Correlation between soil characteristics and cadmium content in aboveground of cacao farming in Nglangeran village, Gunung Kidul - Indonesia

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ABSTRACT
Cadmium (Cd) is one of the metal elements that is often found contained in cacao plantation system. The first gate of Cd contamination is soil as medium of plant growth. The soil characteristics such as texture and pH play vital role in chemical and physical reaction in the soil that may increase mobility of the Cd to the plant. This study aimed to determine the amount and the level of cadmium in cacao soil and correlate it to soil characteristics (texture, particle density, bulk density, pH) of Nglanggeran village in Gunung Kidul, Yogyakarta. Three points from each site of cacao farm were selected diagonally to be taken as the soil sample, where the soil was taken from 0-10 cm and 10-20 cm in depth. Plantation management (tree age, fertilizer, irrigation, drainage, pruning) was noted from an interview to the farmers. The methods used in measuring the Cd content were the AOAC method by using ICP-MS. The Cd content in the soils ranged from 0.05 mg kg^{-1} to 0.24 mg kg^{-1}. This result showed all sites of cacao farms in Nglanggeran were below the critical limit of Cd in agricultural soils based on multiple different country (China 1.5-4 mg kg^{-1}; India 3-6 mg kg^{-1}; Vietnam 2 mg kg^{-1}; and Europe Union 3 mg kg^{-1}). None of the soil properties in all depth showed significant correlation with cadmium content in soil except for soil organic matter in 10-20 cm depth ($r=0.67$, $P<0.05$).

Keywords: *Soil, Cadmium Contamination, Cacao, Nglanggeran Gunung Kidul.*

1. INTRODUCTION

Gunung Kidul is a regency in the south of the Special Region of Yogyakarta which has a total area of 1485.36 km^2 or 148,536 hectares. The total population in Gunung Kidul Regency in 2020 reached 747,161 people, 46% of whom are families whose livelihoods are in the agricultural or plantation sector. The plantations found in Gunung Kidul Regency consist of coconut plantations (81.95%), cacao (13.55%), tobacco (2.7%), sugarcane (1.72%), rubber (0.06%) and coffee (0.01%). The existing cacao plantation area is 1,367.28 hectares (0.086% of Indonesia's cacao plantation area) and with a production of 458.79 tons (0.06% of Indonesia's cacao production) in 2020 [1].

Heavy metal contamination is something that is highly avoided in agricultural systems, including in cacao plantation. The accumulation of heavy metal content that enters the human body can have a negative impact on human health. Cadmium (Cd) is a chemical element which is a soft metal that is often found in cacao plants system from the soil up the cacao plant tissues. Cadmium contamination that enters the human body could cause many health issues and diseases such as cancers, renal diseases, osteomalacia, and osteoporosis [2]. Cadmium contamination can also affect plant growth and root activities [3].

According to [4], in natural, uncontaminated soils, Cd concentration is largely influenced by its amount in the parent rock, and by local weathering conditions, as well as transportation by rivers and deposition in sediments and water by rivers during flooding events. Other natural sources of soil Cd includes volcanic activity, forest fires, wind-blown soil particles and rock dust. However, the

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contribution of natural processes to Cd contamination in the soil is 3 to 10-fold lower than that of anthropogenic sources. Cd pollution or contamination mostly occur through industrial activity, mining, household activity, and agricultural activities such as the use of chemical fertilizers and pesticides [5].

Cd contamination in the field can occur due to the parent rock material content and soil properties. The soil properties (physical, chemical, biological) could increase the chemical reaction of Cd. The Cd contamination can be carried on from the cacao fields into the cacao beans, even into the processed cacao product such as cacao powder and chocolate bar. It is not an exception to the cacao fields in Patuk District, Gunung Kidul.

Patuk District is one of the largest cacao-producing districts in Gunung Kidul Regency. Almost everyone has a cacao tree in their yard. A village in Patuk District called Nglanggeran Village has become an entrepreneurial tourism and cacao product processing village. With all the cacao products being made, as the public is becoming more concerned about health issue, the question arises whether there is Cd contamination in the cacao products that have been produced. Therefore, this study was conducted to determine the Cadmium contamination in cacao soil of Nglanggeran village.

In view of the above, the main objectives of this study are to determine the amount and the level of Cd content and contamination in the soil and identify the relationship between the Cd content and soil properties. This study can be used to find out whether amendments are needed to the soil and the environment if the Cd content in the soil or cacao plants exceeds a predetermined standard. This study can also be used as a reference on the value of Cd content in cacao fields in Nglanggeran Village, Gunung Kidul.

2. MATERIALS AND METHOD

2.1. Time and Location

This study was conducted in Gunung Kidul Regency. The soil samples were taken from Patuk Sub-district of Gunung Kidul Regency, precisely in Nglanggeran Village. The Nglanggeran Village is located between 110°32'20.101" E and 7°51'14.818" S. The soil analysis was carried out in two Laboratories (LaPitaya and Saraswanti) and some of the parameters were also analyzed in Soil Laboratory of Faculty of Agricultural Technology, UGM. This study started on January 17th 2022 until March 13rd 2022. Nglanggeran Village was chosen as the sample location because it is the largest cacao-producing region in Gunung Kidul Regency.

2.2. Materials and Equipment

2.2.1. Soil Sampling

The soil sample is divided into two parts, disturbed and undisturbed soil. Undisturbed soil samples were taken using a hammer and ring sampler with a diameter of 5 and height of 5 cm, while disturbed soil samples were taken using auger. Disturbed soil samples were taken with two depth variations, namely 0-10 cm and 10-20 cm. Soil samples were taken under a live cacao tree, with a distance in the middle between the tree trunk and the tip of the branch farthest from the cacao tree. Soil samples were taken at least three times on each land with the direction diagonal to the land (Figure 1). Soil samples were labelled and stored into plastic bags and tightly sealed. GPS tracker is used to determine the coordinate (longitude and latitude) of each location that soil and plant samples were taken.

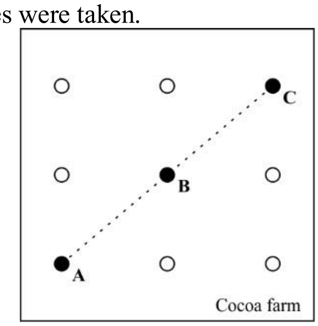


Figure 1 Illustration of soil sampling location in each cocoa plantation

Figure 2 Soil sampling activity

2.2.2. Soil Analysis

Soil samples were oven-dried at temperature of 60°C, pound using mortar and pestle, hereafter sieved through 2 mm size. Dried soil samples were properly labelled and stored into plastic bags. All points of undisturbed soil samples (A, B, and C) of each location at depths 0-10 cm and 10-20 cm were combined together for further soil physical and chemical analysis. Dried soil samples of all depths were analyzed 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 analyzed at Laboratory of Land and Water Resource Engineering, University of Gadjah Mada (UGM). Dried soil samples were shipped to the Laboratory of La Pitaya 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 limit detection 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 of soil properties and Cd analysis

Parameters	Method	Reference
Soil Texture	Robinson Pipette method	(USDA, 2004)
Particle Density	Picnometer method	(Weast and Lide, 1990)
Bulk Density	Cylindrical Core Sampler	(Blake and Hartge, 1986)
Organic Matter	Walkley and Black method	(Hortwitz, 2010)
Soil pH	Suspension 1:5 of soil:H_2O	(Eviati & Sulaeman, 2012; Van Reeuwijk, 1993)
Cd Content	AOAC	(AOAC, 2015)

2.3. Data Analysis

2.3.1. Statistical Analysis

The data were analyzed using JMP® (version 8.0.2). Pearson correlation was applied to determine the relationship between soil properties and Cd content in soils and plants in order to know which major soil properties either contribute to available Cd in soils and Cd uptake by plants. Statistical significance was established at $P < 0.05$.

2.3.1. Spatial Analysis

Spatial distribution maps of soil properties (texture, bulk density, particle density, organic matter, soil pH) and Cd contamination in soils across sampling sites were created using geographic information system (GIS) approach. The software of ArcMap 10.6 was used in this study. The database that contains of attributes (longitude, latitude, and laboratory results) of all locations was prepared using MS Excel and linked into the ArcMap software for geostatistical analysis. This study used IDW interpolation as a spatial analyst tool to predict values of attributes at locations where samples were not collected [6].

3. RESULTS AND DISCUSSION

3.1. Site Description

This study was conducted in Nglanggeran Village, Patuk District, Gunung Kidul Regency. Nglanggeran Village has a total area of 762.1 hectares, with the majority of its land use is for agricultural purposes. According to the Indonesian Bureau of Central Statistics (2020), Gunung Kidul Regency has a total of 2327 mm of rainfall, 26.8°C of mean temperature, and 84% of mean humidity. The oil of the study area is dominated with red latosols and lithosols. The plantations found in Gunung Kidul Regency consist of coconut plantations (81.95%), cacao (13.55%), tobacco (2.7%), sugarcane (1.72%), rubber (0.06%) and coffee (0.01%). The existing cacao plantation area is 1,367.28 hectares (0.09% of Indonesia's cacao plantation area) and with a production of 458.79 tons (0.06% of Indonesia's cacao production) in 2020 [1].

Nglanggeran Village consists of 5 smaller villages or sub-villages namely Doga, Karangsari, Gunung Butak, Nglanggeran Kulon, and Nglanggeran Wetan. The soil and the plant samples were taken from each of the sub-villages (Figure 3) and 2 random points were chosen for each sub-villages, resulting in 10 total different sample locations. These sub-villages are Nglanggeran Kulon (1 and 2), Doga (3 and 4), Karangsari (5 and 6), Gunung Butak (7 and 8), and Nlanggeran Wetan (9 and 10).

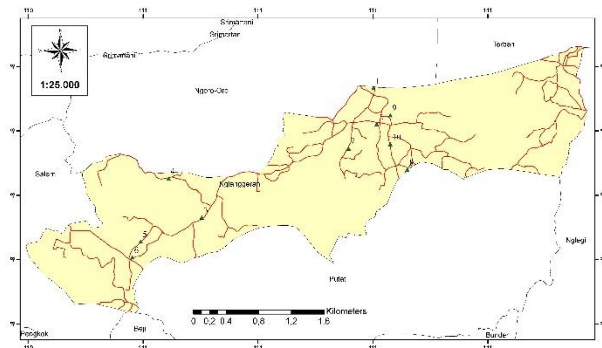


Figure 3 Soil sampling locations in Nglanggeran Village

3.2. Plant Management and Land Condition

Plant management and land condition in the study area was obtained by interview with the farmer and by visual observation. The result is as follows:

Table 2. Plant management and land condition of study area

Loc.	Plant profile and Management		Land condition				
	Age (years)	Agriculture Practices	Trash	Plant Litter	Livestock	Other Plants	Main Roads
1	>10	-	✓	✓	✓	✓	-
2	>10	-	✓	✓	-	✓	✓
3	~20	-	✓	✓	-	✓	-
4	>10	✓	-	✓	-	✓	-
5	~10	-	✓	✓	-	✓	-
6	>10	-	-	✓	✓	✓	✓
7	>10	-	-	✓	-	✓	✓
8	>10	-	-	✓	-	✓	✓
9	>10	-	✓	✓	-	✓	-
10	>10	-	✓	✓	-	✓	✓

✓ = exist/could be found

Table 2 shows that majority of the cacao plantation age in the study area are between 10-20 years. Amongst all of the sample location, only one farmer does an agricultural practice to manage the cacao farm, such as using fertilizer, watering, cleaning, and other maintenances.

3.3. Soil Properties

3.3.1. Soil Texture

The fraction of soil texture in the study area can be seen in Table 3 and Table 4. The table also presents the soil texture class for each sampling point.

Table 3. Soil texture (0-10 cm depth) in study area

Location	Depth (cm)	Silt	Clay	Sand	Texture Class
		(%)			
1	0-10	23.60	58.17	18.23	Clay
2		18.96	42.60	38.45	Clay
3		23.41	66.62	9.97	Clay
4		21.76	50.45	27.79	Clay
5		32.54	51.97	15.49	Clay
6		17.12	65.71	17.17	Clay
7		25.96	63.54	10.49	Clay
8		35.02	42.83	22.14	Clay
9		14.94	73.26	11.81	Clay
10		25.06	64.48	10.46	Clay

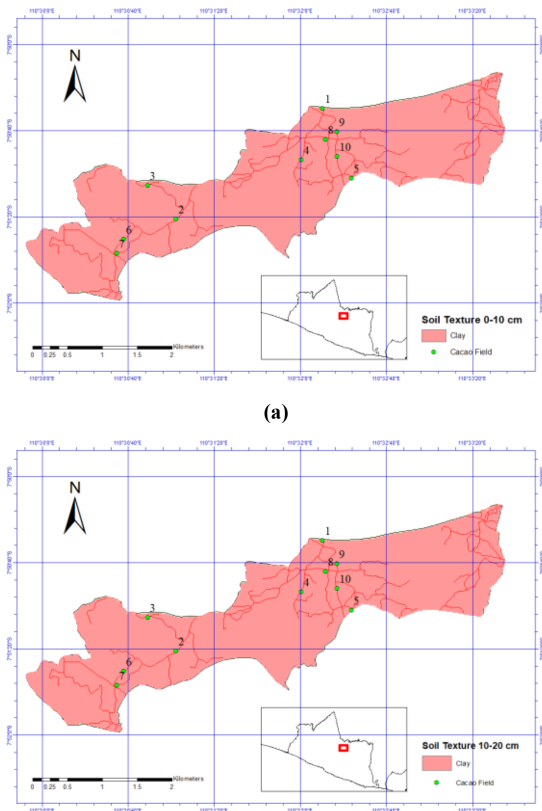
Table 4. Soil texture (10-20 cm depth) in study area

Location	Depth (cm)	Silt	Clay	Sand	Texture Class
		(%)			
1	10-20	23.00	63.51	13.49	Clay
2		18.09	54.52	27.39	Clay
3		24.22	70.41	5.37	Clay
4		22.47	61.47	16.06	Clay
5		26.71	63.87	9.42	Clay
6		16.10	77.37	6.52	Clay
7		25.49	63.32	11.19	Clay
8		31.9	50.64	17.46	Clay
9		10.44	82.31	7.24	Clay
10		13.62	77.41	8.98	Clay

Table 3 and Table 4 shows that the average soil texture class in the study area is clay with clay fraction ranges between 42.6 to 82.31%. The average soil fraction in the study area is 22.52% silt, 62.22% clay, and 15.26% sand. Clay soils (fine textured soils) play important role in soil fertility, which have ability to hold water and have potential to stabilize soil organic matter in the soils that can be used by the plants as nutrients. Nonetheless, clay is poor in aeration and water drainage due to less macro pores. Agroforestry cacao systems are typically established on silty and clay loam soils. These type of soil textures provide moderate to adequate infiltration and only a small portion are poorly drained soils. Loam soil is made with a balance of the three main fraction of soil (silt, clay, and sand). Clay loam soil is a mixture that contains more clay than the other types of soil fraction, which means the clay is around 33 – 40% and the rest is silt and sand. These compositions will influence the soil's water availability, nutrients, and aeration [7].

Soil texture is considered as a crucial environment factor for agricultural sector which eventually affects plant growth systems [8]. Soil texture is able to improve in order to get result in greater root distribution, penetration, and nutrient as well as water uptake for growing plants. For instance, the abilities of sandy soils to retain water and provide nutrients in the soils can be improved by increasing clay content and organic matter levels to the soils. Soil texture influence the dynamics of soil organic matter (OM), which increases in clayey soils, as there was positive relationship between the proportion of clay in the soil and the content of organic matter in agroforestry systems [9]. Moreover, soil texture also affects the amount of Cd in soil and plant uptake due to their ability to bind with Cd in soil [10].

The spatial distribution of soil texture for each soil depths can be seen in Figure 4.



(a)

(b)

Figure 4 Spatial distribution of soil texture in 0-10 cm depth (a); and 10-20 cm depth (b) in study area

3.3.2. Soil Particle Density

The soil particle density of all sample locations in the study area can be seen in Figure 5.

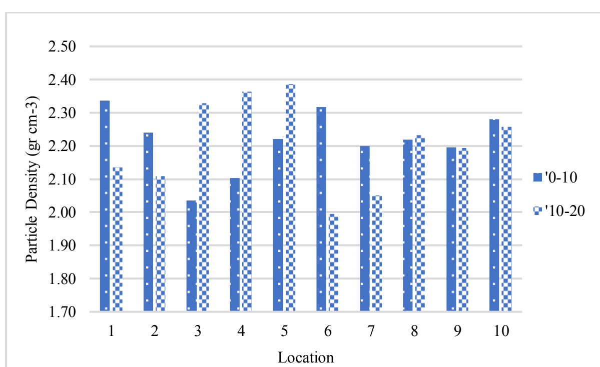


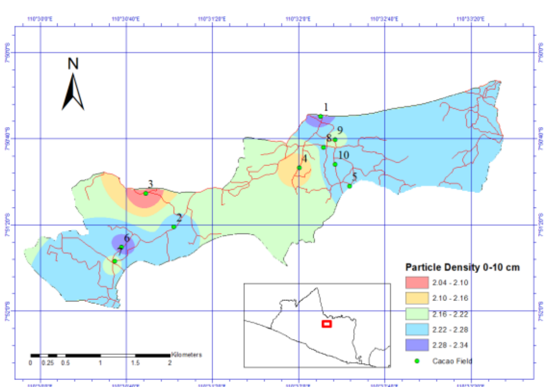
Figure 5 Soil particle density of each depth in the study area

Figure 5 shows that the particle density of soil at depth 0-10 cm ranged between 2.04 to 2.34 g cm^{-3} with an average of 2.22 g cm^{-3}, whereas the particle density of soil at depth 10-20 cm ranges between 2.00 to 2.39 g cm^{-3} with the average of 2.21 g cm^{-3}. Mineral soils have particle density ranging from 2.4 to 2.9 g cm^{-3} [11]. Densities of clay minerals range from 2 to 3, but many are near 2.65 g cm^{-3} [12]. The density of humus is usually less than 1.5 g cm^{-3}.

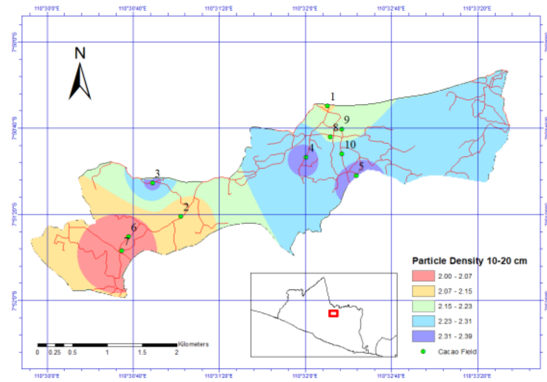
The measured density depends on the relative proportions of constituent minerals and humus. In this study, the measured particle density was slightly lower than that of a mineral soil. This result can occur due to the fact that the soil samples taken were from the very top layer of the soil where it is notably where the organic matters are in. GLOBE [13] states that the particle density of the very top soil was the lowest other 4 horizons (deeper soil). It also noticed that the color of the first horizon (top soil) is much darker than the others, indicating that this horizon had a higher organic matter content. In this study, at the time when soil sample was taken, the soil also had a dark color and roots or litter of other vegetations in the soil, thus can affect the particle density value. However, more than half of the sample location has lower particle density in deeper soil, which generally surface soil should have lower value of particle density due to high content of soil organic matter [14].

The particle density for cacao plantation usually averaged between 2.36 and 2.59 g cm^{-3} [15]. With that in mind, location 5 in Nglanggeran Village has an optimal particle density value for cacao plantation, meanwhile the others have slightly lower particle density meaning that the locations are not as optimal, but can still maintain a good cacao plant cultivation as the quality is not based only on particle density.

The spatial distribution of soil particle density for each soil depths are as follows:



(a)



(b)

Figure 6 Spatial distribution of soil particle density in 0-10 cm depth (a); and 10-20 cm depth (b) in study area

3.3.3. Soil Bulk Density

The soil bulk density of all sample locations in the study area can be seen in Figure 7.

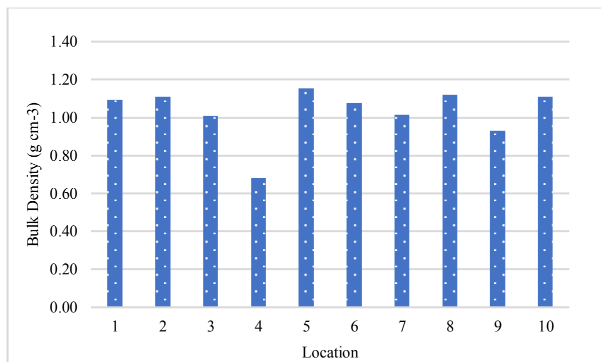


Figure 7 Soil bulk density of each depth in the study area

Figure 7 shows that the bulk density of soil ranging between 0.68 – 1.15 g cm^{-3} with the average of 1.03 g cm^{-3}. The highest bulk density was found in location 5 while the lowest was found in location 4. Mineral soil has bulk density ranging from 0.7 to 1 g cm^{-3}, while a common organic soil has bulk density of 0.1 – 0.9 g cm^{-3} [16]. Bulk density value is influenced by soil texture, soil structure, and organic matter content [17]. Soil bulk density is influenced by parent material, soil porosity, compaction, and consolidation. Soil that has higher organic matter content usually has lower bulk density value than soil with low organic matter content [18]. In general, plants can properly grow in soil with bulk density lower than 1.40 g cm^{-3} [19], meanwhile the bulk density value that is good for cacao plantation is around 1.0 – 1.4 g cm^{-3}.

In this study, Location 4 has significantly lower bulk density value compared to other locations which is 0.68 g cm^{-3} and Location 9 also has lower bulk density value for a cacao plantation soil which is 0.93 g cm^{-3}. This low bulk density can be caused by a higher organic matter content on those locations, but Figure 4.4. shows that on Location 4 and Location 9, the organic matter content is not that high. So, it can be concluded that the organic matter isn't the cause of this low bulk density value. The cause of low bulk density value might be from its parent material, porosity, compaction, soil management, soil structure, and other factors.

The spatial distribution of soil bulk density in the study area is presented in Figure 8:

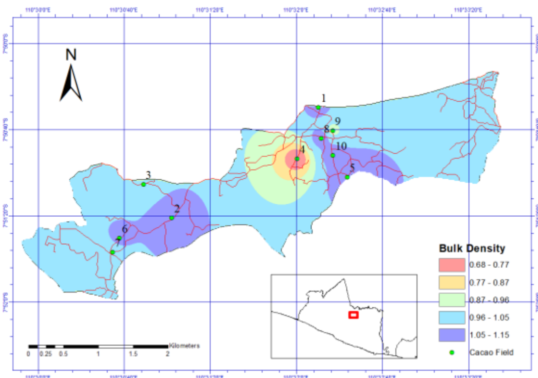


Figure 8 Spatial distribution of soil bulk density in study area

3.3.4. Soil Organic Matter

The soil organic matter content of all sample locations in the study area can be seen in Figure 9.

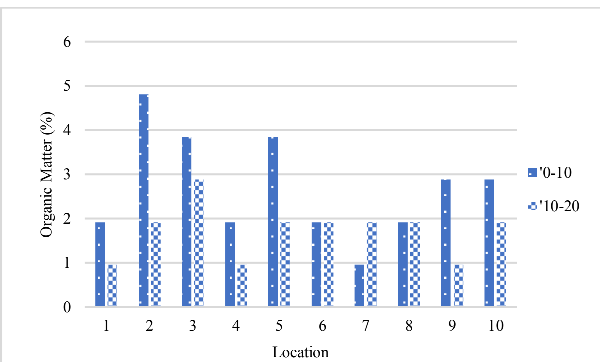


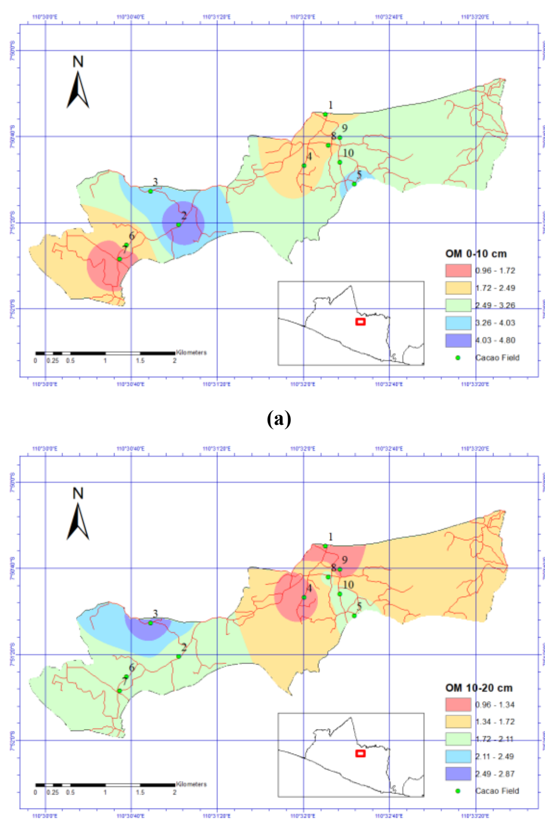
Figure 9 Soil organic matter content of each depth in the study area

Figure 9 shows that soil organic matter at depth 0 – 10 cm ranged between the organic matter content is ranging between 0.96 to 4.8 % with an average of 2.69 %. Meanwhile the soil organic matter at depth 10 – 20 cm ranged between 0.96 to 2.88 % with an average of 1.73 %. Most organic matter in the soil of the study area decreased in deeper soil. The presence of litter and fertilizers on the surface soil will increase the organic matter content, thus making the organic matter in soil with 10 – 20 cm depth are mostly lower than in soil with 0 – 10 cm depth. Cacao plants generally can grow better when topsoils have soil organic matter contents higher than 3% in order to maintain soil fertility [20].

Organic matter (OM) is closely related with plant remains and the type of vegetation influences the quality and content of soil organic matter. For example, cedar-banana agroforestry systems conserve soil OM content throughout the year [21]. It is seen in the organic matter in location 2, 3, 5, and even location 9 and 10, where in those locations there were multiple different vegetations other than the cacao plant in the same area. These different vegetations might act as a natural OM conserver, thus making the corresponding locations contains higher organic matter compared to other locations (location 1, 4, 6, 7, 8) in which in those locations, the other vegetation had a different, separate area from the cacao field. This occurrence strengthens the local farmers advice of having other vegetations in cacao field, which mainly were for shade of the cacao plants, but it actually could conserve the organic matter in the soils as well. The organic matter is also a key factor that reduces the bulk density of the soil, improving aggregate stability and favoring a porous structure [22].

The organic matter content of soils also plays an important role in cadmium bioavailability due to its ability to adsorb cadmium [4]. Organic matter content can also reduce cadmium bioavailability indirectly by affecting other soil properties [23], mainly by increasing soil pH [24]. Studies have reported a decrease in bioavailable soil cadmium and of cadmium uptake by plants using various organic matter amendments such as biochar [25][26], poultry, pig or cattle manure and compost [24][27], vermicompost [28] or activated carbon [29].

The spatial distribution of soil organic matter content for each soil depths can be seen in Figure 10.



(a)

(b)

Figure 10 Spatial distribution of soil organic matter content in 0-10 cm depth (a); and 10-20 cm depth (b) in the study area

3.3.5. Soil pH

The soil pH of all sample locations in the study area can be seen in Figure 11.

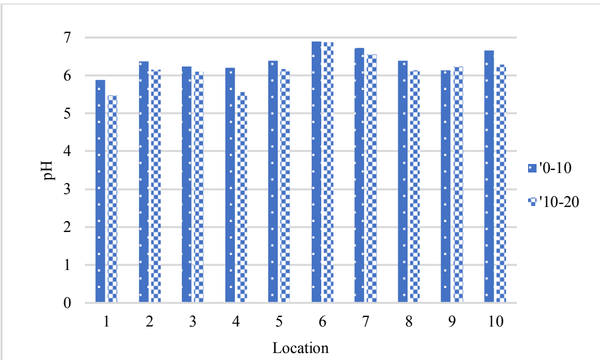
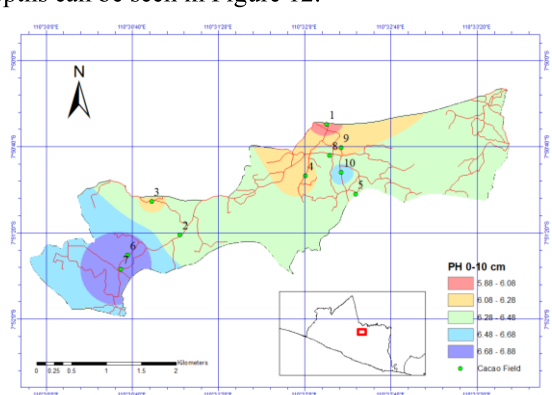


Figure 11 Soil pH of each depth in the study area

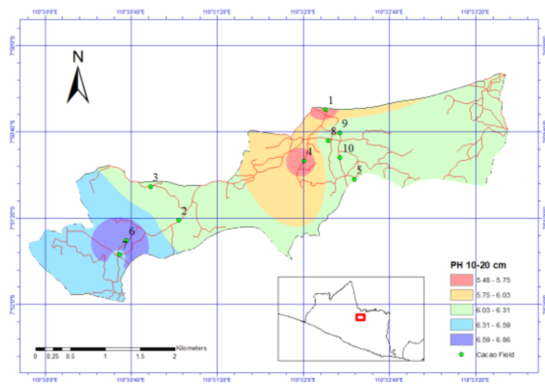
Figure 11 shows that the soil pH in the study area in 0 – 10 cm depth is ranging between 5.88 to 6.89 with an average of 6.39. Meanwhile, the soil pH in 10 – 20 cm depth is ranging between 5.48 to 6.87 with an average of 6.15. The lowest soil pH of the sample is moderately acid (5.48) whereas the highest is close to neutral (6.89). Soils with this value of pH generally have adequately balanced nutrient levels and have great potential for agricultural use [30][31]. Cacao trees grow best in soil with pH levels ranging from 5.0 to 7.5 [32].

In this study, the soil pH decreased in the deeper soil (more acidic). Soil pH is associated with the solubility of nutrient compounds in soils, this also includes the toxic compounds as well such as Cd and other heavy metals [33]. Applying certain amendments to acidic soils that increase the pH can reduce the proportion of Cd that is bioavailable and thus reduce Cd uptake by plants [23][32]. Most studies on cacao find significant and negative correlations between soil pH and bioavailable Cd [34][35][36][37][38]. However, the pH environment in the soils is not uniform as plants exude acids from their roots to improve the solubility of nutrients and ions [39]. This means that even in the study area where the soils are near neutral, and even in neutral or alkaline soils cadmium accumulation in plants tissues may still occur [40].

The spatial distribution of soil pH for each soil depths can be seen in Figure 12.



(a)



(b)

Figure 12 Spatial distribution of soil pH in 0-10 cm depth (a); and 10-20 cm depth (b) in the study area

3.4. Cd Content in Soil

The soil Cd content of all sample locations in the study area can be seen in Figure 13:

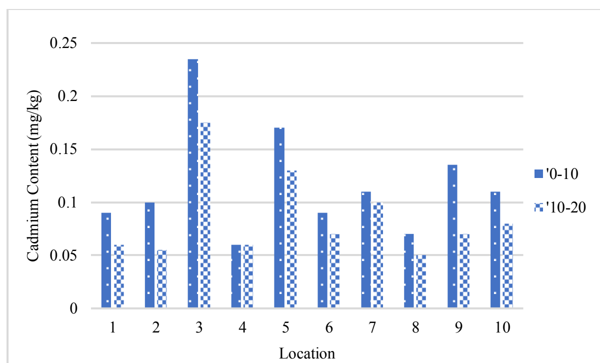


Figure 13 Soil cadmium content of each depth in the study area

Figure 13 shows that the Cd content in the study area in 0 – 10 cm depth is ranging between 0.06 to 0.24 mg kg^{-1} with an average of 0.12 mg kg^{-1}. Meanwhile, the Cd content in 10 – 20 cm depth is ranging between 0.05 to 0.18 mg kg^{-1} with an average of 0.085 mg kg^{-1}. The average Cd content from all of the samples in the study area is 0.1 mg kg^{-1}.

The maximum allowable limit for Cd in agricultural soils in Indonesia is still non-existent, however in some country such as China has 1.5 – 4 mg kg^{-1} limit depending on soil pH [41], India has 3 – 6 mg kg^{-1} [42], and the neighboring country Vietnam has 2 mg kg^{-1} limit [2][43]. Europe Union has the maximum limit of 3 mg kg^{-1} Cd in agricultural soils [44]. Sutrisno and Kuntyastuti [45] stated that heavy metal contamination, including Cadmium contamination is present in majority area of Indonesia, including in Java Island. According to their category, in this study, the average Cd content in soil samples (0.1 mg kg^{-1}) is categorized as contaminated. The lowest Cd content value in Nglanggeran Village of 0.05 mg/kg is still safe, but the highest of 0.24 mg kg^{-1} is not safe. Although not all of the sample locations are categorized as unsafe, the situation still needs its deserved attention. There needs to be a further effort of reducing Cd contamination and other heavy metal contamination in agricultural land.

Based on Figure 13 it is shown that in the deeper soil (10-20 cm depth) has lower Cd content compared to the surface soil (0-10 cm depth). The higher value of Cd content in the surface soil can be caused by human activities or better-known as anthropogenic effects, in this case, such as the use of chemical pesticides, herbicides, and fertilizers [46]. However, based on the interview done with the farmer/landlord, almost all farmer/landlord from all of the sample location barely do any fertilizing on their cacao fields. Location 3, for example in this study, which has the highest Cd content in the soil of 0.24 mg kg^{-1}, the farmer didn't use any fertilizer at all and barely do any maintenance to the cacao field. Meanwhile in Location 4, where the farmer actively fertilizing their cacao field with organic fertilizer and performing maintenance, has a lower value of Cd content (0.11 mg kg^{-1}). This occurrence might indicate that the Cd content has a correlation with the cacao field maintenance done by the farmer. The best example is the locations where the farmer cleans their cacao fields from litters of leaves and other organic waste (Location 1, 4, 6) has relatively low Cd contamination.

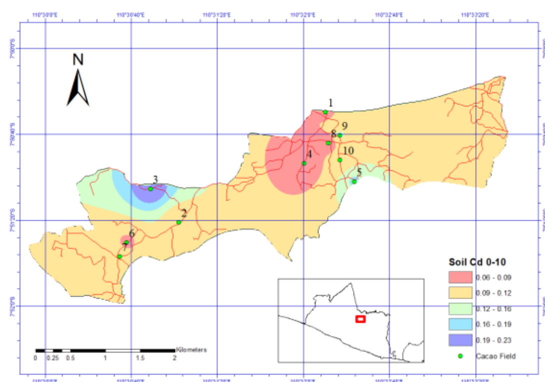
Cd is not reported to be essential for any biological process in plants, but is still absorbed by both root and leaf systems from soils [47][48]. Cd is also absorbed from soils and subsequently distributed among its various tissues [49]. The litter of leaves from the cacao plant on the cacao field can also be a source of Cd in the soil. According to multiple studies, cacao leaves actually has the highest Cd concentration amongst the cacao plant tissues [32][35][36][37][49]. Withered leaves containing Cd would fall back to the ground and act similarly as an external source of Cd, which originally is the Cd from the soil itself. Getting rid of the leaves would help on reducing the Cd in the top soil. Even so, some farmers intentionally let the fallen leaves so that it can act as an organic fertilizer.

Regarding the fertilizer, the use of non-organic or chemical fertilizer could increase the cadmium content in the soil [34]. In this study, none of the farmer in the sample location use any chemical fertilizer, but that doesn't mean other farmers in Nglanggeran Village didn't use any chemical fertilizer so the results in this study might not indicate the absolute true value of the Cd in Nglanggeran soil.

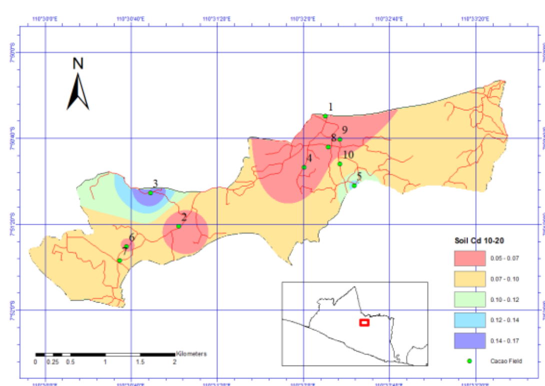
Another factor that can influence the Cd contamination in soil is the soil parent material. In natural contaminated soils, Cd concentration is influenced by the amount of Cadmium in the parent rock. According to Gunung Kidul's official government website, Gunung Kidul has limestone as its dominant parent material in most of the area, but in Patuk Sub-District where Nglanggeran Village is located, has volcanic rock and hurricane sediment as the parent material. It has been recorded that in this location there was a volcanic activity in tertiary era. In this modern time, the volcano or better known as Gunung Api Purba had been eroded by the process of erosion, so that the inside was exposed. Comparing different soil types, those derived from igneous rocks typically contain low amounts of Cd, soils derived from metamorphic rocks are intermediate, and soils derived from sedimentary rocks (especially shales) contain high amounts [4]. Volcanic originated soil could also contain high level of cadmium [50].

The contribution of natural processes to soil Cd contamination is 3 to 10-fold lower than that of anthropogenic sources. In tropical soils in humid area, migration of naturally occurring cadmium down the soil profile is more likely to occur than its accumulation in the top layer [47][51]. Thus, the results from multiple studies on cacao-growing soils show significantly higher concentrations of cadmium in their top layer compared to other layers, and a general decrease with depth have been interpreted as a result of recent anthropogenic activity [35][36][46][52][53][54].

The spatial distribution of soil Cd content for each soil depths in the study area can be seen in Figure 12.



(a)



(b)

Figure 12 Spatial distribution of soil cadmium content in 0-10 cm depth (a); and 10-20 cm depth (b) in the study area

3.5. Correlation of Cd Content with Soil Properties

Analysis of the correlation between cadmium concentration in soil with soil properties is presented in Table 5.

Table 5. Pearson's correlation between cadmium content and soil properties

	Cd-soil	Sand	Silt	Clay	PD	BD	OM	pH
0-10 cm								
Cd-soil	1**	-0.51	0.03	0.42	-0.50	0.20	0.54	-0.12
Sand		1**						
Silt			1**					
Clay				1**				
PD					1**			
BD						1**		
OM							1**	
pH								1**
10-20 cm								
Cd-soil	1**	-0.57	0.21	0.23	0.42	-	0.67*	0.15
Sand		1**						
Silt			1**					
Clay				1**				
PD					1**			
BD						1**		
OM							1**	
pH								1**

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

The analysis shows that there were different correlation factor in each soil depth sample. The results shows that there is no significant correlation between soil particle density, soil bulk density, and soil pH, and soil texture in both of the soil depths with Cd content in the soil.

In soil with 10 – 20 cm depth, there is a significant positive correlation between soil organic matter with soil Cd content ($r = 0.67$, $P < 0.05$). This means that higher organic matter content in the sub-surface soil (10 – 20 cm depth) increase the accumulation of Cd in the 10 – 20 cm soil. Meanwhile, soil in 0 – 10 cm depth shows no significant correlation between the organic matter content and soil Cd content.

This result regarding the organic matter content correlation with cadmium content is partly not in accordance with various studies that have been done previously. Soil organic matter content in cacao plantations in Honduras and Bolivia was found to be significantly and negatively correlated to soil bioavailable Cd [36][37]. In this study, the organic matter has a positive correlation with Cd in soil. Among the possible explanation of this occurrence is that organic matter have the ability to adsorb/bind with Cd. These organic matter is binding with Cd therefore restricting Cd movements in soils [10], hence higher the organic matter results in also higher Cd content.

4. CONCLUSION

Based on the results, the following conclusions can be drawn:

1. Cadmium (Cd) contamination has been detected in the soils (0-10 cm and 10-20 cm depth) under cacao plantation in the study areas of Nglanggeran Village. In the study area, Cd concentrations in soils ranging between 0.05 to 0.24 mg kg^{-1} with the average of 0.1 mg kg^{-1}.
2. The concentrations of Cd in all soils of study area were below the maximum limit of Cd contents in agricultural soils in multiple different country (China 1.5 – 4 mg kg^{-1}; India 3 – 6 mg kg^{-1}; Vietnam 2 mg kg^{-1}; and Europe Union 3 mg kg^{-1}), indicating no harmful Cd contamination occurred in soil depths of 0-10 cm and 10-20 cm.
3. Correlation analysis showed that organic matter has a significant positive correlation with Cd content in the soil ($r = 0.67$, $P < 0.05$), precisely in sample with 10 – 20 cm depth. This correlation occur because organic matter is capable to bind adsorb/bind cadmium which resulting in higher Cd content in soils with higher organic matter content. None other soil properties (texture, bulk density, particle density, pH) has a significant correlation with Cd content in the soil.

AUTHORS' CONTRIBUTIONS

Ilham Bintang Pratama collect the soil samples, cacao plantation management, analyze the soil in laboratory, perform the analysis, and write the paper. Ngadisih, Chandra Setyawan, and Katharina Keiblinger supervising the all process of research and writing thesis as well as paper. Rizki Maftukhah and Axel Mentler mentoring the laboratory work.

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REFERENCES

[1] BPS-Statistics Indonesia, 2020. Indonesian Cacao Statistics.

[2] Yuan, C., Li, Q., Sun, Z. and Sun, H. 2021. Effects of natural organic matter on cadmium mobility in paddy soil: A review. Journal of Environmental Sciences. 104, 204-215.

[3] Tezotto, T., Favarin, J. L., Azevedo, R. A., Alleoni, L. R. F. and Mazzafera, P. 2012. Coffee is highly tolerant to cadmium, nickel, and zinc: Plant and soil nutritional status, metal distribution and bean yield. Field Crops Research. 125, 25-34.

[4] He, S., He, Z., Yang, X., Stoffella, P. J., & Baligar, V. C. 2015. Chapter Four - Soil Biogeochemistry,

Plant Physiology, and Phytoremediation of Cadmium-Contaminated Soils. D. L. Sparks, Ed. 135–225.

[5] Wuana, R. A. and Okieimen, F. E. 2011. Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. ISRN Ecology. 2011, 1-20.

[6] Khatri, S. and Suman, S. 2018. Spatial Interpolation and Mapping of Soil Geotechnical Properties of Udham Singh Nagar District using GIS. International Journal of Engineering Research Computer Science and Engineering. 5, 2, 323-326.

[7] Chang, H. H, Qiang, T. F. and Ping, H. H. 2011. Soil particle size distribution and its relationship with soil water and salt under mulched drip irrigation in Xinjiang of China. Science China Technological Sciences. 54, 6, 1568-1574.

[8] Shete, P. P., Kayte, J. N. and Deshmukh, R. R. 2019. Determination of soil texture distribution (clay, sand, and silt) by using spectral measurement: a review. Journal of Emerging Technologies and Innovative Research. 6, 2, 625-629.

[9] West, T. O. and G. Marland. 2003. Net carbon flux from agriculture: carbon emissions, carbon sequestration, crop yield, and land-use change. Biogeochemistry, 63: 73-82.

[10] Adamu, Y. A. 2019. Relationship of soil properties to fractioanation and mobility of lead and cadmium in soil. Dutse Journal of Pure and Applied Sciences. 5, 2b, 215-222.

[11] Rühlmann,J., Korschens, M.,Graefe, J., 2006. A new approach to calculatethe particle density of soils considering properties of the soil organic matter and the mineral matrix. Geoderma 130, 272–283.

[12] Blake, G. R. 1986. Particle Density. In Methods of Soil Analysis, Part 1. Second ed. Agron. 9 Am. Soc. of Agron., Madison, WI. 377-382.

[13] GLOBE. 2014. Soil Particle Density Protocol. https://globe.gov

[14] Schjønning, P., McBride, R. A., Keller, T. and Obour, P. B. 2017. Predicting soil particle density from clay and soil organic matter contents. Geoderma. 286, 83-87.

[15] León-Moreno, C. E., Rojas-Molina, J., & Castilla-Campos, C. E. 2019. Physicochemical characteristics of cacao (Theobroma cacao L.) soils in Colombia: Are they adequate to improve productivity?. Agronomía Colombiana, 37(1), 28-38.

[16] Tarigan, B., Sinarta, E., Guchi, H., & Marbun, P. 2015. Evaluasi status bahan organik dan sifat fisik tanah (bulk density, tekstur, suhu tanah) pada lahan tanaman kopi (coffea sp.) di beberapa kecamatan kabupaten Dairi. Jurnal Agroekoteknologi Universitas Sumatera Utara, 3(1), 103124.

[17] Murtinah V, Edwin M, dan Bane O. 2016. Dampak Kebakaran Hutan terhadap Sifat Fisik dan Kimia Tanah di Taman Nasional Kutai, Kalimantan Timur. Jurnal Pertanian Terpadu. 5(2): 128-134.

[18] Chaudhari, P. R., Ahire, D. V., Ahire, V. D., Chkravarty, M. and Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of coimbatore soil. International Journal of Scientific and Research Publications. 3 , 2, 1-8.

[19] Ramasamy, J. and Ramalingam, K. 2019. Influence of soil organic matter on bulk density in Coimbatore soils. International Journal of Chemical Studies. 7, 3 3520-3523.

[20] Van Vliet, J. A., Slingerland, M., and Giller, K. E. 2015. Mineral nutrition of cacao: A review. Wageningen: Wageningen University and Research Centre. 57.

[21] Maldonado, M. F., M. J. Jasso, J. L. Palma, S. G. Salgado and V. A. Gonzalez. 2006. Dynamics of organic matter, P and K in soils of the agroforestry system “spanish cedar-banana” in Tabasco, Mexico. Rev. Fitotec., 29: 223-230.

[22] Murray-Nunez, R. M., J. I. Bojorquez-Serrano, A. Hernandez-Jimenez, M. G. Rosco-Benitez and J. D. Garcia-Paredes. 2011. Effect of organic matter on soil physical properties in an agroforestry system in the northern coastal plain of Nayarit Mexico. Biociencias, 1: 27-35.

[23] Shahid, M., Dumat, C., Khalid, S., Niazi, N. K., & Antunes, P. M. C. (2016). Cadmium Bioavailability, Uptake, Toxicity and Detoxification in Soil-Plant System. In P. de Voogt (Ed.), Reviews of Environmental Contamination and Toxicology Volume 241 (pp. 73–137).

[24] Khan, M. A., Khan, S., Khan, A. and Alam, M. 2017. Soil contamination with cadmium, consequences and remediation using organic amendments. Science of the Total Environment. 601-602, 1591-1605.

[25] Anawar, H. M., Akter, F., Solaiman, Z. M., & Strezov, V. (2015). Biochar: An Emerging Panacea for Remediation of Soil Contaminants from Mining, Industry and Sewage Wastes. Pedosphere, 25(5), 654–665.

[26] Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: A review. Chemosphere, 99, 19–23.

[27] Zamora, C. D. 2018. Cooperative Agroindustrial Cacao Alto Huallaga – Paquete Technologico para disminuir el contenido de cadmio de los granos de cacao.

[28] Pinto, T. de O., García, A. C., Guedes, J. do N., do A. Sobrinho, N. M. B., Tavares, O. C. H., & Berbara, R. L. L. 2016. Assessment of the Use of Natural Materials for the Remediation of Cadmium Soil Contamination. PLOS ONE, 11(6), 1–14.

[29] Xu, D., Zhao, Y., Sun, K., Gao, B., Wang, Z., Jin, J., Wu, F. 2014. Cadmium adsorption on plant and manure-derived biochar and biochar-amended sandy soils: Impact of bulk and surface properties. Chemosphere, 111, 320–326.

[30] Davila, M. 2007. Soil characterization identifying potential capability areas to establish agroforestry system in “Finca Ula”, caparo experimental station. Agric. Andina, 12: 41-53.

[31] Rousseau, G. X., O. Deheuvels, I. R. Arias and E. Somarriba. 2012. Indicating soil quality in cacao-based agroforestry system and old-growth forest: The potential of soil macrofauna assemblage. Ecol. Indicat., 23: 535-543.

[32] Ramtahal, G., Yen, I. C., Hamid, A., Bekele, I., Bekele, F., Maharaj, K., & Harrynanan, L. 2018. The Effect of Liming on the Availability of Cadmium in Soils and Its Uptake in Cacao (Theobroma Cacao L.) In Trinidad & Tobago. Communications in Soil Science and Plant Analysis, 0(0), 1–9.

[33] Tahar, K. and Keltoum, B. 2011. Effects of heavy metals pollution in soil and plant in the industrial area, west Algeria. Journal of the Korean Chemical Society. 55, 6, 1018-1023.

[34] Bravo, D., Diaz, S., Benavides-Erazo, J., Rengifo-Estrada, G., Braissant, O., & Leon-Moreno, C. 2018. Cadmium and cadmium-tolerant soil bacteria in cacao crops from northeastern Colombia. Journal of Applied Microbiology, 124, 1175–1194.

[35] Barraza, F., Schreck, E., Lévêque, T., Uzu, G., López, F., Ruales, J., Maurice, L. 2017. Cadmium bioaccumulation and gastric bioaccessibility in cacao: A field study in areas impacted by oil activities in Ecuador. Environmental Pollution, 229, 950–963.

[36] Gramlich, A., Tandy, S., Andres, C., Paniagua, J. C., Armengot, L., Schneider, M. and Schulin, R. 2017. Cadmium uptake by cacao trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment. 580, 677-686.

[37] Gramlich, A., Tandy, S., Gauggel, C., López, M., Perla, D., Gonzalez, V., & Schulin, R. 2018. Soil cadmium uptake by cacao in Honduras. Science of The Total Environment, 612 (September 2017), 370–378.

[38] Argüello, D., Chavez, E., Lauryssen, F., Vanderschueren, R., Smolders, E., & Montalvo, D. (2019). Soil properties and agronomic factors affecting cadmium concentrations in cacao beans : A nationwide survey in Ecuador. Science of the Total Environment, 649, 120–127.

[39] Dong, J., Mao, W. H., Zhang, G. P., Wu, F. B., & Cai, Y. (2007). Root excretion and plant tolerance to cadmium toxicity – a review. Plant Soil Environment, 2007(30571097), 193–200.

[40] Remigio, A. J. 2014. Determinación de procedimientos, interpretación de resultados de análisis y elaboración de interrelaciones de los diferentes estudios para determinar la concentración de cadmio en los granos de cacao.

[41] China Ministry of Ecology and Environment, 2018. Soil Environmental Quality: Risk Control Standard for Soil Contamination of Agricultural Land (GB 15618-2018). Beijing, China.

[42] Kumar Sharma, R., Agrawal, M., Marshall, F. 2007. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol. Environ. Saf. 66, 258-266.

[43] Chaiwonga, S., Sthiannopkao, S., Susanpaiboon, W., Chuenchoojit, S., Pupatwibul, K., Poodendaen, C. 2013. Urinary cadmium concentrations in a population downstream: from a zinc mining area in Mae Sot District, Tak Province, Thailand. Environ. Geochem. Health 35, 69-78.

[44] European Union, EU. 2002. Heavy Metals in Wastes, European Commission on Environment. http://ec.europa.eu/environment/waste/studies/pdf/heavymetals-report.pdf.

[45] Sutrisno, S., & Kuntyastuti, H. 2015. Pengelolaan cemaran kadmium pada lahan pertanian di Indonesia. Buletin Palawija, 13(1), 83-91.

[46] Chavez, E., He, Z. L., Stoffella, P. J., Mylavarapu, R. S., Li, Y. C., Moyano, B., & Baligar, V. C. 2015. Concentration of cadmium in cacao beans and its relationship with soil cadmium in southern Ecuador. Science of the Total Environment, 533, 205–214.

[47] Kabata-Pendias, A. 2010. Trace Elements in Soils and Plants, Fourth Edition. Retrieved from Khan, M. A., Khan, S., Khan, A., & Alam, M. 2017. Soil contamination with cadmium, consequences and remediation using organic amendments. Science of The Total Environment, 601–602, 1591–1605.

[48] Benavides, M. P., Gallego, S., & Tomaro, M. 2005. Cadmium Toxicity in Plants. Brazilian Journal of Plant Physiology, 17, 21–34.

[49] Fauziah, C. I., Rozita, O., Zauyah, S., Anuar, A. R., & Shamshuddin, J. 2001. Heavy metal content in soils of Peninsular Malaysia grown with cacao and in cacao tissues. Malaysian Journal of Soil Science, 5, 47–58.

[50] Beckett, S. T. 2009. Industrial Chocolate Manufacture and Use. New Jersey: Blackwell Publishing Ltd.

[51] Rieuwerts, J. S. 2007. The mobility and bioavailability of trace metals in tropical soils: A review. Chemical Speciation and Bioavailability, 19(2), 75–85.

[52] Arévalo-Gardini, E., Arévalo-Hernández, C. O., Baligar, V. C., & He, Z. L. 2017. Heavy metal accumulation in leaves and beans of cacao (Theobroma cacao L.) in major cacao growing regions in Peru. Science of The Total Environment, 605–606, 792–800.

[53] Mite, F., Carrillo, M., & Durango, W. 2010. Avances del monitoreo de presencia de cadmio en almendras de cacao, suelos y aguas en Ecuador. XII Congreso Ecuatoriano de La Ciencia Del Suelo. Santo Domingo, 17-19 de Noviembre Del 2010. Santo Domingo.

[54] Albarrcín, H. S. R., Contreras, A. E. D., & Henao, M. C. 2019. Spatial regression modeling of soils with high cadmium content in a cacao producing area of Central Colombia. Geoderma Regional, 16, e00214.