The impact of land application of palm oil mill effluents on some soil chemical characteristics in The District Karang Tinggi, Bengkulu Tengah Regency, Province of Bengkulu

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Abstract. Palm oil mill effluents are envisaged as fertilizer alternatives in palm oil plantations. This research aimed to estimate the impact of the land application on soil some soil chemical characteristics in the District of Karang Tinggi, Bengkulu Tengah Regency, Province of Bengkulu, Indonesia. The implementation of Land applications of POME was carried out by flowing it from palm oil mill effluent ponds on the ditches (roraks) of palm oil plantation land. The soil sample was collected from the soil with land applications, soil between land applications, and soil without land applications. The result showed that land applications of POME contributed to the increasing soil acidity (pH), K, Ca, Mg, KTK, and base saturation in the soil, with the value tend to decline in soil depth. The land applications of POME also contributed to the increasing phosphor and oil/fat in the topsoil.

1 Introduction

In the last two decades, oil palm (*Elaeis guineensis*) has had a substantial role in Indonesia. The total area increased significantly from 9.1 million ha in 2011 to 14.6 million ha in 2021 [1]. Indonesia is the world's top producer and exporter of crude palm oil, with an annual of production 256.6 million tons of fresh fruit bunch in 2021, an increase significantly from 41 million tons in 2001 and 157.3 million tons in 2011 [2]. Oil palm contributed to the national economic growth.

Oil palm is a vital food crop and is cultivated commercially in Indonesia. Oil palm is a good source of vegetable oil. In Indonesia, most people use it as a frying oil, substancial ingradience to cook their food. Oil palm is associated with diets and food security [3]. As a strategic commodity, oil palm is assosiated to the generating income of farmer households. In Jambi, Sumatera, reported that palm oil has a significant positive effect on farmers livelihoods [4].

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Oil palm expansion also harms the environment. In general, oil palm expansion is subjected to deforestation. During 1995-2015, the average oil palm plantation growth was 450,000 ha every year, while deforestation meant 117,000 ha each year. The average of deforestation by plantation tends to decrease from 54% in 1995-2000 to 18% in 2010-2015 [5]. Palm oil companies emerge as powerful actors in land use conflicts, especially in the forest conversion to oil palm plantations [6]. Economic and political incentives reinforce each other as drivers of forest loss and land conversion for oil palm cultivation [7]. Oil palm expansion also contributed to increasing greenhouse gas (GHG) emissions and social conflicts, thus oil palm expansion should be accompanied by effective smallholder development programs to achieve the best outcome for the local farmers and avoid the conflicts [8].

In line with the increasing oil palm plantations, the oil palm mills increase rapidly, thus increasing the capacity of fresh fruit bunch waste or effluent discharge. In order to produce one ton of crude palm oil (CPO), it required more than 5 tons of water in the process. About 50% of the water turns into palm oil mill effluents (POME). POME is more polluted than municipal sewage which has a high biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The effluent also contains higher concentrations of organic nitrogen, phosphorus, and different supplement substances [9]. As by-product of palm industry, POME releases large amounts of greenhouse gases (GHGs). POME also potentially as pollutant to water system if it released into nonstandard ponds or river, harm to the lives of fish and water fowl. With the higher content of organic materials, POME potentially as a good source of nutrients [10].

As a good source of nutrients, palm oil mill effluent envisaged as an alternative fertilizer by applying it on land. Land application of palm oil mill effluent arranged by the government with the regulation of the Ministry of Environment and Forestry Republic Indonesia No. 5 year 2021. The aims of this research were to estimate the impact of land application of palm oil mill effluent on some soil chemical characteristics in the District of Karang Tinggi, Bengkulu Tengah Regency, Province of Bengkulu, Indonesia.

2 Methodology

2.1 Time and Place

This research was conducted from January to December 2022 in the District of Karang Tinggi, Bengkulu Tengah Regency, Bengkulu Province, Indonesia. The distance of the research location from Bengkulu City is 20 km. The soil type of the location is classified as Ultisols. Soil sampling was collected from palm oil land with land application of POME and palm oil land without land application of POME.

2.2 Research Procedure

Land application of POME refers to the regulation of land application of POME by the Ministry of Environment and Forestry of the Republic of Indonesia (Permen LHK RI No. 5 Tahun 2021). The palm oil mill effluent is applied by flowing it into the ditch on the palm oil land (roraks). After six months of land application, soil sampling was conducted by collecting it in 6 classes of soil depth, 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm, and 100-120 cm. The location of soil sampling is soil in the roraks of land application, soil between the roraks of land application, and soil without land application (Figure 1). The soil samples tested in the Soil Science Laboratory at IPB University, Bogor, Indonesia. The variable of soil characteristics consists of some soil chemical characteristics, consist of soil

acidity (pH), C-organic, N-total, P, K, Ca, Mg, Na, cation exchange capacity (CEC), base saturation, and the content of fat/oil. The data of soil characteristics analysis is described by comparing the properties of soil with land application and without land application of POME.

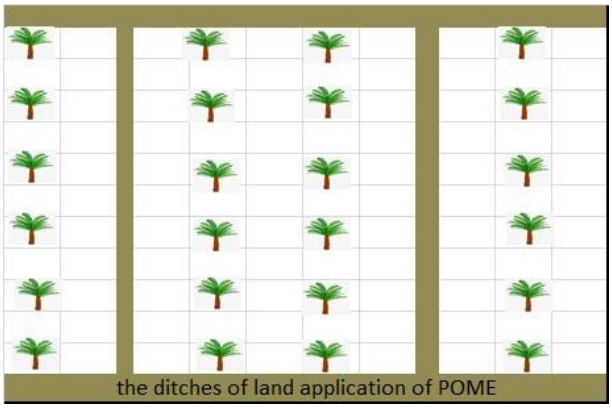

Fig. 1. The design of land application of POME

3 Result

Palm oil mill effluent potentially affects the quality of soil and environment. The results showed that soil acidity in the roraks was higher than in the control and between the roraks of land application. The pH value in the soil depth 0-40 cm at the roraks is considered neutral, slightly acidic at 40-100 cm, and strongly acidic at 100-120 cm. The high value of soil pH in the roraks indicates that the land application of POME contributes to an increase in soil acidity. At a neutral pH, the availability of nutrients for plants is high (Figure 2).

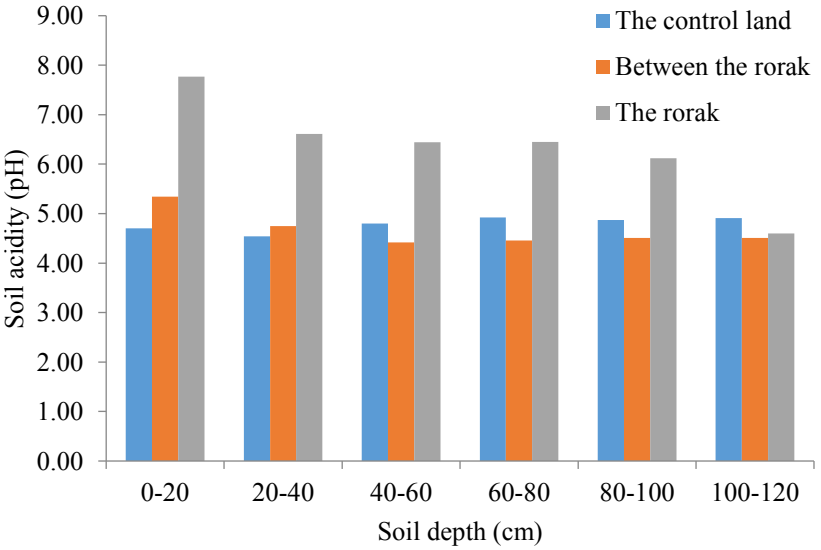

Fig. 2. The soil acidity on the land of application of POME

The C-organic content in the soil depth of 0-40 cm at the rorak was lower than in the control and between the rorak. At the soil depth of 40-120 cm, C-organic levels vary, indicating that the contribution of land application of palm oil mill effluent at the study site is still low. The C-organic content in the soil depth 0-60 cm is low (1.0-2.0), and very low (<1.0) in the 60-120 cm. Meanwhile, in the control and between the rorak, at the soil depth of 0-20 cm is medium (2.0-3.0 %). In the control land, at the soil depth of 20-60 cm, C-organic content categories are low, and very low in the soil depth of 60-120 cm. In the soil depth of 20-120 cm, the C-organic content categories are very low. The c-organic content of the soil showed in the Table 1.

Table 1. The content of soil C-organic of the soils in the soil depths 0-120 cm

Sample Location	Soil C-Organic (%)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
Control	2.63	1.95	1.04	0.75	0.49	0.41
Between the roraks	2.58	0.61	0.91	0.77	0.71	0.68
Rorak	1.12	1.08	1.09	0.96	0.86	0.54

The content of N-total showed that the N-total in the roraks was lower than in the control and between the roraks at soil depth 0-20 cm, while at 20-60 cm, the soil N-total of the roraks was lower than in the control but higher than between the roraks. At the soil depth of 60-120 cm, the content of N-total in the roraks was higher than in the control and between the roraks. At the soil depth of 60-120 cm, N-total in the roraks was higher than in the control and between the roraks, indicating that land application of POME to the increase in soil N-total was still very small (Table 2).

The result of analysis phosphorus showed that the P content in the 0-80 cm soil depth of roraks was higher than the control and between the roraks. This indicates that the application of POME contributes to an increase in P levels in the topsoil. At a layer of 80-120 cm, the P content in the roraks was lower than the P levels in the control and between the roraks (Table 3).

Table 2. The content of N-total in the soils in the soil depths 0-120 cm

Sample Location	N-total (%)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	0.28	0.11	0.10	0.07	0.06	0.06
Between the roraks	0.16	0.07	0.07	0.06	0.06	0.06
Rorak	0.09	0.09	0.09	0.10	0.08	0.09

Land application of palm oil mill effluent contributes to the increasing exchangeable potassium (K-dd) levels in the soil. The K-dd content in the roraks was higher than the K-dd content in the control and between the roraks. The K-dd content in the roraks is very high in all soil depths. Meanwhile, in the control field, K-dd levels were low at the soil depth of 0-40 cm, and very low at the soil depth of 40-120 cm. Whereas in between the roraks, K-dd levels of layers 0-20 cm were very high, moderate in the soil depth 20-40 cm, and low in layers of 40-120 cm (Table 4).

Table 3. The content of P-total in the soils in the soil depths 0-120 cm

Sample Location	P (ppm)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	1.87	1.57	1.49	1.48	1.72	1.74
Between the roraks	3.88	1.29	1.76	1.29	3.06	1.98
Rorak	9.17	2.71	2.68	2.02	1.26	1.49

Table 4. The content of exchangeable potassium of the soils in the soil depths 0-120 cm

Sample Location	Exchangable potassium (K-dd) (Me/100 g)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	0.14	0.11	0.09	0.09	0.06	0.14
Between the roraks	1.10	0.46	0.14	0.12	0.10	0.10
Rorak	11.50	9.75	9.95	10.62	9.51	6.64

The exchangeable calcium (Ca-dd) levels indicated that the Ca-dd levels in the roraks were higher than those in the control and between the roraks. This indicates that the application of POME at the study site contributed to an increase in Ca-dd levels in the soil. Ca-dd levels decreased with increasing soil depth. The Ca-dd levels in the soil depth of 0-100 cm of the roraks are low, and very low at the soil depth of 100-120 cm. Meanwhile, in the control area, it was very low at all soil depths. Whereas in the between the roraks, Ca-dd levels in layers 0-20 cm are low, and very low in layers 20-120 cm (Table 5).

Table 5. The content of exchangeable calcium of the soils in the soil depths 0-120 cm

Sample Location	Ca-dd (Me/100 g)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	1.04	0.78	0.35	0.21	0.20	0.28
Between the roraks	3.09	0.68	0.33	0.35	0.29	0.32
Rorak	4.27	3.24	3.28	3.10	2.84	0.84

The exchangeable magnesium (Mg-dd) analysis showed that the Mg-dd content in the roraks was higher than in the control and between the roraks at all soil depths. This indicates that land application of POME contributed to an increase in Mg-dd levels in the soil. The Mg-dd levels in the roraks at the soil depth of 0-100 cm are very high and moderate in the soil depth of 100-120 cm. Meanwhile, in the control field, Mg-dd levels were low in all layers of soil depth. Whereas in the between the roraks, Mg-dd levels of layers 0-20 cm were high, low in layers of 20-40 cm, and very low in layers of 40-120 cm (Table 6).

Table 6. The content of exchangeable magnesium of the soils in the soil depths 0-120 cm

Sample Location	Mg-dd (Me/100 g)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	0.99	0.82	0.52	0.43	0.45	0.62
Between the roraks	3.08	0.62	0.18	0.21	0.16	0.19
Rorak	12.62	9.47	8.72	9.14	8.36	1.77

In general, the exchangeable sodium (Na-dd) at levels in the roraks were higher than those in the control and between the roraks. It indicates that land application of POME contributes to an increase in soil Na levels. The Na content in the roraks is low at all soil depths. Meanwhile, in the control land, it was low in layers 0-20 cm and 80-120 cm, and very low in layers with a depth of 40-80 cm. Whereas in the between the roraks, it is low in all layers of soil depth (Table 7).

Table 7. The content of exchangeable sodium of the soils in the soil depths 0-120 cm

Sample Location	Na (Me/100 g)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	0.10	0.08	0.09	0.09	0.15	0.11
Between the roraks	0.10	0.11	0.17	0.12	0.13	0.11
Rorak	0.18	0.17	0.17	0.17	0.18	0.17

The analysis of cation exchange capacity (CEC) content showed that the CEC on the roraks was higher than that on the control and between the roraks. This indicates that the application of POME at the study site contributed to an increase in soil CEC. In general, based on the classification of soil chemical properties, soil CEC on the roraks is high at all soil depths. Meanwhile, in the control land at the soil depth 0-20 cm was low, medium in the 20-80 cm, and high in the 80-120 cm. Whereas in the between roraks, the soil CEC was low at soil depths 0-20 cm and 40-100 cm, and moderate at 20-40 cm and 100-120 cm (Table 8).

Table 8. The cation exchange capacity (CEC) of the soils in the soil depths 0-120 cm.

Sample Location	Cation Exchange Capacity (Me/100 g)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	15.31	19.98	22.05	23.32	28.54	30.22
Between the roraks	15.65	21.75	16.43	15.84	14.03	23.33
Rorak	28.49	31.82	28.21	31.54	30.45	33.21

Base saturation on the roraks was higher than in the control and between roraks. This indicates that the application of POME at the study site contributed to an increase in soil base saturation. Soil base saturation decreases with increasing soil depth. In general, the level of base saturation in the roraks is categorized as very high at a soil depth of 0-80 cm, high at 80-100 cm, and low at 100-120 cm. Meanwhile, in control land, it was very low at all layers of soil depth. Meanwhile, in the between the roraks, the base saturation is moderate at a depth layer of 0-20 cm, and very low at a layer depth of 20-120 cm (Table 9).

Table 9. The base saturation of the soils in the soil depths 0-120 cm

Sample Location	Base saturation (%)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	14.79	8.98	4.80	3.53	3.02	3.79
Between the roraks	47.08	8.59	4.97	5.07	4.84	3.11
Rorak	100.00	71.10	78.40	73.04	68.60	28.36

The oil/fat content in the roraks was higher than in the control fields and the top layer between the roraks (0-20 cm). At a soil depth of 20-120 cm, the levels varied when compared to control and between the roraks. In layers 20-40, the oil/fat content in the roraks was lower than the control but higher than between the roraks. In the 40-80 cm layer, the roraks levels were higher than in the controls and between the roraks. At a depth of 80-120 cm, levels are lower than control but higher than between the roraks. The oil/fat content decreased as the increasing soil depth, indicates that land application of POME contributed to the increasing oil/fat content in the soil, especially at the topsoil (Figure 3).

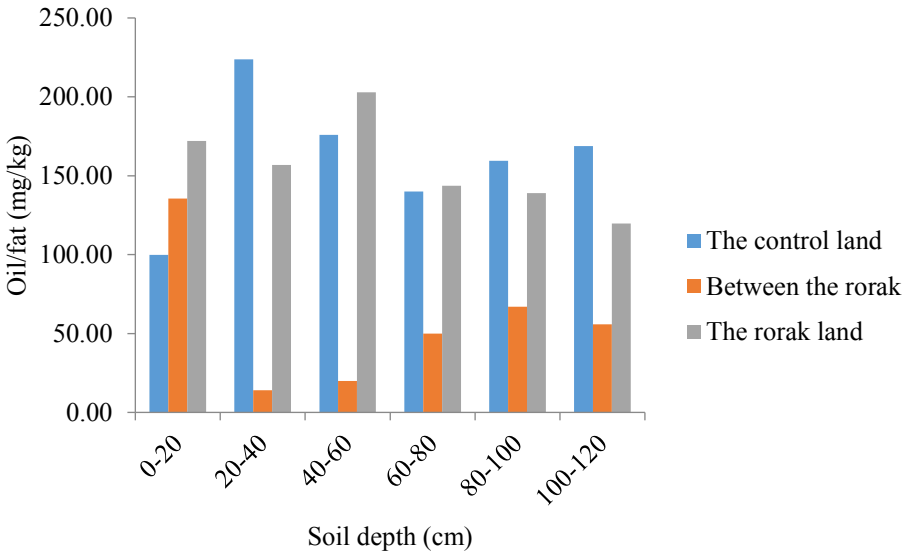

Fig. 3. The content of oil/fat in the fields

The Cu content in the soil depth 0-40 cm of the roraks was lower than in the control and between the roraks. In the soil depths of 40-60 cm, it is higher than in the control field but lower than between the roraks. In the soil depth of 60-100 cm, it is higher than the control and between the roraks. In the 100-120 cm of soil depth, it is higher than the control field but lower than the between the roraks. This condition indicates that the application of POME has the potential to increase Cu levels in the subsoil. Cu levels in the soil, both on the land with land application and without land application, were still within the tolerable threshold (Table 10).

Table 10. The content of Cu in the soil depths 0-120 cm

Sample Location	Cu (ppm)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	1.61	1.60	0.94	0.55	0.38	0.28
Between the roraks	2.16	1.23	1.09	0.80	0.71	0.68
Rorak	1.02	1.11	1.07	1.12	1.00	0.53

The Zn content in the roraks was lower than in the control and between the roraks at soil depth 0-60 cm. At the soil depth of 60-100 cm, the Zn content was higher than that of the control but lower than the content in the field between the roraks. In layers 100-120 cm higher than the control and between the roraks. This indicates that the application of POME has the potential to increase Zn levels in the subsoil. The Zn content at the study site, both in the land with land application and without land application of POME was still within the permissible threshold (Table 11).

Table 11. The content of Zn in the soil depths 0-120 cm

Sample Location	Zn (ppm)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	4.43	3.45	1.81	0.81	0.50	0.46
Between the roraks	2.68	1.95	3.08	1.65	1.66	1.77
Rorak	1.70	1.39	1.60	1.42	1.23	7.00

The Pb content in the soil depth 0-80 cm of the roraks was lower than in the control and between the ditch roraks. In the soil depth of 80-120 cm, it is higher than the control, but still below the content in between the roraks. This indicates that the application of POME has not contributed to the increase in Pb levels in the soil. Pb levels, both in the land with land application and without land application of POME are still at the permissible threshold (Table 12).

Table 12. The content of Pb in the soil depths 0-120 cm

Sample Location	Pb (ppm)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	2.48	2.98	3.08	2.09	0.95	0.31
Between the roraks	5.41	8.17	7.96	7.22	7.07	6.66
Rorak	1.43	1.78	1.61	1.73	1.56	1.14

The Cd levels were only detected in the control at soil depth 0-20 cm and 80-100 cm. At the other soil depth, as well as on the roraks and between the roraks, Cd elements were not detected. This indicates that the application of POME has not contributed to an increase in Cd levels in the soil (Table 13).

Table 13. The content of Pb in the soil depths 0-120 cm

Sample Location	Cd (ppm)					
	Soil Depth (cm)					
	0-20	20-40	40-60	60-80	80-100	100-120
The control land	0.01	0.00	0.00	0.00	0.01	0.00
Between the roraks	0.00	0.00	0.00	0.00	0.00	0.00
Rorak	0.00	0.00	0.00	0.00	0.00	0.00

4 Discussion

Palm oil mill effluent is a non-toxic liquid waste since chemicals are not used during oil extraction. Palm oil mill effluent contains organic nitrogen, phosphorus, and different supplement substances. As organic materials, palm oil mill effluents potentially contribute to the increasing amount of soil nutrients. Degradation of organic materials results in nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sodium, and other macro or microelements. POME consists of around 2% oil, 2-4% suspended solid, and 94-96% water [9-10]. Palm oil mill effluents are envisaged as an alternative fertilizer on palm oil plantation land.

Palm oil mill effluents are potentially adverse to the environment if it is released into nonstandard ponds or rivers. If palm oil mill effluent reached the water system with conditions below the standard of the released waste management system, it would be harmful, especially to the lives of fish. To reduce the negative impact of POME on the environment, there are so many technologies to manage the effluent or by-products of the palm oil industry. There is a wide range of promising current POME treatments including biological microorganisms, physicochemical methods of coagulation, and membrane and thermochemical processes [11-12].

Copper (Cu), lead (Pb), cadmium (Cd), and zinc (Zn) are elements that potentially harm the environment [13]. Generally, the threshold of the elements in the soil is 60-125 ppm for Cu, 100 ppm for Pb, 0.5 ppm for Cd, and 70 ppm for Zn. The result of the analysis of Cu, Pb, Cd, and Zn in the land with land application of POME showed the content still in the range of tolerable area.

Copper (Cu) is an essential element for humans and plants when present in a lesser amount, while in excessive amounts it exerts detrimental effects. The content of Cu in the soil depends on complex interfaces between parent materials, physio-chemical characteristics, and additions due to agronomic practices or industry. The amount of Cu in the soil is generally around 2 – 109 ppm [14]. The content of Cu in the land application of POME is 0,53 ppm to 1.12 ppm in the roraks, and 0.68 ppm to 2.16 ppm in the soil between the roraks. The content of Cu is still in the range of tolerable content.

Naturally, lead occurs in all soil [13]. The content of lead in the soil with the land application is 1.14 – 1.78 ppm in the roraks, 5.41 – 8.17 ppm in the land between the roraks, and 0.31 – 3.08 ppm in the control land. The result showed that land application of POME less contributed to the increasing Pb in the soil.

Cadmium is considered to be one of the most toxic elements in the environment [15]. Cadmium pollution in the soil is linked to the industrial activities. Land application of POME potentially increases the content of Cd in the soil. However, the result of the analysis showed that Cd was not detected in the roraks and land between the roraks. The cadmium was detected only in the control land, with a value very low (0.01 ppm).

Zink is an essential trace element for the proper growth of plants. It is also reported as a cause of contamination in soil, water, and plants [16]. The soil with a content of Zn more than 70 ppm is stated as contaminated soil. the result of the analysis showed that the content of Zn in the roraks and between the roraks is still in the range of tolerable area.

Although still in the range of tolerable content, land application of POME potentially contributed to the increasing micro/toxic elements, Pb, Cu, Zn, and Cd. As an alternative fertilizer, land application of POME also potentially harmed the environment. Therefore, the land application of POME should be strict to the regulation of land application of POME in the plantation land.

5 Conclusion

The land applications of POME contributed to the increasing soil acidity (pH), K, Ca, Mg, KTK, and base saturation in the soil, with the value tend to decline in soil depth. The land applications of POME also contributed to the increasing phosphor and oil/fat in the topsoil. Increasing some soil chemical characteristics indicates that land application of POME could be considered as fertilizer alternatives in the plantation land. However, the application of POME on the plantation land should be strict to the regulation because of their harmful potential, especially to the water system.

References

1. Statistics Indonesia, Plantation Area by Province (Statistics Indonesia, 2023). www.bps.co.id
2. FAOSTAT, FAO Statistical data crops and livestock product (FAO, 2023). https://www.fao.org/faostat/en/#data/QCL
3. M.P.Jr. Tabe-Ojong, Z. Alamsyah, K.T. Sibatu. Oil Palm Expansion, food security and diets: Comparative evidence form Cameroon and Indonesia. *Journal of Cleaner Production.* **418,** 138085 (2023)
4. C. Kubitza, V.V. Khrisna, Z. Alamsyah, M. Qaim. The Economics Behind an Ecological Crisis: Livelihood Effects of Oil Palm Expansion in Sumatra, Indonesia. *Hum Ecol.* **46,** 107-116 (2018)
5. A.G. Austin, A. Mosnier, J. Pirker, I. McCallum, S. Fritz, P.S. Kashibatla. Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. *Land Use Policy* **69,** 41-48 (2017)
6. D. Prabowo, A. Maryudi, Senawi, M.A. Imron. Conversion of forests into oil palm plantations in West Kalimantan, Indonesia: Insights from actors' power and its dynamics. *Land Use Policy* **78,** 32-39 (2017)
7. E. Cisneros, K. Kis-Katos, N. Nuryantono. Palm oil and the politics of deforestation in Indonesia. *Journal of Environmental Economics and Management* **108,** 102453 (2021)
8. M.A. Sahputra, Z. Zhen. Positive and Negative Impacts of Oil Palm Expansion in Indonesia and the Prospect to Achieve Sustainable Palm Oil. IOP Conf. Series: Earth and Environmental Science **122**, 012008 (2018)
9. H. Kamyab, S. Chelliapan, M.F.M. Din, S. Rezania, T. Khademi, A. Kumar. Palm Oil Mill Effluent as an Environmental Pollutant. Palm Oil. InTech (2018)
10. S.E. Hosseini, M.A. Wahid. Pollutant in palm oil production process. *J Air Waste Manag Assoc*.**65**(7):773-81 (2015)

11. S. Mohammad, S. Baidurah, T. Kobayashi, N. Ismail, C.P. Leh. Palm Oil Mill Effluent Treatment Processes—A Review. *Processes* **9,** 739 (2021)
12. M.A.B.H. Yusof, Y.J. Chan, C.H. Chong, C.L. Chew. Effects of operational processes and equipment in palm oil mills on characteristics of raw Palm Oil Mill Effluent (POME): A comparative study of four mills. *Cleaner Waste Systems* **5**, 100101 (2023)
13. A. Kushwaha, N. Hans, S. Kumar, R. Rani. A critical review on speciation, mobilitation and toxicity of lead in soil-microbe-plant system and bioremediation strategies. *Ecotoxicology and environmental safety* **147** 1035-1045 (2018)
14. V. Kumar, S. Pandita, G.P.S.Sidhu, A. Sharma, K. Khanna, P. Kaur, A.S. Bali, R. Setia. Copper bioavailability, uptake, toxicity and tolerance in plants: a comprehensive review. *Chemosphere* **262** 127810 (2021)
15. A. Kubier, R.T. Wilkin, T. Pichler. Cadmium in soils and groundwaters: A review. *Applied geochemistry* **108** 104388 (2019)
16. C. Noulas, M. Tziouvalekas, T. Karyotis. Zinc in soils, water, and food crops. *Journal of trace elements in medicine and biology* **49** 252-260 (2018)