the Bray No. 2 method and was measured by the molybdate blue method. Exchangeable acidity was extracted with 1 M potassium chloride and was measured by alkaline titration.

A pot experiment was conducted in a well-ventilated greenhouse with a glass roof and wire mesh wall at the main campus of Andalas University from June to September 2015. The mean daily air temperature was 27°C (max.=32°C; min.=21°C) and the mean daily relative humidity was 82–86% (max.=100%; min.=55%) during the experiment. A 22 L plastic pot (upper diameter=30 cm; bottom diameter=21 cm; height=25 cm) was filled with 8 kg of the culture soil (on an oven dry basis). POME+DC was mixed thoroughly with the soil inside the pot 2 weeks before soybean seeds were sown. Three soybean seeds were sown and emerged shoots were thinned to one in each pot 7 days after sowing (DAS). Chemical fertilizers were incorporated into the surface soil around the points where the seeds were sown at 7 DAS. Soil moisture was maintained at a field moisture capacity (42.8%) throughout the experimental period, and the soybeans were grown until they ripened for the harvest. Plants were kept free from insects and weeds by spraying insecticide (Alika 247 ZC, Syngenta Indonesia, Bogor) and manually weeding during the experiment, respectively.

The experiment was designed with a completely randomized layout with three replications using two fixed factors: five different POME+DC application rates, i.e., 0, 5, 10, 15 and 20 t ha^{-1}, and three different chemical fertilizer rates, i.e., nil, half and full amounts of the recommended rate for soybean production (YAIAT, 2008), i.e., 50 kg ha^{-1} of urea (23 kg N ha^{-1}), 200 kg ha^{-1} of double superphosphate (DSP) (72 kg P_2O_5 ha^{-1}), and 100 kg ha^{-1} of muriate of potash (MOP) (60 kg K_2O ha^{-1}).

Soil samples were taken from the pot 2 weeks after the application of POME+DC, but prior to the application of chemical fertilizer, to evaluate the influence of POME+DC on soil chemical properties. The whole plant body in each pot was harvested at 95 DAS and was divided into four parts: seeds, pods, stem and leaves, and roots. These plant tissues were rinsed with water and dried in an oven at 60°C for 48 hours to determine the seed yield and biomass production. Herein, the summed weight of seeds, pods, leaves and stems was considered to represent the aboveground biomass, while the root weight represented the belowground biomass. The harvest index was computed by dividing the seed weight by the aboveground biomass.

Analysis of variance (ANOVA) was applied to determine the effects of POME+DC on the soil properties (one factor: five different POME+DC application rates) and soybean production (two factors: five different POME+DC application rates and three different chemical fertilizer application rates), separately. Tukey's test was applied to separate the means of 9 and 3 replications for soil properties and soybean production, respectively. All the statistical analyses were carried out using SAS 9.2 (SAS Institute Inc., Cary, NC, USA) and $P<0.05$ was considered as significant in this study.

Results

The ANOVA revealed that the application of POME+DC significantly affected all the soil properties except for total N (Table 1). As the application rate was increased (up to 20 t ha^{-1}), the exchangeable acidity significantly decreased from 2.6 to nearly nil cmol$_c$ kg^{-1}, while the pH, organic C, available P, and exchangeable K, Ca and Mg significantly increased from 5.0 to 6.1, from 19 to 34 g kg^{-1}, from 1.9 to 53 mg kg^{-1}, from 0.1 to 0.8 cmol$_c$ kg^{-1}, from 2.3 to 7.1 cmol$_c$ kg^{-1} and from 0.3 to 1.9 cmol$_c$ kg^{-1}, respectively (Table 2). In addition, the application of POME+DC significantly increased the effective CEC from 5.8 to 10 cmol$_c$ kg^{-1} and the base saturation from 55% to 100% in the culture soil and significantly decreased its exchangeable Na from 0.5 to 0.2 cmol$_c$ kg^{-1}.

The ANOVA revealed that the application of POME+DC significantly affected all soybean production indicators (Table 3). In contrast, no influence of chemical fertilizer alone at the recommended application rate was found to a significant extent, nor was an interactive effect of POME+DC and chemical fertilizer, on any of the soybean production indicators except for an interactive effect on seed yield. The weight and number of seeds per plant increased from 0.2 to 1.9 t ha^{-1} and from 12 to 187 seeds plant^{-1}, respectively, as the application rate was increased (up to 20 t ha^{-1}) (Table 4). The 100-seed weight and harvest index were found to be highest in the control, which received neither of POME+DC nor any chemical fertilizer. The former showed few significant differences from the other treatments, but the latter had significantly higher values than many of the other treatments. The application of POME+DC also increased the aboveground and belowground biomasses from 0.4 to 8.5 t ha^{-1} and from 0.03 to 0.34 t ha^{-1}, respectively, as the application rate was increased (up to 20 t ha^{-1}). However, there was no significant difference in seed yield nor in the aboveground or belowground biomasses between the treatments when more than 10 t ha^{-1} of POME+DC was applied.

Table 1. Results of analysis of variance on soil fertility parameters with one fixed factor: 5 levels of POME+DC.

Parameter	R^2	CV (%)	F value
pH (H_2O)	0.93	2.1	<0.001***
Organic C	0.70	17.9	<0.001***
Total N	0.13	16.7	0.234^{ns}
Avail. P	0.96	15.8	<0.001***
Exch. K	0.89	19.4	<0.001***
Exch. Ca	0.97	6.6	<0.001***
Exch. Mg	0.99	5.5	<0.001***
Exch. Na	0.98	9.6	<0.001***
Total acidity	0.98	18.3	<0.001***
Effective CEC	0.96	4.7	<0.001***
Base saturation	0.98	2.7	<0.001***

Abbreviations: R^2=coefficient of determination; CV=coefficient of variation
*** and ns indicate significant difference ($P<0.001$) and insignificant difference ($P\geq0.05$), respectively.

Table 2. Soil fertility parameters as affected by application of POME+DC.

Parameter	Unit	P0	P5	P10	P15	P20
pH (H_2O)	–	5.0e ± 0.05	5.3d ± 0.04	5.7c ± 0.04	5.9b ± 0.03	6.1a ± 0.03
pH (KCl)	–	4.00e ± 0.00	4.27d ± 0.01	4.78c ± 0.00	5.16b ± 0.03	5.37a ± 0.01
Organic C	g kg^{-1}	19.4c ± 0.64	16.5c ± 1.05	30.0ab ± 2.27	27.6b ± 1.53	34.0a ± 1.60
Total N	g kg^{-1}	2.3a ± 0.06	2.4a ± 0.06	2.5a ± 0.09	2.5a ± 0.20	2.8a ± 0.21
Avail. P	mg kg^{-1}	1.9e ± 0.20	12.8d ± 0.59	23.2c ± 0.80	34.7b ± 1.00	53.1a ± 2.59
Exch. K	cmolc kg^{-1}	0.1d ± 0.00	0.3c ± 0.00	0.5b ± 0.01	0.6b ± 0.01	0.8a ± 0.06
Exch. Ca	cmolc kg^{-1}	2.3e ± 0.03	3.6d ± 0.08	5.1c ± 0.15	6.2b ± 0.11	7.1a ± 0.11
Exch. Mg	cmolc kg^{-1}	0.3e ± 0.00	0.8d ± 0.02	1.2c ± 0.02	1.7b ± 0.02	1.9a ± 0.03
Exch. Na	cmolc kg^{-1}	0.5a ± 0.00	0.1c ± 0.00	0.1c ± 0.01	0.2b ± 0.00	0.2b ± 0.01
Exch. Acidity	cmolc kg^{-1}	2.6a ± 0.05	1.1b ± 0.09	0.3c ± 0.04	0.1cd ± 0.02	0.0d ± 0.02
Exch. Al	cmolc kg^{-1}	1.93a ± 0.06	0.70b ± 0.05	0.05c ± 0.05	0.00c ± 0.00	0.00c ± 0.00
Exch. H	cmolc kg^{-1}	0.74a ± 0.03	0.49b ± 0.06	0.26bc ± 0.09	0.08c ± 0.01	0.02c ± 0.01
Effective CEC	cmolc kg^{-1}	5.8d ± 0.05	5.9d ± 0.05	7.2c ± 0.15	8.7b ± 0.14	10.1a ± 0.15
Base saturation	%	54.5d ± 0.63	80.9c ± 1.47	96.4b ± 0.61	98.9ab ± 0.24	99.6a ± 0.07

POME+DC application rate: P0=0 t ha^{-1}, P5=5 t ha^{-1}, P10=10 t ha^{-1}, P15=15 t ha^{-1}, P20=20 t ha^{-1}.
Figures shown in the table indicate means ± standard errors.
Means with the same letters within the row are not significantly different ($P \geq 0.05$).

Table 3. Results of analysis of variance on soybean production parameters with two fixed factors: 5 levels of POME+DC and 3 levels of chemical fertilizer.

Parameter	R^2	CV (%)	POME+DC (P)	Fertilizer (F)	P × F
Seed yield	0.90	23.1	<0.001***	0.266^{ns}	0.028*
Number of seeds	0.92	18.7	<0.001***	0.794^{ns}	0.220^{ns}
100-seeds weight	0.51	20.4	0.014*	0.130^{ns}	0.210^{ns}
Harvest index	0.69	19.4	<0.001***	0.147^{ns}	0.156^{ns}
Aboveground biomass	0.90	21.2	<0.001***	0.791^{ns}	0.358^{ns}
Belowground biomass	0.70	38.2	<0.001***	0.977^{ns}	0.901^{ns}

Abbreviations: R^2=coefficient of determination; CV=coefficient of variation
*** and * respectively indicate significant difference at $P<0.001$ and $P<0.05$, while ns shows insignificant difference ($P \geq 0.05$).

Discussion

Ultisols generally show a strongly acidic reaction with high acidity and low exchangeable base and available P contents (Kang and Spain, 1986). These characteristics, which are typical of Ultisols, were all seen in the cultural soil used in this study (Table 2). The application of POME+DC improved the fertility characteristics of the studied Ultisol due to the increases in soil pH up to neutral reactions and the elimination of soil acidity as well as the provision of plant nutrients such as P, K, Ca and Mg (Tables 1 and 2). Both the elevation of soil pH and an increase in soil organic matter content would contribute to the enhancement of soil CEC, which can reduce soil Al toxicity due to an increased buffering capacity against acidification (Brady and Weil, 2002; Brown *et al.*, 2008). Ultisols are dominated by 1:1 type phyllosilicate clay minerals such as kaolins and free Fe/Al oxyhydoxides, and thus they have pH-dependent negative electric charges, which are generated on the surface of soil colloids by the dissociation of H^+ from hydroxyl groups, and which increase with increasing soil pH (Juo, 1980). Soil organic matter also has pH-dependent negative charges derived from alcoholic, phenolic and carboxylic groups (Brady and Weil, 2002). Also, the amelioration of soil acidity can enhance soil P availability and base retention, both of which can contribute to an increase in crop production (Kang and Spain, 1986; Dierolf *et al.*, 2001). On the other hand, the application of POME+DC did not increase the soil total N in spite of the fact that the POME+DC had a certain amount of N (16.5 g kg^{-1}). This suggests that the applied N was lost rapidly through volatilization and/or leaching. The addition of Ca and Mg to the soil through the application of POME+DC may cause the decrease in exchangeable Na through leaching, as the soil preferentially adsorbed Ca and Mg more preferentially than Na on its cation exchange sites (Brady and Weil, 2002).

All these ameliorations led to improvement of the soybean seed yield (ca. 1500% at max) and biomass production (ca. 2100% for aboveground; 1100% for belowground at max) (Table 4). In contrast, the application of a dozen recommended chemical fertilizers alone was not able to significantly increase the soybean seed yield or the biomass production (Table 3). This indicates that the amelioration of soil acidity by liming is crucial to increase soybean production in Ultisols (Kang and Spain, 1986; Dierolf *et al.*, 2001) and that the POME+DC that we prepared for this study can be effective as a liming material (Table 2). Soybeans are moderately sensitive to soil acidity, and the optimum soil pH range of soybean growth is 6.0 to 6.5 (Rao and Reddy, 2010). In acidic soils with pH<6.0, soybeans may suffer from Al toxicity, deficiencies of bases and P and a diminished capacity of symbiotic N fixation due to low molybdenum availability (Gupta, 1997; Brady and Weil, 2002), resulting in a reduction in the soybean yield (Dierolf *et al.*, 2001; Brown *et al.*, 2008).

The original POME often shows strongly acidic reactions, and thus its use in the agricultural sector has been restricted, as it may exacerbate soil acidity problems regardless of its potential as a fertilizer. In addition, the original POME is in a liquid state, and it is not easy for farmers to transport/handle. These two important properties result in major constraints on the use of POME in crop production. As demonstrated in this study, by mixing POME with dolomite and chicken manure, it can be utilized as an easy-to-handle soil amendment that can improve soil fertility and crop production through the amelioration of soil acidity and the addition of some nutrients.

Nevertheless, the combined application of the highest application rates of POME+DC (20 t ha^{-1}) and a dozen recommended chemical fertilizers resulted in no significant increase in the soybean seed yield or biomass production. Therefore, the application of POME at 10–15 t ha^{-1} without any chemical fertilizer seems to be the best treatment to optimize the soybean yield in the studied soil. On the other hand, the acidity amelioration efficiency and nutrient contents of POME+DC can vary considerably based on the quality of the materials (POME, dolomite, chicken manure) used for the POME+DC preparation and the ratio at which they are mixed. So, the ex-ante quality test of the materials and/or final product (POME+DC) will be crucial to optimize the use of POME+DC in crop fields.

In this study, we demonstrated that POME can be utilized as a soil amendment for crop production in Ultisols, which are highly weathered tropical soils, by mixing it with dolomite and chicken manure. In particular, POME+DC was effective to eliminate soil acidity and provide essential nutrients (e.g., P, K, Ca, Mg) or enhance their availability in the soil. All such ameliorations were effective for increasing crop production in Ultisols.

Table 4. Soybean production parameters as affected by application of POME+DC and chemical fertilizer.

Parameter	Unit	P0			P5			P10			P15			P20		
		CR	1/2R	FR	CR	1/2R	FR	CR	1/2R	FR	CR	1/2R	FR	CR	1/2R	FR
Seed yield	t ha^{-1}	0.15e±0.01	0.15e±0.05	0.11e±0.02	1.04cd±0.10	0.66de±0.33	1.10cd±0.18	1.57abc±0.16	1.51abcd±0.14	1.10cd±0.36	1.89abc±0.10	1.86abc±0.14	2.03ab±0.09	1.90abc±0.10	2.30a±0.07	1.42bcd±0.19
Number of seeds	n plant^{-1}	12.3d±0.7	12.7d±4.2	9.7d±1.8	111.7bc±7.5	74.0cd±37.0	113.3bc±13.5	139.3abc±15.0	155.0ab±13.3	150.7ab±2.3	174.7ab±20.4	164.7ab±9.2	195.3a±10.6	186.7a±1.9	205.7a±1.5	172.0ab±8.5
100-seed weight	g	8.72a±0.28	8.63a±0.64	7.45ab±0.41	6.53ab±0.21	4.23b±2.13	6.81ab±0.29	7.98ab±0.20	6.89ab±0.26	5.20ab±1.72	7.80ab±0.77	8.01ab±0.75	7.37ab±0.37	7.18ab±0.42	7.90ab±0.20	5.85ab±0.82
Harvest index	%	35.9a±2.2	32.8ab±2.0	25.9abc±2.2	19.2c±0.10	12.6c±6.3	20.0bc±0.9	21.8bc±0.5	22.3bc±1.0	16.9c±5.1	23.3abc±1.7	23.7abc±3.3	22.2bc±0.8	22.2bc±0.5	25.5abc±1.2	21.3bc±1.5
Aboveground biomass	t ha^{-1}	0.43e±0.06	0.50de±0.20	0.39e±0.06	5.40bc±0.54	4.18cd±1.09	5.46bc±0.63	7.18abc±0.59	6.86abc±0.94	6.37abc±0.23	8.23ab±0.99	8.03ab±0.86	9.23a±0.71	8.52ab±0.24	9.07ab±0.61	6.86abc±1.28
Belowground biomass	t ha^{-1}	0.03bc±0.01	0.03bc±0.01	0.01c±0.00	0.31abc±0.05	0.41a±0.20	0.44a±0.01	0.38a±0.05	0.29abc±0.05	0.34ab±0.01	0.33abc±0.05	0.32abc±0.03	0.30abc±0.02	0.34ab±0.02	0.34ab±0.02	0.34ab±0.07

POME+DC application rate: P0=0 t ha^{-1}, P5=5 t ha^{-1}, P10=10 t ha^{-1}, P15=15 t ha^{-1}, P20=20 t ha^{-1}.
Fertilizer application rate as Urea-DSP-MOP (N-P_2O_5-K_2O kg ha^{-1}): CR=0-0-0 (0-0-0); 1/2R=25-100-50 (11.5-36-30); FR=50-200-100 (23-72-60).
Figures shown in the table indicate means±standard errors.
Means with the same letters within the row are not significantly different ($P \geq 0.05$).

Our findings indicate that the utilization of POME as POME+DC can contribute not only to increasing crop productivity through soil amelioration but also to decreasing the environmental pollution risk in the palm oil industry through recycling POME.

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