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Characterization of Physicochemical Properties and and Heavy Metals Content of Soils under Kratom (*Mitragyna speciosa*) Cultivation, Kapuas Hulu District, Indonesia

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ABSTRACT

Background: Kapuas Hulu is a district in West Kalimantan Province, Indonesia, which is famous for its production of kratom (*Mitragyna speciosa*), a traditional medicinal plant. Kratom is the main cultivated plant carried out by farmers. However, data regarding the physicochemical properties of kratom plantation soil are still limited, especially regarding the heavy metal content. This research aimed to determine the physicochemical properties and heavy metal content of soil planted with kratom.

Methods: This research was conducted on alluvial soil and peat planted with kratom. This research is survey of 2 fields where sampling from each land was carried out using the diagonal method, where 5 sub-samples were taken per land and composited, except for volume Weight.

Result: Mineral land and peat land can be used as land for Kratom cultivation because the physicochemical properties of both lands support the growth of Kratom plus the heavy metal content is below the critical threshold.

Key words: Chemicals, Metal, *Mitragyna speciosa*, Physics, Soil.

INTRODUCTION

Mitragyna speciosa or purik is a traditional medicinal plant native to Kapuas Hulu District, West Kalimantan Province, Indonesia (Kementan, 2020) and classified as a non-narcotic plant (Kemenkes, 2019 and 2020). The global market name of *M. speciosa* is kratom and it was exported to the USA and India until the end of 2020.

Kratom's cultivation is still traditionally managed and carried out on alluvium land and river banks. Alluvial plain soil is formed from several materials and deposited at flat to nearly flat slope due to the process of fluvial/colluvial through gravity force and water flow (Hikmatullah, 2007), which cause variations in chemical, physical and mineral properties and nutrient content (Brubaker *et al*., 1993). This causes the productivity of alluvial soil to sometimes be higher than the productivity of upland soil. On the other hand, the soil characteristics of kratom plants in this area have not been widely studied. Therefore, studying this aspect is important because soil properties affect the yield and quality of kratom production. Apart from that, based on the results of our pre-survey, several kratom production locations are former gold mining sites without permits (PETI). On the other hand, heavy metals and metalloids such as Pb, As, Hg and Cd are requirements for the quality of traditional medicine raw materials, where the presence of these heavy metals must be absent (BPOM, 2014). Considering that there is still very little scientific data regarding the characteristics of the soil where kratom grows, it is necessary to carry out this research to provide information regarding the physicochemical properties and heavy metal content of soil planted with kratom.

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The physical properties of the soil play an important role in the ability of plants to utilize soil nutrients and water. In evaluating agricultural practices, soil physical properties are an important indicator (Yang *et al*., 2012). Poor land management can lower soil quality, which will make kratom farming less sustainable. The texture of the soil has an impact on soil water circulation, plant roots, plant absorption of nutrients and soil cultivation. (Lal and Shukla, 2004). High soil density can inhibit the movement of soil water and plant roots; On the other hand, low soil density makes it very easy for groundwater to pass through so that plants have sufficient water availability. Soil porosity characteristics are closely related to soil physical properties, water movement and root penetration (Pagliai and Vignozzi, 2002; Sasal *et al*., 2006). Very high and/or very low total soil porosity will inhibit the development and growth of cultivated plants. Field capacity water content is the initial limit for soil water storage for plants (Shukla, 2013). In addition, the content of heavy metals in soil and plants depends on the physicochemical properties of the soil, cultivation method, type of plant, as well as the availability, solubility and type of metal in the soil (Sinha *et al*., 2006).

MATERIALS AND METHODS

Study areas

The research was conducted in Kapuas Hulu Regency which is located at Located between 0°04′20″N-1°37′20″ N latitude and between 111°34′20″E-114°09′20″E longitude which is the easternmost tip of West Kalimantan Province. The research area is in the lowlands and hills, with an average annual rainfall of 404.7 mm. For the mineral soil, the sample was taken in Nanga Mentebah Village; for the peat soil, it was taken in Kedamin Darat Village, South Putussibau District. For the mineral soil, Nanga Mentebah Village served as the sampling location, while Kedamin Darat Village, South Putussibau Sub-District, served as the place for the peat soil. The coordinates of sampling locations and their codes are shown in Table 1 and codes and description of the sampling locations in Table 2, while the study locations on a map is as in Fig 1.

Sampling and preparation

Soil samples with three replications were collected during the rainy season (February-March, 2020) from six sampling locations at a depth of 0-30 cm. Whole soil samples were used to analyze for the weight, total porosity and water content at field capacity. Meanwhile, non-intact soil samples were used for soil texture analysis, particle density, pH, concentration of N, P and K and heavy metals. All those samples were stored in sterile boxes and then brought to the laboratory for further analysis.

Soil physicochemical analysis

Soil-specific gravity was analyzed using the ring sampler (core) method, particle density using the pycnometer method, total porosity using mathematical equations and texture using the hydrometer method. Soil acidity (pH) was analyzed using a pH meter, total N was measured using the Kjeldahl method, P_2O_5 using the Bray I method and K using the 1*N* NH_4OAC at pH: 7 extraction method.

Metals analysis

Analysis of the metal elements lead (Pb), cadmium (Cd) and chromium (Cr) contained in each soil sample was tested by using Atomic Absorption Spectrophotometry ((AAS-6300, Shimadzu), with the samples previously prepared using wet digestion of nitric acid (HNO_3).

RESULTS AND DISCUSSION

Soil physical properties

The soil's physical properties are displayed in Table 3. The textures of mineral soils were classified as sandy loam and silty clay loam. The peat soil was classified as hemic to sapric maturity. These textures can be considered suitable for plant growth. The clay texture, including a slightly fine texture, may increase corn and wheat production (Jalota *et al*., 2010) and is suitable for plant growth, root development, seed germination and *Senna obtusifolia* nurseries (Abubakar, 2017). The bulk density of the minerals soil was categorized as moderate. Rieley *et al*. (1996) found that the bulk density of tropical peat is generally low, ranging from 0.1-0.32 g/cm^3. The bulk density character of mineral soil was consistent with the analysis of soil texture obtained. Gama-Castro *et al*. (2000) stated that the bulk density range of alluvial soils might be extensive; smaller values were observed in the Ap horizons and increased with depth. A very high bulk density of 1.7 g/cm^3 will inhibit root penetration and further reduce the roots' ability to reach a usable amount of water at specific soil depths (Reeve, 1986). The suitable total porosity for agricultural land is 50-60% (Arsyad, 2010). For peat soil at the research location, the total porosity is around 76.8%, which has a low bulk density and peat maturity. As emphasized by Buol *et al*. (1973) which states that the total porosity of sapric peat is less than 85%; where the presence of water and air is balanced and dynamic. Becomes an optimal medium for plant growth and development. It becomes the optimum media for plant growth and development.

At the mineral soil research location, the water content and field capacity of mineral soil is related to total porosity indicated almost all soil pores are filled with water (92.1% by vol). Soil bulk density, field capacity water content and total porosity in this study are similar to profile four at a depth of 0-30 cm in Tworków (Borek and Bogdał, 2018). Hong *et al*. (2013) explained that the most influential mineral

Table 1: Codes and coordinates of soil Sampling locations.

Village	Code	Coordinate 49 N; UTM
Nanga Mentebah	At1	0699579 ; 0059870
	At2	0699547 ; 0059907
	At3	0699510 ; 0059962
	Bt1	0700049 ; 0060454
	Bt2	0700019 ; 0060454
	Bt3	0699986 ; 0060570
	Ct1	0699923 ; 0060662
	Ct2	0699978 ; 0060664
	Ct3	0700030 ; 0060668
	Dt1	0699835 ; 0660871
	Dt2	0699843 ; 0060819
	Dt3	0699842 ; 0060758
	Et1	0695600 ; 0062775
	Et2	0695606 ; 0062695
	Et3	0695597 ; 0062614
Kedamin Darat	Ft1	0714952 ; 0087402
	Ft2	0714926 ; 0087382
	Ft3	0714895 ; 0087365

soil agricultural factor is field capacity water content (at pF 2.5), which ranges between 0.2690 and 0.6784 cm^3.

For peatlands, it is approximately ±3 km away from the river with a depth of groundwater level that is also quite deep (50-70 cm), so the field capacity water content is lower than the results of research by Schwärzel *et al*. (2002) which states that the water content of peat soil is pF 2.54 ranges from 69 -76% vol, at pF 4.2 ranges from 23-38% vol and available water content ranges from 31-53% vol. However, the peat water content at the research location is in line with research by Suryadi, (2013). Thus, the physical characteristics of the soil at the research location are suitable for kratom cultivation.

Table 2: Codes and description of the sampling locations.

Code	Description of location
At	Mineral soil, highlands, ±50 m from river, un-flooded
Bt	Mineral soil, river side and flooded
Ct	Mineral soil, river side and flooded
Dt	Mineral soil, river side and alalways flooded
Et	Ex PETI land, river side and flooded
Ft	Peat soil, ±3 km from river, ground water level 50-70 cm

Note: PETI (Gold Post Mining Land).

Soil chemical properties

The chemical properties of mineral soil and peat soil in Table 3 show acidic properties (pH 4.6-5.7) as stated by Gunawan *et al*. (2019) which states that the soil pH in Eucalyptus sp-based vegetable agroforestry forests is acidic to very acidic (pH 2.65-4.85), as well as in peat soils, it has a very acidic pH (pH 2.8), supported by Utami and Indrawati, (2024) which states that peat is soil that is poor in macro and micro nutrients and has an acidic pH. The

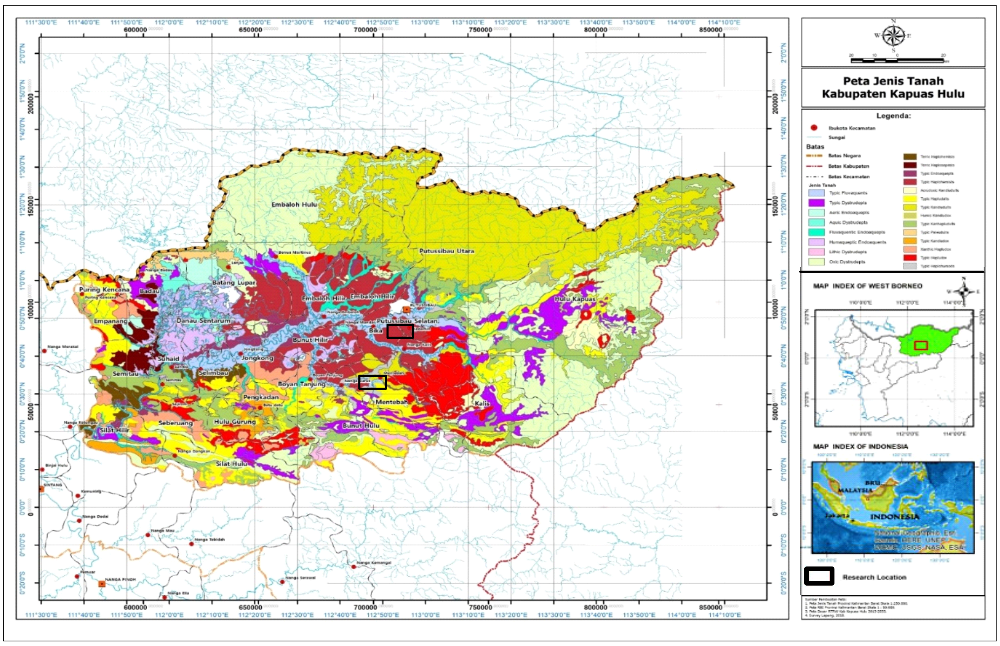

Fig 1: Map of Kapuas Hulu District.

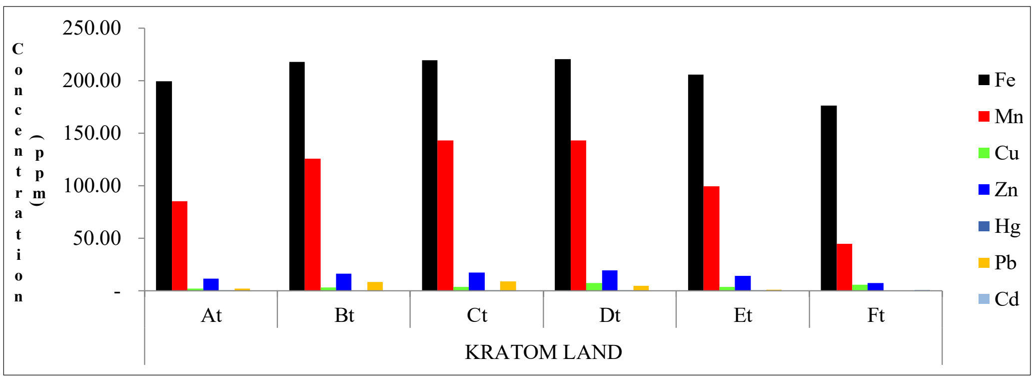

Fig 2: Heavy Metal of Kratom Land.

Table 3: Soil physics and chemicals properties of kratom land cultivation.

Location	Soil	Texture	Bulk density (g.cm^{-1})	Total porosity (%)	Field capacity volumetric water content (% vol)	pH	Total-N (%)	Available-P (ppm)	Exchangeable-K (cmol(+).kg)
Nanga mentebah	Mineral	Sandy loam	1.07±0.07	54.89±2.85	52.75±9.34	5.87±2.56	0.14±0.02	33.84±8.31	0.13±0.02
		Silty clay loam	0.91±0.1	59.91±4.43	59.19±6.26	4.04±0.22	0.36±0.05	25.85±2.92	0.22±0.02
			0.83±0.02	60.37±0.60	52.45±1.34	4.42±0.25	0.33±0.04	39.47±3.76	0.27±0.04
			0.81±0.06	60.56±3.60	53.43±2.91	4.36±0.31	0.37±0.04	37.72±4.13	0.24±0.03
		Sandy loam	0.99±0.06	56.00±5.85	50.73±4.05	4.61±0.23	0.20±0.11	29.24±3.56	0.15±0.03
Kedamin darat	Peat	-	0.27±0.04	76.84±2.95	48.70±10.95	2.80±0.17	1.86±0.02	194.94±49.63	0.39±0.18

chemical characteristics of peat soil in Indonesia are very diverse and are determined by the mineral content, thickness, types of plants that make up the peat, types of minerals in the substratum (at the bottom of the peat) and the level of peat decomposition. The N nutrient content (%) in mineral soil is classified as low to medium (0.14-0.37%) as stated by Cyio (2017) and Gunawan *et al*., (2019), but is classified as very high in peat soil (1, 86%). The P content (ppm) in mineral soil is classified as high to very high with a value of 25.85-39.47 and is very different from peat soil which is classified as very high with a value of 194.94. The K content [cmol (+) Kg^{-1}] in mineral soil is low (0.13-0.27) and in peat soil it is also moderate (0.39). Based on the data, the chemical properties of the soil at this research location are considered fertile for kratom cultivation. The Physical and Chemical Properties of Soil in Kratom Land Processing can be seen in Table 3.

Heavy metals content

Heavy metal content is showed in Fig 2 and Table 4. The metal content was found below the critical limit as stated by Haris and Aris (2013) for Fe and Cd metals (Syachroni, 2018), Cu, Zn, Pb and Cd metals (Sun *et al*., 2020). The presence of heavy metals that are still below the critical threshold is possible in the upstream part of the research, there is gold mining without permits, so the metals are carried away by the current downstream. According to Gaur *et al*. (2023), Iron is one of the most deficient nutrients in Indian soils. It is a structural component of cytochrome, hematin and leghaemoglobin. It is also important in activation of several enzymes including fumaric hydrogenase, catalase, dehydrogenase, oxidase and peroxidase. It helps in the absorption of other plant nutrients. Iron is also associated with chloroplast and protein synthesis. Molybdenum is an essential plant nutrient found in soil. It is also known as ultramicronutrient as this is required in very less amount. As its less amount is required, the deficiency and sufficiency range are narrow. Meanwhile, according to Patel and Parikh (2012), many metals are essential, all metals are toxic at higher concentrations because they cause oxidative stress by the formation of free radicals.

According to Karalić *et al*. (2013) and Kashem and Singh (2001), in acidic soil, the availability of heavy metals is higher than in neutral or alkaline soil. Koèevar Glavaè *et al*. (2017) found that the availability of this metal will depend on several factors other than pH. Rieuwerts *et al*. (1998) stated that in mineral soils the factors that cause the presence of heavy metals are mineral composition, soil microbiota and redox potential, while in peat soils the concentration of soil organic matter, fulvic acid and humic acid are potential ligands for the complexation of these metals. The Hg element is stable in the soil environment. It has a strong tendency to form complexes with other anions (such as Cl^-, OH^- and S^{2-}) and humic matter. Yin *et al*. (1996) observed in an experimental study that soil adsorption decreased significantly above pH 5 as a result of increased

Table 4: Soil metals of kratom land cultivation.

Village	Soil	Fe	Mn	Cu	Zn	Pb	Cd	Hg
		(ppm)						
Nanga mentebah	Mineral	199.11±21.63	85.31±47.34	2.01±0.87	11.51±66.2	2.27±1.99	1.00±1.00	0.011
		217.79±3.40	125.88±19.98	3.10±2.31	16.66±4.56	8.29±2.76	4.00±1.00	<0.010
		219.43±3.62	143.29±3.23	3.87±2.95	17.46±3.09	8.88±0.65	7.00±1.00	0.095
		220.07±2.86	143.18±3.13	3.71±1.71	19.71±3.48	4.82±6.43	10.00±1.00	0.035
		205.48±8.14	99.34±37.06	4.02±1.63	14.59±6.92	0.95±1.65	13.00±1.00	0.036
Kedamin darat	Peat	176.02±41.37	44.76±30.66	6.06±6.31	7.56±3.57	0.00±0.00	0.06±0.05	<0.010

amounts of dissolved organic matter and the tendency of mercury to complexly strong against organic carbon. However, heavy metals' relative phytotoxicity may depend on plant species, soil properties, age of the plant and heavy metals types and concentration (Maleki *et al*., 2017). It is further stated that these metals may influence secondary metabolite production, which is substantially signiûcance in medicinal plants.

CONCLUSION

The research results show:

On mineral soil:

Soil texture is classified as sandy loam and silty clay, Soil specific gravity is low to medium, Total porosity is suitable for plant growth, Field capacity water content ranges from 50-59.2% vol, Soil reaction: acid to very acid, Total N is low to medium, P availability is high to very high, Potassium exchangeability is low, Fe, Mn, Cu, Zn, Pb, Hg and Cd metals in the soil are below the critical limit.

On peat soil:

The specific gravity of the soil is very low, the total porosity is classified as porous so that groundwater can easily pass through it, the field capacity water content is around 48.7% vol., the total N content is very high, the availability of P is very high, the exchangeability of potassium is moderate and. The metals Fe, Mn, Cu, Zn, Pb, Hg and Cd in the soil are below the critical limit.

The research results show that both lands for kratom cultivation are fertile. Further research is expected to increase understanding regarding the transport of heavy metals from soil to plants, as well as from plants to extracts.

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Conflict of interest

There is no conflict of interest.

REFFERENCES

Abubakar, A. (2017). Effects of soil texture on vegetative and root growth of senna obtusifolia seedlings indigenous to bichi, sudan savannah of Northern Nigeria, in green house conditions. IOSR Journal of Agriculture and Veterinary Science. 10: 70-74. https://doi.org/10.9790/2380-1004027074.

Arsyad, (2010). Konservasi Tanah dan Air. IPB Press, Bogor.

Borek, J., Bogdał, A. (2018). Soil water retention of the Odra River alluvial soils (Poland): Estimating parameters by RETC model and laboratory measurements. Applied Ecology and Environmental Research. 16: 4681-4699. https://doi.org/10.15666/aeer/1604_46814699.

BPOM Republic of Indonesia, (2014). Regulation of the Head of the Drug and Food Control Agency Republic of Indonesia About Quality Requirements for Traditional Medicine.

Brubaker, S.C., Jones, A.J., Lewis, D.T., Frank, K. (1993). Soil properties associated with landscape position. Soil Science Society of America Journal (USA).

Buol, S.W., Hole, F.D., McCracken, R.J. (1973). Soil Genesis and Classification. The Iowa State University Press, Ames.

Cyio, M.B. (2017). Analisis Tingkat Kesuburan Tanah Entisol Akibat Pemberian Bahan Organik yang Diinkubasi Melalui Pendekatan Indeks Biokimia. Agroland: Jurnal Ilmu-ilmu Pertanian. 13: 337-342.

Deng, Y., Xia, D., Cai, C., Ding, S. (2016). Effects of land uses on soil physic-chemical properties and erodibility in collapsing-gully alluvial fan of Anxi County, China. Journal of Integrative Agriculture. 15: 1863-1873. https://doi.org/10.1016/S2095-3119(15)61223-0.

Gama-Castro, J.E. Solleiro-Rebolledo, E., Vallejo-Gómez, E. (2000). Weathered pumice influence on selected alluvial soil properties in west Nayarit, Mexico. Soil and Tillage Research. 55: 143-165. https://doi.org/10.1016/S0167-1987(00)00114-8.

Gaur, D., Maheta, A., Jadav, N.J. and Gaur, S. (2023). Effect of iron, molybdenum and rhizobium on biological properties of soil in summer groundnut (*Arachis hypogaea* L.). Journal of Progressive Agriculture. 35 (4): 130-37. https://doi.org/10.9734/ijpss/2023/v35i42809.

Gunawan, G., Wijayanto, N., Budi, S.W. (2019). Karakteristik Sifat Kimia Tanah dan Status Kesuburan Tanah pada Agroforestri Tanaman Sayuran Berbasis Eucalyptus Sp. Jurnal Silvikultur Tropika. 10: 63-69.

Haris, H., Aris, A.Z. (2013). The geoaccumulation index and enrichment factor of mercury in mangrove sediment of Port Klang, Selangor, Malaysia. Arabian Journal of Geosciences. 6: 4119-4128.

Hikmatullah, Al-Jabri, M. (2007). Soil properties of the alluvial plain and its potential use for agriculture in donggala region, central sulawesi. Indonesian Journal of Agricultural Science. 8: 67-74. https://doi.org/10.21082/ijas.v8n2.2007.p67-74.

Hong, S.Y. Minasny, B., Han, K.H., Kim, Y., Lee, K. (2013). Predicting and mapping soil available water capacity in Korea. Peer J. 1: 71. https://doi.org/10.7717/peerj.71.

Jalota, S.K., Singh, S., Chahal, G.B.S., Ray, S.S., Panigraghy, S., Bhupinder-Singh, Singh, K.B. (2010). Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize-wheat cropping system: Field and simulation study. Agricultural Water Management. 97: 83-90.

Karalić, K., Lonèarić, Z., Popovic, B., Zebec, V., Kerovec, D. (2013). Liming effect on soil heavy metals availability. Poljoprivreda. 19: 59-64.

Kashem, M.A., Singh, B.R. (2001). Metal availability in contaminated soils: I. Effects of floodingand organic matter on changes in Eh, pH and solubility of Cd, Ni and Zn. Nutrient Cycling in Agroecosystems. 61: 247-255. https://doi.org/10.1023/A:1013762204510.

Koèevar Glavaè, N., Mraèević, S., Ražić, S., Kreft, S., Veber, M. (2017). Accumulation of heavy metals from soil in medicinal plants. Archives of Industrial Hygiene and Toxicology. 68. https://doi.org/10.1515/aiht-2017-68-2990.

Lal, R., Shukla, M. (2004). Principles of Soil Physics. Marcel Dekker, New York.

Maleki, M., Ghorbanpour, M., Kariman, K. (2017). Physiological and antioxidative responses of medicinal plants exposed to heavy metals stress. Plant Gene, Abiotic Stress Tolerance in Plants: Growth Regulators and Transcriptional Control of Multiple Signaling Pathways. 11: 247-254. https://doi.org/10.1016/j.plgene.2017.04.006.

Ministry of Health, (2020). Regulation of the Minister of Health of the Republic of Indonesia Number 44 of 2019 concerning Changes in the Classification of Narcotics.

Ministry of Health, (2019). Regulation of the Minister of Health of the Republic of Indonesia Number 44 of 2019 concerning Changes in the Classification of Narcotics.

Ministry of Agriculture, (2020). Regulation of the Minister of Agriculture of the Republic of Indonesia Number 104 of 2020 concerning Commodities Assisted by the Ministry of Agriculture.

Pagliai, M., Vignozzi, N. (2002). Soil pore system as an indicator of soil quality. Advances in GeoEcology. 35: 71-82.

Patel, V., Parikh, P. (2012). Assessment of soil quality parameters and heavy metal load in Mini River Basin, Vadodara. International Journal of Environmental Sciences. 3(1): 562-569.

Reeve, M.J. (1986). Water retention, porosity and composition inter-relationships of alluvial soils in mid Hawke's Bay and their relevance in irrigation planning. New Zealand Journal of Agricultural Research. 29: 457-468. https://doi.org/10.1080/00288233.1986.10423498.

Rieley, J.O., Ahmad-Shah, A.A., Brady, M.A. (1996). Tropical Lowland Peatlands of Southeast Asia. IUCN. Gland, Switzerland.

Rieuwerts, J.S., Thornton, I., Farago, M.E., Ashmore, M.R. (1998). Factors influencing metal bioavailability in soils: Preliminary investigations for the development of a critical loads approach for metals. Chemical Speciation and Bioavailability. 10: 61-75. https://doi.org/10.3184/095422998782775835.

Sasal, M.C. andriulo, A.E., Taboada, M.A. (2006). Soil porosity characteristics and water movement under zero tillage in silty soils in argentinian pampas. Soil and Tillage Research. 87: 9-18. https://doi.org/10.1016/j.still.2005.02.025.

Schwärzel, K., Renger, M., Sauerbrey, R., Wessolek, G. (2002). Soil physical characteristics of peat soils. Journal of Plant Nutrition and Soil Science. 165: 479-486. https://doi.org/10.1002/1522-2624(200208)165: 4<479::AID-JPLN479>3.0.CO;2-8.

Shukla, M.K. (2013). Soil Physics/ : An Introduction, 1st ed. CRC Press. https://doi.org/10.1201/b14926.

Sinha, S., Gupta, A.K., Bhatt, K., Pandey, K., Rai, U.N., Singh, K.P. (2006). Distribution of metals in the edible plants grown at Jajmau, Kanpur (India) receiving treated tannery wastewater: Relation with physico-chemical properties of the soil. Environ Monit Assess. 115: 1-22. https://doi.org/10.1007/s10661-006-5036-z.

Sun, T., Huang, J., Wu, Y., Yuan, Y., Xie, Y., Fan, Z., Zheng, Z. (2020). Risk assessment and source apportionment of soil heavy metals under different land use in a typical estuary alluvial island. Int J. Environ Res Public Health. 17. https://doi.org/10.3390/ijerph17134841.

Suryadi, U.E., Bambang, H.S., Nuryani, S. (2013). Dampak Pembendungan Kanal Terhadap Watak Fisika Dan Kimia Gambut Ombrogen Dalam Usaha Pemulihan Lahan Terdegradasi. UGM, Yogyakarta.

Syachroni, S.H. (2018). Analisis Kandungan Logam Berat Kadmium (Cd) pada Tanah Sawah di Kota Palembang. Sylva. 6: 23-29.

Utami, S.N.H. and Indrawati, U.S.Y.V. (2024). Oil palm empty fruit bunch biochar fertilizer as a solution to increasing the fertility of peat soil for sustainable agriculture. International Journal of Recycling Organic Waste in Agriculture (IJROWA). 13(1): 1-11. https://dx.doi.org/10.57647/j.ijrowa.2024.1301.03.

Yang, Z., Xu, M., Zheng, S., Nie, J., Gao, J., Liao, Y., Xie, J. (2012). Effects of long-term winter planted green manure on physical properties of reddish paddy soil under a double-rice cropping system. Journal of Integrative Agriculture. 11: 655-664. https://doi.org/10.1016/S2095-3119(12)60053-7.

Yin, Y., Allen, H.E., Li, Y., Huang, C.P. and Sanders, P.F. (1996). Adsorption of mercury (Ii) by soil: effects of Ph, chloride and organic matter. Journal of Environmental Quality. 25: 837-844.