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Correlation between soil characteristics and cadmium content in the aboveground of cocoa crops in Sungailiat District of Bangka Island – Indonesia

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ABSTRACT
The cocoa bean production (quality and quantity) influenced by soil and climate characteristics as well as farming management (fertilizer, irrigation, drainage, etc). Soil characteristics such as texture and pH closely related to particles transportation from soil to all part of plants (root, stem, leaf, fruit). Cadmium (Cd) contamination is top issue of cocoa bean quality, because it may increase the risk of human health. This study was addressed to identify soil characteristics (texture, particle density, bulk density, pH) and to correlate its characteristics to cadmium content in aboveground of cocoa plantation in Sungailiat district of Bangka Island. Soil samples were taken from 12 villages in Sungailiat district. Three points each site of cocoa land in the village were selected diagonally, where the soil was taken from 0 to 10 cm and 10 to 20 cm. Plantation management (tree age, fertilizer, irrigation, drainage, pruning) was recorded from interview to the farmers. The methods used in measuring the Cd content were the AOAC method by using ICP-MS. The soil texture (silt, clay, sand), particle density, bulk density, organic content, and soil pH ranged from 1.61 to 16.89%, 16.24 to 47.98%, 47.27 to 82.15%, 2.33 to 2.75 gr cm^{-3}, 0.81 to 1.13 gr cm^{-3}, 1.44 to 5.28%, and 4.56 to 6.62, respectively. The Cd content in the soils ranged from not detected (< 0.0005 mg kg^{-1}) to 0.18 mg kg^{-1}. This result showed that 12 sites of cocoa farms in Sungailiat are below the critical limit of Cd in agricultural soils based on European Standard (3 mg kg^{-1}).

Keywords: *soil, cadmium, cocoa crops, Bangka Island*

1. INTRODUCTION

Cadmium (Cd) is one of the most toxic heavy metals which may pose a potential threat due to its negative effects in soil-plant systems and human health though at low concentrations [1]. In the soils, Cd contamination has been reported to affect the activities of soil enzymes, biogeochemical cycles, microflora of the soil, leaf chlorosis, reduction in uptake of macro and micronutrients by plants [2]. Other studies reported Cd in soil has negative effects on growth and root activity, and could also impair the ability of roots to absorb water [3]. The effects of Cd toxicity in human health could cause diseases such as various cancers, renal diseases, osteomalacia, and osteoporosis [4]. Moreover, Cd toxicity leads to infertility, prenatal death, and occasionally structural and functional disturbances in the male or female reproductive system [2]. This Cd exposure in the human body occurs through food crops. High Cd exposure in soil-plant systems could dangerously join the foodstuffs [5]. Thus, the frequent consumption of those products leads to serious health problems on human health [6].

The major sources of Cd pollution in the environment can be originated from natural and anthropogenic/human activities [7]. Geological weathering of parent materials is a natural source which controls the amount of Cd in soils. Cd in the Earth's crust usually has a low concentration with range between 0.1 to 0.41 mg kg-1, besides Cd is released

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from sedimentary rocks generally has value of 0.3 mg kg-1 and mostly mineral contains high concentration of Cd can be found in greenockite [8, 9]. Likewise, volcanic eruption is also considered as a natural source of Cd concentration in the environment [10]. Anthropogenic sources such as mining, smelting, metals ore processing (occurs in all types of Cu, Pb, and Zn ores), landfills, wastewater irrigation, industrial and combustion emissions, and manufacturing (rubber and textile) have significantly increased the total concentration of Cd both in soils and plants [8]. The application of agriculture inputs, for example phosphate fertilisers, pesticides, and biosolids or sewage sludge also lead to the accumulation of Cd in soils [11]. Other sources of Cd enrichment are from the improper use of several household products such as detergents and refined petroleum products [12]. In addition, Cd content may also be added to soil adjacent to major roads which is emitted from tyres of vehicular and lubricant oils [13].

Cocoa (*Theobroma cocoa* L.) is an important agricultural commodity for chocolate production which could be cultivated in tropical countries such as Indonesia. World Cocoa Production by Country in the study of [14] reported the biggest Cocoa production countries are Ivory Coast (Africa), Ghana, Ecuador, Indonesia, Cameroon, Nigeria, Brazil, and Papua New Guinea. Ivory Coast produced 2,01 million ton of cocoa beans in 2016 to 2017 and it was recorded as the highest production. Indonesia produced 260 ton of cocoa beans and it was listed in fourth position of Cocoa production in the world.

Bangka Island is one of the regions in Indonesia which contributed to cocoa production. In 2019, the Department of Agriculture of Bangka recorded that the total area for cocoa plantations in Bangka was 533.85 ha with 284 tons of cocoa produced. Cocoa plantations in Bangka Regency managed to contribute 92.51% of the total cocoa production of Bangka Belitung Province and contributed 0.03% nationally [15]. The contributor of cocoa production in Bangka distributed in eight regions, namely Mendo Barat (1,76%), Merawang (6,69%), Puding Besar (1,76%), Sungailiat (15,49%), Pemali (5,28%), Bakam (32,04%), Belinyu (13,03%), and Riau Silip (23,94%).

High concentration of Cd in cocoa crops commonly originated from polluted soil which is affected by various factors including soil pH, soil organic matter, soil texture, and the amount of Cd in soil [6]. Consequently, the presence of Cd in cocoa beans is capable of reducing the quality of beans and food safety [16]. Many studies across the world have investigated the contamination of Cd in soils aboveground of cocoa crops. [17] reported that Cd levels in soils from Honduras were 0.14 ± 0.01 mg kg^{-1} in topsoils and 0.08 ± 0.01 mg kg^{-1} in subsoils. However, no studies to date have been conducted regarding Cd exposure in soils aboveground of cocoa crops in Bangka Island, Indonesia. Therefore, the objectives of this study were to calculate Cd content in soils aboveground of cocoa crops particularly in Bangka Island, determine the level of Cd contamination in soils, and to identify and explore the relationship between soil properties and Cd content in soils.

2. MATERIALS AND METHODS

2.1. Time and Location

This study was conducted on October 7th, 2021 to June 15th, 2022. The selected area is located in Sungailiat district which had been established as one of the highest cocoa production areas in Bangka Island, Indonesia. Soil samples were collected based on administrative area from small-scale cocoa farms in 12 villages in Sungailiat district, namely (1) Surya Timur; (2) Parit Padang; (3) Srimenanti; (4) Sungailiat; (5) Kuday; (6) Matras; (7) Sinar Jaya; (8) Sinar Baru; (9) Bukit Betung; (10) Lubuk Kelik; (11) Kenanga; and (12) Jelitik. Soil samples were analysed at the Laboratory of Soil Agriculture and Biosystem Engineering, Laboratory of LaPitaya, and Laboratory of Saraswanti Indo Genetech. Sampling points of the study area are shown on Figure 1.

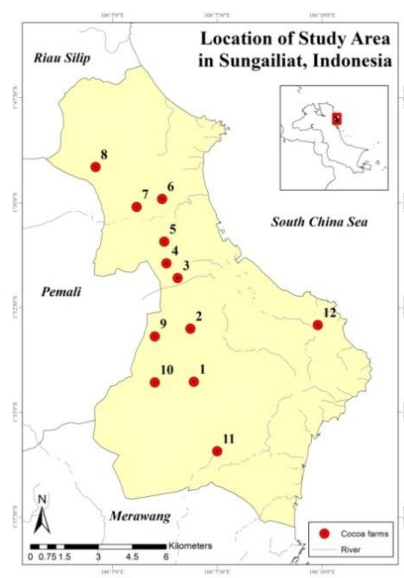

Figure 1 Cd concentration in the soils of 12 locations in Sungailiat district

2.2. Soil Sampling

Soil samples were taken into two types, namely undisturbed soil samples and disturbed soil samples. Undisturbed soil samples were taken using a hammer and soil core sampler with a diameter of 5 cm and length of 5 cm. Disturbed soil samples were taken using soil auger at two depth variations, namely 0-10 cm and

10-20 cm from the surface soils. Soil samples were taken under productive cocoa trees, with a distance in the middle between the tree trunk and the tip of the branch farthest from the cocoa tree. Soil samples were taken at least three sampling points in each location with the direction diagonal to the land (Fig. 2).

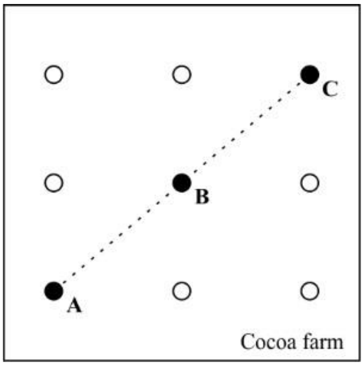

Figure 2 Illustration of soil sampling method (diagonal); soil samples were taken from points A, B, and C

Subsequently, soil samples were labelled and stored into plastic bags and tightly sealed. At each field, at least one of the cocoa pods was collected randomly from the cocoa tree as a sample of the plant. During the sampling, a Global Positioning System (GPS) tracker is used to obtain the coordinate (longitude and latitude) of each location where soil and plant samples were taken.

2.3. Soil Analysis

Undisturbed soil samples were oven-dried at temperature of 105 °C for 24 h to measure bulk density, whereas disturbed soil samples were oven-dried at temperature of 60 °C for 72 h, ground using mortar and pestle, hereafter sieved through a 2 mm stainless steel mesh. These disturbed dried soil samples were properly labelled and stored into plastic bags. All points of disturbed soil samples (A, B, and C) of each location at depths 0-10 cm and 10-20 cm were thoroughly combined together into a composite homogenous sample for further soil physical and chemical analysis. Disturbed dried soil samples of all depths were analysed for particle size distribution (sand, silt, and clay), particle density, bulk density, organic matter, and pH. All soil physical and chemical properties with exception of soil organic matter were analysed at Laboratory of Land and Water Resource Engineering, Universitas Gadjah Mada (UGM). Dried soil samples were shipped to the Laboratory of LaPitaya to determine soil organic matter (SOM) and were also shipped to the Laboratory of Saraswanti to determine the concentration of Cd using inductively coupled plasma-mass spectrometry (ICP-MS) with the detection limit of <0.0005 mg kg-1. The methods and references of soil properties analysis and the concentration of Cd in soils that were used in this research are presented in Table 1.

Table 1. Methods and references that were used to determine soil properties (physical and chemical) and Cd content in soils

Parameters	Methods	References
Texture	Pipette	[18]
ρ_s	Pycnometer	[19]
ρ_d	Cylindrical Core Sampler	[20]
OM	Walkley and Black	[21]
pH	Suspension with distilled water (1:5 soil:H2O)	[22, 23]
Cd	Microwave Digestion	[24]

ρ_s = particle density, ρ_d = bulk density, OM = organic matter

2.4. Data Analysis

2.4.1. Statistical Analysis

The data were analysed using the software IBM SPSS Statistics 20, whereas graphs and tables of the results were created using Microsoft Excel 2010. Pearson's correlation analysis was applied to determine the relationship between soil properties and soil Cd content in order to predict the major soil properties which contribute to the availability of Cd in soils aboveground of cocoa crops. The highest correlation coefficients were selected in this study. Two tailed statistical significance was established at $P < 0.01$ and $P < 0.05$.

2.4.2. Spatial Analysis

Spatial distribution maps of Cd contamination in soils across sampling sites were created using geographic information system (GIS) approach. The software of ArcMap 10.5 was used in this study. The database that contains attributes (longitude, latitude, and laboratory results) of all locations was prepared using MS Excel and linked into the ArcMap software for deterministic analysis. This study used IDW interpolation as a spatial analyst tool to predict values of attributes at locations where samples were not collected [25].

3. RESULTS AND DISCUSSION

3.1. Site Description

Sungailiat is a district in Bangka regency, Bangka-Belitung province of Indonesia which is located at 106°7'9.116" E and 1°50'51.821" S. The regional climate is classified as a tropical rainforest climate (type Af) according to the Köppen-Geiger classification, with the monthly rainfall varies between 114 to 395 mm.

Sungailiat has an average temperature of 26.6 oC and relative humidity of 85%. The geology of Sungailiat is distinguished into Klabat Granite (74%), Alluvium (26%), and Pemali Complex (1%). Mostly, type of soil in Sungailiat is dominated as Alluvial and Cambisol, with the soil acidity (pH) having a value of 3.5 to 5.5 [26]. Sungailiat's soil contains tin ore minerals and other excavated materials, thereby this region is known as the location for tin mining [27].

Total production of agriculture crops in Sungailiat district was 2.9 thousand ton in 2019. The most common production crops in Sungailiat were coconut (53%), palm (30%), rubber (15%), and cocoa (2%) [15]. According to Indonesian Cocoa Statistics (2019) Sungailiat is one of the most producers of cocoa and has contributed 15.49% of total cocoa production in Bangka Island after Bakam (32.04%) and Riau Silip district (23.94%).

3.2. Land Conditions and Managements Aboveground of Cocoa Crops in the Study Areas

This study was conducted in the small-scale cocoa farms that belong to the smallholders/local farmers with an average land area of approximately 500 m^2. The land condition and plant management factors of each cocoa farm were explored and recorded by interviewing the farmers and direct observations in order to ascertain the origin of Cd contamination in soils. Land condition factors consist of the existence of waste drainage, plant litter, livestock, shade/other crops, and the adjacency to main road; whereas land management consist of agriculture practices (the application of fertilisers and pesticides).

The amount of Cd in soils could be depended on the conditions either along or within the cocoa plantations. Waste drainage was only present in location 8. Waste water drainage containing rich amount of Cd may increase the concentration of Cd in soils, hence uptake by cocoa plants [28]. Most cocoa farms were cultivated nearby to local roads (rarely vehicle activities), while only locations 8 and 12 were located adjacent to the main road. The vehicular activity has been mentioned as the source of Cd contaminated in soils and plants. Only locations 5, 7, and 11 had livestock (poultry) near the cocoa trees. In addition, locations 3, 9, 10, and 12 had plant litter (leaves) under their cocoa trees. Decomposition and deposition of litter from cocoa trees can raise the amount of Cd in the surface soils [28]. Agriculture practices both fertilisers and pesticides were not applied by all cocoa farmers in 12 locations. Thus, the sources of Cd contamination derived from the applications of those agriculture practices were negligible in this study.

3.3. Soil Physical and Chemical Properties

Soil physical and chemical properties of 12 sites of cacao farms in Sungailiat district are presented in Table 2.

3.4. Concentration of Cadmium (Cd) in Soils

The results of Cd content in soils which were collected from 12 cocoa farms in Sungailiat district are shown on Figure 3.

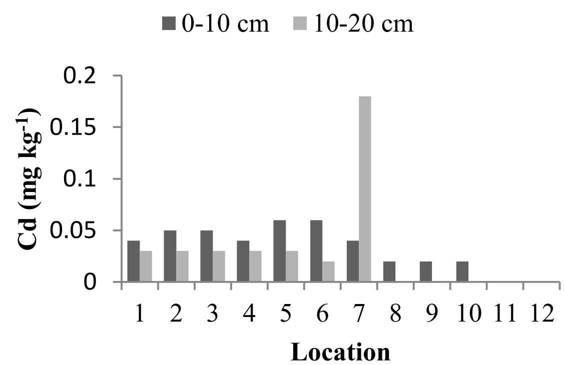

Figure 3 Cd concentration in the soils of 12 locations in Sungailiat district

Based on Figure 3, the concentrations of Cd in soils were in the range below the detection limit to 0.06 mg kg^{-1} for 0-10 cm deep soil and had Cd content below the detection limit to 0.18 mg kg^{-1} for 10-20 cm deep of soil. The detection limit of Cd measurement (ICP-MS) which was used in this study was less than 0.0005 mg kg^{-1}. The highest Cd concentrations were found in locations 5 and 6 at soil depth of 0-10 cm, whereas a greater amount of Cd was recorded in location 7 at soil depth of 10-20 cm. However, both of Cd content in soils at all depths in 12 locations of cocoa farms in Sungailiat district were below the maximum limit for agricultural soils established by EU (3.00 mg kg-1) and US EPA (0.43 mg kg-1) [29, 30].

This relatively low concentration indicated that no Cd contamination occurred in all cocoa farm soils of the areas studied. The study of [31] detected low concentration of soil Cd in Bangka ranging between 0.02 to 0.22 mg kg^{-1}. Most locations had high Cd content at a depth of 0-10 cm and decreased in deeper soils, with the exception of location 7. In this study, the results of Cd content in soils showed conformity to other studies. [32] observed the amounts of Cd contents were greater in topsoils and declined with increasing soil depths. Additionally, [33] also reported the contamination of Cd in soils of some sites in southern Ecuador were higher in upper soils and decreased in the deeper layers of soils. Enrichment of Cd concentrations in topsoils are generated by

Table 2 Soil physical and chemical analysis of 12 cocoa farms in Sungailiat district, Bangka Island at each soil depth

Loc.	Depth (cm)	Particle Size Distribution (%)			Texture Class	ρ_s	ρ_d	OM	pH
		Silt	Clay	Sand					
1	0-10	14.41	16.43	69.17	Sandy Loam	2.68	0.89	4.32	5.41
2		5.44	27.15	67.41	Sandy Clay Loam	2.69	1.05	3.84	5.74
3		4.43	24.66	70.91	Sandy Clay Loam	2.68	0.91	3.84	5.96
4		4.36	36.01	59.64	Sandy Clay	2.46	0.92	3.84	4.62
5		9.44	16.65	73.91	Sandy Loam	2.62	1.02	3.84	5.08
6		3.55	18.55	77.91	Sandy Loam	2.43	1.02	4.8	5.55
7		4.73	28.22	67.05	Sandy Clay Loam	2.42	0.85	2.4	5.81
8		13.98	29.12	56.90	Sandy Clay Loam	2.59	1.13	2.4	5.12
9		13.24	24.73	62.03	Sandy Clay Loam	2.33	1.00	5.28	4.98
10		9.14	35.89	54.97	Sandy Clay	2.48	0.81	4.32	5.01
11		4.51	41.64	53.86	Sandy Clay	2.66	0.99	3.36	5.11
12		3.22	21.02	75.76	Sandy Clay Loam	2.59	1.00	1.44	5.33
1	10-20	16.89	22.62	60.49	Sandy Clay Loam	2.75	-	2.4	5.08
2		6.61	29.01	64.38	Sandy Clay Loam	2.68		1.92	5.37
3		4.35	33.35	62.30	Sandy Clay Loam	2.45		2.4	5.03
4		2.35	43.35	54.30	Sandy Clay	2.65		2.88	4.56
5		9.04	21.64	69.32	Sandy Clay Loam	2.49		2.88	4.8
6		3.38	28.86	67.77	Sandy Clay Loam	2.62		2.88	5.17
7		5.99	24.21	69.80	Sandy Clay Loam	2.61		4.32	6.62
8		10.16	37.32	52.52	Sandy Clay	2.59		2.88	4.75
9		12.41	23.41	64.18	Sandy Clay Loam	2.66		2.4	4.89
10		9.61	35.53	54.86	Sandy Clay	2.50		3.84	4.67
11		4.75	47.98	47.27	Sandy Clay	2.54		1.44	4.72
12		1.61	16.24	82.15	Sandy Loam	2.67		1.92	5.6

evidence of anthropogenic activities and decomposition of plant litter (containing Cd) in surface soils which return Cd availability in soils [34]. Mining activities, vehicular activities, waste drainage, application of fertiliser have been considered as the sources of Cd contamination in soils [8]. In contrast, the elevation of Cd in the deeper soil layer (10-20 cm) in location 7 could be caused by its high soil pH (slightly acidic) compared to other locations that had lower pH (strongly acid to moderately acidic). In response to a change in pH, this high soil pH might potentially reduce the leaching intensity of Cd and increase the ability of soils to retain Cd. Cd is high water solubility that is susceptible to leach downwards into deeper soil layers, particularly occurs in sand soil and acidic soils [35]. Such soil conditions were found in these study areas, indicating that Cd contents in soils at depths of 0-10 cm and 10-20 cm were in low ranges due to their easily moved into deeper soil layers. The spatial distributions of soil Cd content in the study areas are presented on Figure 4.

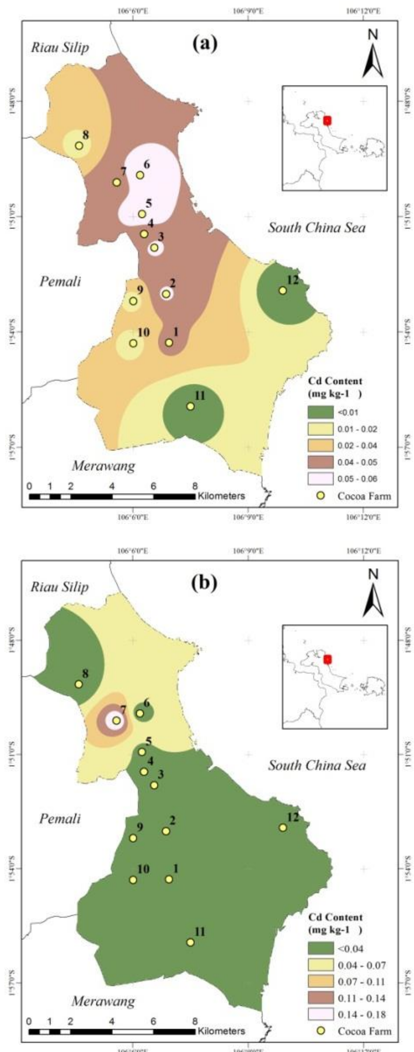

Figure 4 Spatial distribution of Cd contamination in soils at depth 0-10 cm (a); at depth 10-20 cm (b)

3.5. Correlation of Soil Properties and Cd Content in Soils

The correlation between soil properties and Cd content in soils aboveground of cocoa crops was done by using Pearson's correlation analysis are shown in Table 3. The relationship between Cd concentrations in this study did not significantly correlate with soil densities and soil textures in both of the soil depths, indicating these soil properties were not the major factors that affect the amounts of Cd in soils in the area studied. For the soils at depth 0-10 cm, Cd content in soil was not correlated to any soil properties, whereas at depth 10-20 cm, Cd content in soil was significantly very strong correlated with soil pH ($r = 0.82$, $P < 0.01$) and significantly strong correlated with organic matter ($r = 0.62$, $P < 0.05$) which means high soil pH in soils of the areas studied could increase the concentration of Cd in soils and means high content of soil organic matter could increase the concentration of Cd in soils, respectively. This consistent with study of [16] who reported the correlations between soil properties in surface soils (0-5 cm) were weaker than in subsurface soils (5-15 cm) due to the high amount of organic matter in surface soil which could enhance Cd bound to the organic particles.

Soil physical and chemical properties such as clay content, organic matter and soil pH have been reported to control the presence of Cd in soils [36]. Soil organic matter and clay contents may play a crucial role for retaining the Cd and restricting Cd movement in soils thereby reducing the absorption of Cd into plant tissues [37]. Large amounts of organic matter in soils may alter the speciation of Cd from soluble to oxidizable fraction [16]. In contrast, some studies have reported Cd content in soils had a negative correlation with soil pH. [37] found inverse correlation between Cd uptake and soil pH. Discrepancy of the results with other studies might occur because of its difference in soil characteristics, plant species and morphologies. Soil pH may be associated with the mobility, solubility, and speciation of Cd in soils hence leads to its phytoavailability in plant systems [38]. However, several studies also found positive correlations between soil pH and soil Cd. The study of [5] reported the soil pH across the study sites in Peru were positively correlated with Cd contents in soils.

4. CONCLUSION

Based on the results that were obtained by the research, Cd contamination has been detected in the soils under cocoa cultivations in the study areas in Sungailiat district though at low concentrations which were in the range between 0.00 to 0.06 mg kg-1 and

Table 3 Pearson's correlation (r) between Cd concentration in soils, cacao beans, and soil properties at each depth

	Cd-soil	Sand	Silt	Clay	ρ_s	ρ_d	OM	pH
0-10 cm								
Cd-soil	1.00**	0.54^{NS}	-0.08^{NS}	-0.51^{NS}	0.03^{NS}	-0.04^{NS}	0.43^{NS}	0.38^{NS}
Sand		1.00**						
Silt			1.00**					
Clay				1.00**				
PD					1.00**			
BD						1.00**		
OM							1.00**	
pH								1.00**
10-20 cm								
Cd-soil	1.00**	0.27^{NS}	-0.09^{NS}	-0.23^{NS}	0.05^{NS}	-	0.62*	0.82**
Sand		1.00**						
Silt			1.00**					
Clay				1.00**				
PD					1.00**			
BD						1.00**		
OM							1.00**	
pH								1.00**

* $P < 0.05$; ** $P < 0.01$; NS = not significant; ρ_s = particle density; ρ_d = bulk densiy, OM = organic matter

0.00 to 0.18 mg kg^{-1} at each soil depth (0-10 cm and 10-20 cm). The concentrations of Cd in all soils aboveground of cocoa crops in the study areas were below the maximum limit of Cd contents in agricultural soils established by EU (3.00 mg kg-1) and US EPA (0.43 mg kg-1), indicated no Cd contamination occurred in soils. Coefficient correlation (r) between soil Cd content at soil depth 10-20 cm was very strong correlated with soil pH ($r = 0.82$, $P < 0.01$) and strong correlated with soil organic matter ($r = 0.62$, $P < 0.05$).

AUTHORS' CONTRIBUTIONS

Raden Ferian Leo Mahendrasta: Conceptualization, methodology, data analysis, writing-original draft preparation, writing-review and editing

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