Study to Determine Level of Cadmium in Cacao Plantation Soil and Its Correlation to Soil Properties in Kulon Progo, Yogyakarta, Indonesia

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ABSTRACT

Indonesia is the third largest cacao producer and exporter in the world after Ghana and Ivory Coast. Cadmium (Cd) is one of the metal elements that is often found contained in cacao plants which usually accumulates in cacao bean. Excessive accumulation of Cadmium (Cd) can cause harmful effects on soil, plants, microorganisms, and humans. Soil properties such as texture and pH closely related to Cd elements transportation from soil to cacao bean through plant uptake. The purpose of this study was to determine the value of metal cadmium (Cd) in cacao plantation soil in Kulon Progo, Yogyakarta and its correlation with soil properties. Soil samples in Banjarharjo village were taken from 10 location of different cacao farm and then divided into two types: disturbed with 2 different lengths (0 – 10 cm and 10 - 20 cm) and undisturbed. Land conditions and farm management (tree age, treatment, other type of trees, and environment) was recorded from interview to the farmers. The soil texture (silt, clay, sand), particle density, bulk density, organic content, and soil pH ranging between silt (26,82 %), clay (22,26 %) and sand (11.96 %) until silt (39.24 %), clay (52.09 %) and sand (49.04 %); 1.85 g/cm^3 until 2.52 g/cm3; 0.66 g/cm^3 until 1.08 g/cm^3; 0.48 % until 5.76 %; and 5.85 until 7.68, respectively. The AOAC method was used to measure the Cd content with instrument using ICP-MS. Cd content in soil ranging between 0.105 mg/kg until 0.27 mg/kg with The highest concentration of Cd in cacao farm soil 0 – 10 cm were found in location 6 and cacao farm soil in 10 – 20 cm were found in locations 6 and 9. This result showed that 10 sites of cacao farms in Banjarharjo were below the critical limit of Cd in agricultural soil based on EU (3 mg kg^{-1}) and US EPA (0.43 mg kg^{-1}). Concentration Cd in soil at depth 0 – 10 cm positively strong correlated with organic matter ($r = 0.83$, $P < 0.01$). Concentration Cd in soil at depth 10 – 20 cm negatively correlated with clay percentage in soil ($r = -0.68$, $P < 0.05$).

Keywords: *Cacao, Cadmium, Soil, Kulon Progo, Contamination*

1. INTRODUCTION

Kulon Progo is one of the districts in Yogyakarta Province with an area of 58,630 ha consisting of 12 sub-districts and 88 sub districts. Total population in Kulon Progo district is 445.655 and those who work in agriculture, forestry and fishery are 5.56 % of the total working population. Land usage in Kulon Progo district consists of moor (26.56%), rice fields (17.5%), farms (11.49%), not agriculture (23.95%) and others (20.5%) [1]. From the total use of farm land, there are several types of farm commodities such as tea, clove, coconut, coffee and cacao. The use of cacao land is spread in various villages such as Temon, Wates, Panjatan, Sentolo, Pengasih, Kokap, Grimulyo, Nanggulan, Kalibawang and Samigaluh with total productivity of 1371,02 tons/year and contributing 69,78% cacao farm land in Yogyakarta province [1]. The high productivity of cacao fruit mainly came from Kokap, Kalibawang and Girimulyo villages.

Cacao (*Theobroma cacao* L.) is an important agricultural commodity for chocolate production which

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could be cultivated in tropical countries such as Indonesia. World Cacao Production by Country reported the biggest Cacao production countries are Ivory Coast (Africa), Ghana, Ecuador, Indonesia, Cameroon, Nigeria, Brazil, and Papua New Guinea [2]. Ivory Coast produced 2,01 million ton of cacao bean in 2016 to 2017 and it was recorded as the highest production. Indonesia produced 260 ton of cacao bean and it was listed in fourth position of Cacao production in the world.

Heavy metal contamination is highly avoided in agricultural products, especially in cacao products. The accumulation of heavy metal content that enters the human body can make deterioration in human health. Cadmium (Cd) is one of the metal elements that is often found contained in cacao plants which usually accumulates in cacao bean. The major sources of Cd pollution in the environment can be originated from natural and anthropogenic/human activities [3]. Geological weathering of parent materials is a natural source which controls the amount of Cd in soil. 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 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 [4][5].

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 soil and plants [4]. The application of agriculture inputs, for example phosphate fertilizers, pesticides, and bio solids or sewage sludge also lead to the accumulation of Cd in soil [6]. Other sources of Cd enrichment are from the improper use of several household products such as detergents and refined petroleum products [3]. In addition, Cd content may also be added to soil adjacent to major roads which is emitted from tires of vehicular and lubricant oils [7].

Cd can be adsorbed by plants via direct contact of their certain organs such as roots, shoots or leaves. Availability of Cd in soil is a primary indication of the amount available for plant uptake than in air through foliar uptake. Once Cd is accumulated in soil, ultimately they will retain in the roots and easily transfer to other parts of the plant, with minimal translocation to the leaves and fruits [8]. In the root, absorption of Cd occurs as inorganic complexes ($Cd_{2+}SO_4$, $CdCl_+$, and $CdCl_2$) or organic forms [9]. Subsequently, Cd is transferred through ascent of sap and can be easily transported through shoots in the form of metallo-organic complexes into vascular bundles, namely phloem and xylem [10].

Cadmium contamination in the field can correlate with the soil properties that could increase or decrease Cadmium chemical reaction, such as physical properties and chemical properties. Cadmium 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 Banjarharjo Village, Kulon Progo.

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

2. MATERIALS AND METHOD

2.1. Time and Location

This study was conducted in Banjarharjo Village, Kulon Progo Regency. Banjarharjo Village is located between 7°40'15.1098" to 7°42'15.372" South Latitude and 110°13'35.9934" to 110°16'15.1752" East Longitude. 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 February 2022 until May 2022. Banjarharjo Village was chosen as the sample location because it is one of the largest cacao-producing region in Kulon Progo 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 2).

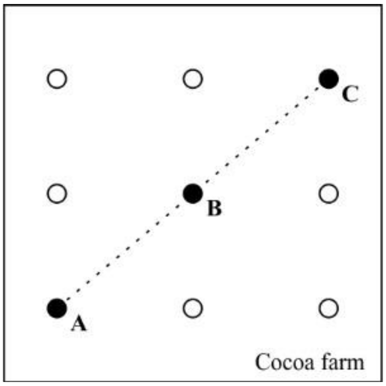

Figure 1 Illustration of soil sampling method

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 10.5 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 [11].

3. RESULTS AND DISCUSSION

3.1. Site Description

This study was conducted in Banjarharjo Village, Kalibawang District, Kulon Progo Regency. Banjarharjo Village has a total area of 12.34 km^2, with the majority of its land use is for agricultural purposes. Kalibawang district located in 200 – 400 msal with weather condition for the rainfall in 2017 is 3496.1 mm with the highest in November (622.9 mm) and the lowest in August (0 mm) [1]. Average temperature in Kalibawang district ranging between of 26,23°c – 26,5°c, solar radiation ranging between 19 – 31.63 W/m^2/month and humidity ranging between 81.84% – 85.97% [1].

Soil type in Kalibawang mainly consist of andisol and alfisol which is ideal type of soil for cacao plants to grow [12] while according to BPS Kulon Progo consist of lathosol and grumosol [1] with the soil acidity (pH) has value from 5,5 - 7 [13]. 10 samples of soil with two variety depths (0 cm - 10 cm and 10 cm – 20 cm) and cacao fruits were taken from 10 sub village, these are Padaan Kliwonan (1), Padaan Ngasem (2), Mbeku (3), Padaan Wetan (4), Padaan Kulon (5), Gerpule (6), Demangan (7), Ngrajun (8), Duwet 3 (9), and Duwet 1 (10) with 2-3 replication as shown in Figure 3.

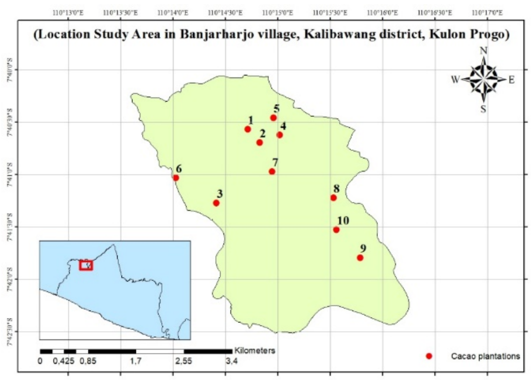

Figure 3 Soil sampling locations in Banjarharjo Village

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 shown in Table 2:

Table 2. Plant management and land condition of study area

Loc.	Plant Profile and Management			Land Conditions				
	Cocoa Variety	Age (years)	Agriculture Practices	Waste Drainage	Plant Litter	Livestock	Other Crops	Main Road
1	Forastero	5-15	✓	-	✓	✓	✓	-
2		15-25	-	-	✓	-	✓	✓
3		20-30	-	-	-	-	✓	-
4		5-25	-	-	✓	-	✓	✓
5		15-20	-	-	-	-	✓	✓
6		15-20	-	✓	✓	-	✓	✓
7		5-15	-	-	✓	-	✓	✓
8		10-25	-	✓	✓	-	✓	-
9		15-20	-	-	✓	✓	✓	✓
10		15-20	-	-	✓	✓	✓	-

✓ = exist/could be found

Table 2 shows that majority of the cacao plantation age in the study area are between 10-20 years. Among all of the sample location, only one farmer did 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	Textural Class
		(%)			
1	0-10	35.02	42.85	22.13	Clay
2		28.72	28.25	43.03	Clay loam
3		33.78	50.94	15.27	Clay
4		30.88	38.41	30.71	Clay loam
5		30.98	27.69	41.33	Clay loam
6		37.85	40.77	21.39	Clay
7		38.67	37.83	23.5	Clay loam
8		28.7	22.26	49.04	Loam
9		39.24	25.52	35.25	Loam
10		38.92	41.25	19.83	Clay

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

Location	Depth (cm)	Silt	Clay	Sand	Textural Class
		(%)			
1	10-20	36.46	51.58	11.96	Clay
2		27.94	40.75	31.31	Clay
3		29.25	48.63	22.12	Clay
4		30.06	42.83	27.11	Clay
5		26.82	35.83	37.34	Clay loam
6		34.75	29.10	36.15	Clay loam
7		37.29	40.74	21.97	Clay
8		28.99	29.91	41.1	Clay loam
9		33.76	32.65	33.59	Clay loam
10		31.59	52.09	16.33	Clay

Table 3 and Table 4 shows that percentation of silt, clay and sand that are classify the soil texture in the soil is differ in two different depths with the range of percentation between silt (26,82 %), clay (22,26 %) and sand (11.96 %) until silt (39.24 %), clay (52.09 %) and sand (49.04 %). Soil textural classes in 10 locations were represented in five type of textural classes namely clay - clay, clay - clay loam, clay loam - clay, clay loam – clay loam and loam – clay loam. 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.

Agroforestry cacao systems are typically established on silty and clay loam soils. Cacao plant is well-growth in clay loamy soil which have the composition of 20 - 45% sand and 27 – 40% clay [14]. These compositions will influence the soil's water availability, nutrients, and aeration [15]. This explained the majority of the soil locations are ideal for cacao plant growth and indicated that Banjarharjo's soil had characteristic of moderate to high water holding capacity, drains water slowly to moderate, and low nutrient leaching [16]. In addition soil texture can affect the amount Cd content residing in the soil and plant sample due to plant uptake. The cadmium concentration and mobility are influenced by the percentage of clay [17].

The spatial distribution of soil texture for each soil depths are shown in Figure 4:

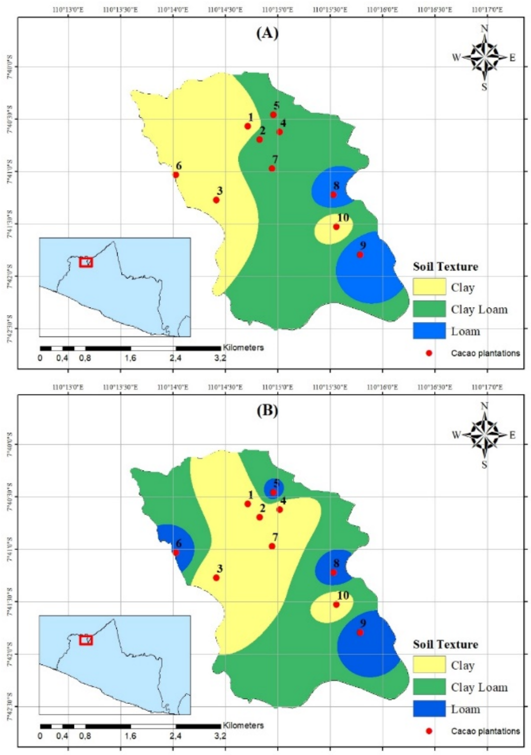

Figure 4 Spatial distribution of soil texture in 0-10 cm depth (A); and 10-20 cm depth (B) in study area

3.3.2. Soil Particle Density

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

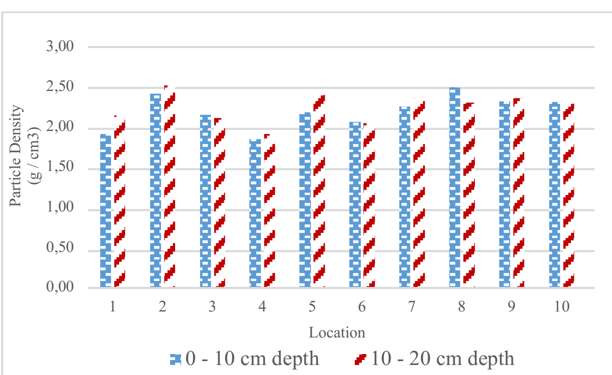

Figure 5 Soil particle density of each depth in the study area

Figure 5 shows the value of particle density of soil in 10 sites with 2 different depths ranging between 1.85 g/cm^3 until 2.52 g/cm^3 with the average value of 2.23 g/cm^3. The lowest value of particle density in 0 – 10 cm depth which is 1.85 g/cm^3 founded on location 4. The lowest value of particle density in 10 - 20 cm depth which is 1.92 g/cm^3 also founded on location 4. The highest value of particle density in 0 – 10 cm depth which is 2.5 g/cm^3 founded in location 8 while the highest value of particle density in 10 – 20 cm depth which is 2.52 g/cm^3 founded in location 2.

Particle density's most value more increase the deeper the soil in Figure 5. Upper soil tends to have lower particle density value because of the increasing content of soil organic matter [18]. Soil particle density is an important soil physical property and depends on the composition of both the mineral and the organic soil components. Value for particle density in mineral soil usually ranges between 2.4 to 2.9 g/cm^3 which normally has value of 2.65 g/cm^3 [19] while for organic soil can decrease to approximately 1.5 g/cm^3. This explained cacao farm soil in 10 location were consist of mixed mineral soil and organic soil and acceptable for cacao plant.

The spatial distribution of soil particle density for each soil depths are shown in Figure 6:

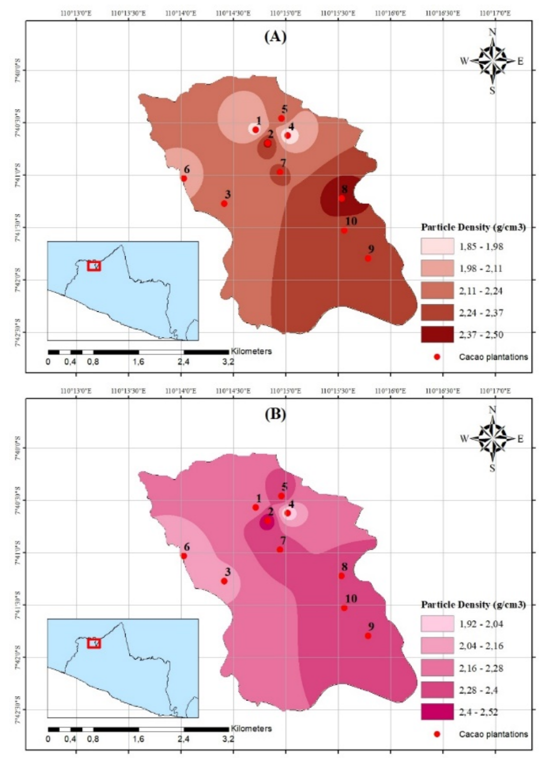

Figure 6 Spatial distribution of soil particle density in 0-10 cm depth (A); and 10-20 cm depth (B) in study area

3.3.3. Soil Bulk Density

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

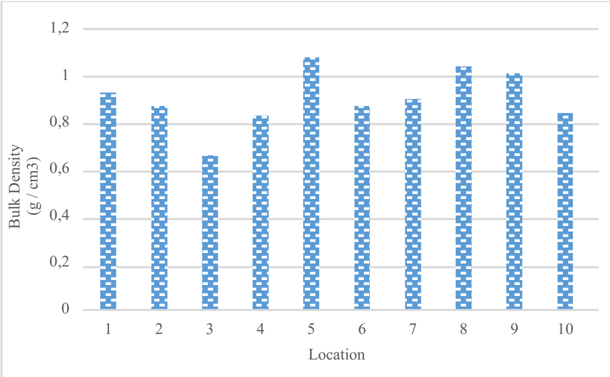

Figure 7 Soil bulk density of each depth in the study area

Figure 7 shows that the the value of bulk density of soil in 10 sites ranging between 0.66 g/cm^3 until 1.08 g/cm^3 with the average value of 0.9 g/cm^3. The lowest value of bulk density which is 0.66 g/cm^3 founded on location 3 while the highest value of bulk density which is 1.08 g/cm^3 founded in location 5.

Bulk density of soil is an important factor of soil physical property that correlated with soil compaction and other soil properties [20]. Bulk density is also can be an indicator of soil porosity and moisture content as it is dependant on soil texture and structure [21]. The higher value of bulk density, the more compact soil has become thus resulting in obstructed penetration of plant's root [22]. The ideal value of bulk density in soil is lower than 1.4 g/cm^3 so the plant can properly grow, which explained bulk density in 10 locations of Banjarharjo village ideal for cacao plant's growth.

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

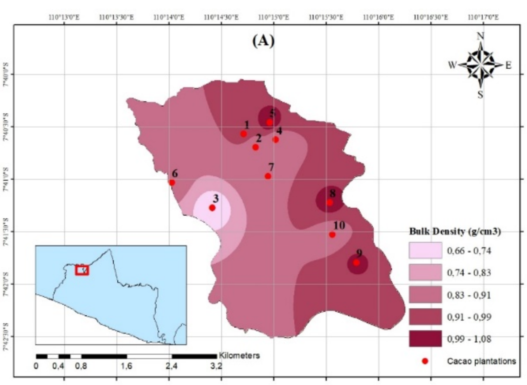

Figure 8 Spatial distribution of soil bulk density in study area

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:

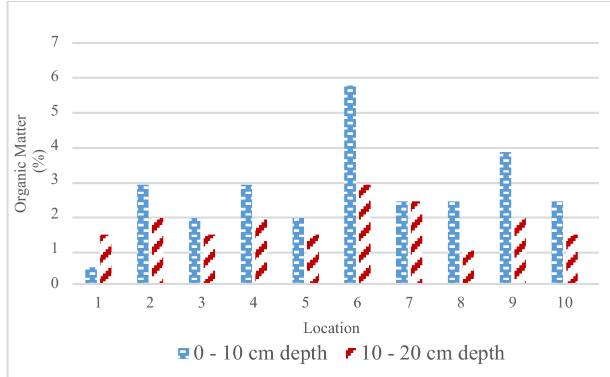

Figure 9 Soil organic matter content of each depth in the study area

Figure 9 shows that the value of organic matters of soil in 10 sites with 2 different depths ranging between 0.48 % until 5.76 % with the average value of 2.23 %. The lowest value of organic matters in 0 – 10 cm depth which is 0.48 % founded on location 1. The lowest value of organic matters in 10 - 20 cm depth which is 0.96 % founded on location 8. The highest value of organic matters in 0 – 10 cm depth which is 5.76 % founded in location 6 while the highest value of organic matters in 10 – 20 cm depth which is 2.88 % also founded in location 6. 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.

Organic matter is one of the essential factor to increase the quality of plant's growth by maintaining soil fertility and ecological functions [23]. Increasing organic matters in soil can be done by using various organic materials such as animal waste, crop residues, sewage or sludge [24]. Soil organic carbon (SOC) is one of the important factor that determined the value of soil organic matter because contained about 58% SOC [25]. General operational level of SOC in most agricultural soil under dryland agriculture are ranging between 0.7% to 3% [26]. Similar study was conducted by Loveland and Webb, they took a review under critical values of SOM for agricultural soil and they found a specific threshold value of SOC and SOM (2% for SOC and 3,4% for SOM) [27]. Below the specific value mentioned the soil were considered to be low productive capacity.

The spatial distribution of soil organic matter content for each soil depths are shown in Figure 10:

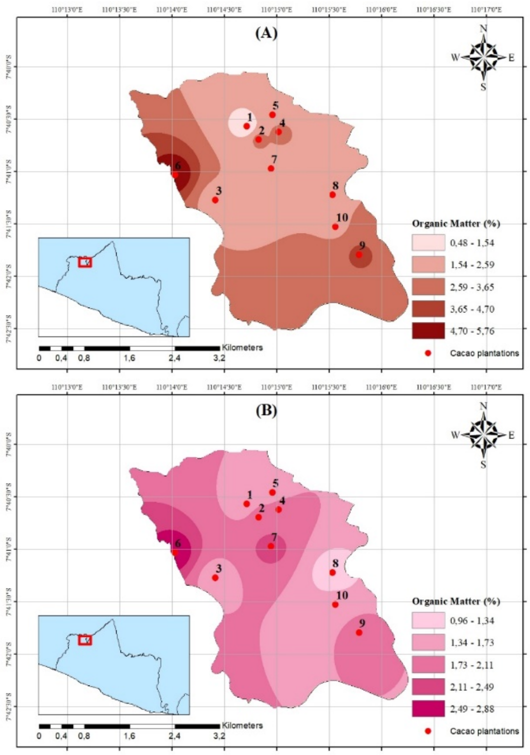

Figure 10 Spatial distribution of soil organic matter content in 0-10 cm depth (A); and 10-20 cm depth (B) in the study area

3.3.5. Soil pH

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

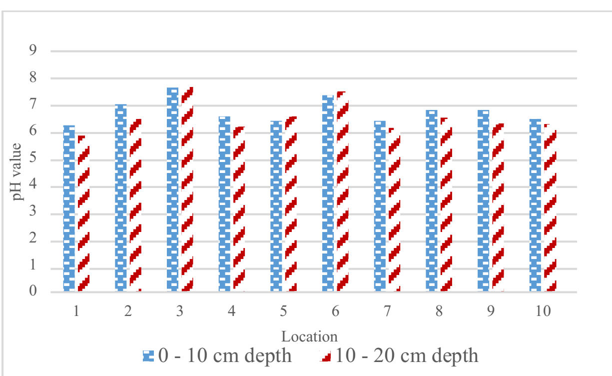

Figure 11 Soil pH of each depth in the study area

Figure 11 shows that the value of pH of soil in 10 sites with 2 different depths ranging between 5.85 until 7.68 with the average value of 6.66. The lowest value of pH in 0 – 10 cm depth which is 6.23 founded on location 1. The lowest value of pH in 10 - 20 cm depth which is 5.85 is also founded on location 1. The highest value of pH in 0 – 10 cm depth which is 7.64 founded in location 3 while the highest value of pH in 10 – 20 cm depth which is 7.68 is also founded in location 3.

Soil pH greatly affects the availability of a range of soil nutrients for plant growth, and normally for many plants to achieve optimal growth the pH value is considered between 6 and 7.5 [28]. Soil pH also has an enormous influence on soil biogeochemical processes as well described as the master soil variable that can affect all soil properties [29]. One of the processes including trace element mobility, causing soil pH to controls the solubility, mobility and bioavailability of trace elements which determine their translocation in plants. The transfer become dependent to the partition of the elements between solid and liquid soil phases, through reactions such as precipitation and dissolution.

Low soil pH tends to increase the solubility of trace elements because of high desorption and low adsorption, Cd at pH soil 5.3 has adsorption onto a sediment composite consisting of Al-, Fe-, and Si-oxides was 60% [30]. Meanwhile that 50% of Cd absorbed onto humic acids between pH 4.8 – 4.9 [30]. Similar studies were conducted and concluded that while the pH soil decreasing, the solubility of most trace elements will increase [31]. Cacao farms utilize wide variety of soil with pH value varying from 4 until 7 [32].

The spatial distribution of soil pH for each soil depths are shown in Figure 12:

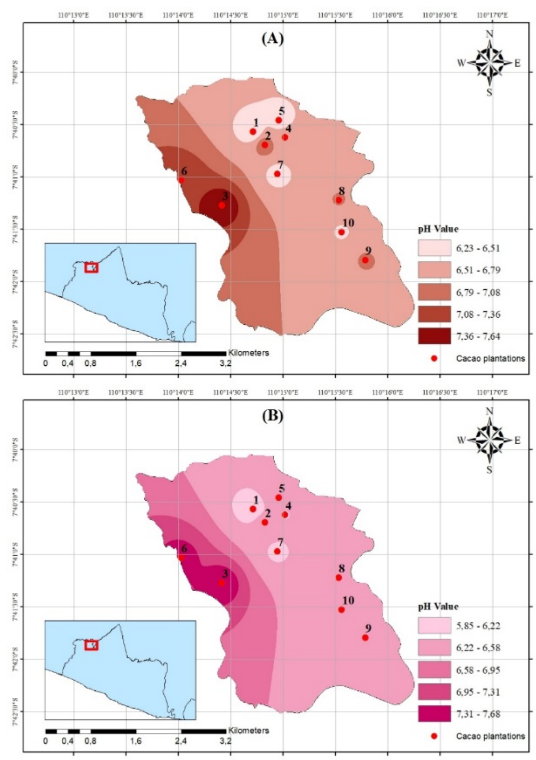

Figure 12 Spatial distribution of soil pH in 0-10 cm depth (A); and 10-20 cm depth (B) in the study area

3.4. Cadmium Content in Soil

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

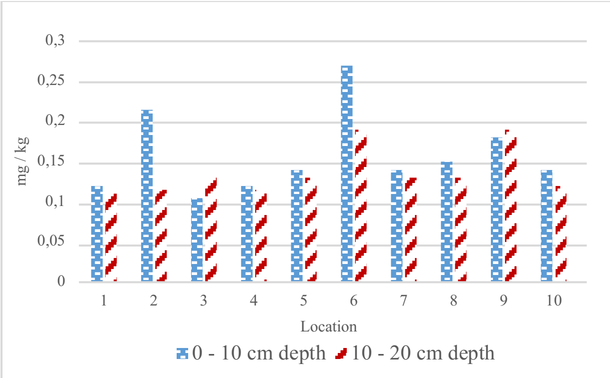

Figure 13 Soil cadmium content of each depth in the study area

Figure 13 shows that the value of cadmium content in 10 sites' soil with 2 different depths ranging between 0.105 mg/kg until 0.27 mg/kg with the average value of 0.15 mg/kg. The lowest value of cadmium content in 0 – 10 cm depth which is 0.105 mg/kg on location 3. The lowest value of cadmium content in 10 - 20 cm depth which is 0.11 mg/kg on location 1. The highest value of cadmium content in 0 – 10 cm depth which is 0.27 mg/kg in location 6 while the highest value of organic matters in 10 – 20 cm depth which is 0.19 mg/kg also in location 6 and 9. However, both of Cd content in soil at all depths in 12 locations of cacao farms in Banjarharjo village were below the maximum limit for agricultural soil established by 3.00 mg kg^{-1} [33] and 0.43 mg kg^{-1} [34].

Major contribution of Cd found in topsoil has been identified come from decomposition of leaves that fall from the plant and crop residues (containing Cd) within cultivation plot that return Cd availability content to the soil [35] and anthropogenic activities [36]. This explained most upper soil (0 -10 cm) from the farm has a higher Cd value then lower soil (10 – 20 cm) except location 3 and 9 because most of the farm let the cacao leaves decayed and become organic fertilizer, which in line with similar studies [37,38]. The higher cadmium concentration within top-soil relative to subsoil may be caused by the accumulation over the years of cadmium from leaves and husks [32,39].

In contrast at location 3 and 9 there is higher value in cadmium content in lower soil than higher soil. This could be happen because in location 3 the farm is neglected and located in the middle of the forest, thus created natural environment with no anthropogenic activites. The soil derived from igneous or metamorphic rocks are contain fewer Cd than those derived from sedimentary rocks [40]. Meanwhile in location 9 the owner of the cacao farm often clear the leaves from the cultivation plot and has a relatively low pH value than other farms. Low pH in soil can make influences Cd availability in the soil solution [41]. This can cause Cd to seep down to subsoil as in acidic soil cadmium tends to be more bioavailable as it is weakly bound to soil particles [42].

The spatial distribution of soil cadmium content for each soil depths in the study area are shown in Figure 14:

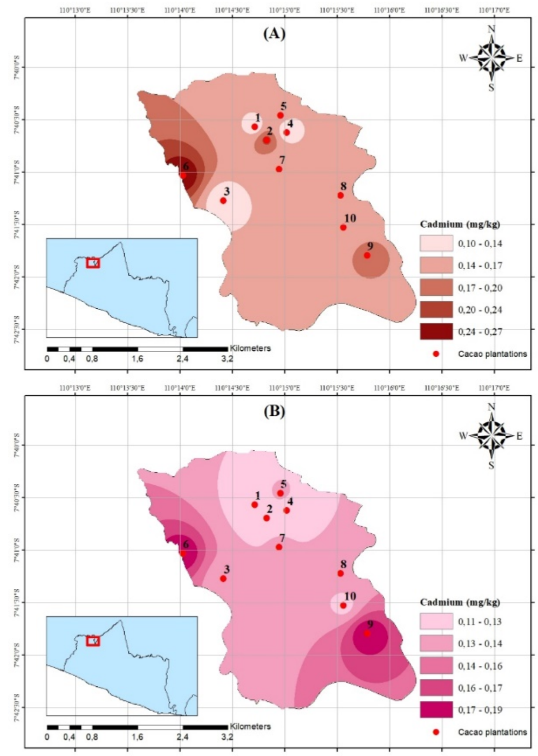

Figure 14 Spatial distribution of soil cadmium content in 0-10 cm depth (A); and 10-20 cm depth (B) in the study area

3.5. Correlation of Cadmium 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	0.17	0.135	-0.276	0.226	0.15	0.83**	0.391
Sand	0.17	1						
Silt	0.135		1					
Clay	-0.276			1				
PD	0.226				1			
BD	0.15					1		
OM	0.83**						1	
pH	0.391							1
10-20 cm								
Cd-soil	1	0.484	0.302	-0.68*	-0.61		0.547	0.425
Sand	0.484	1						
Silt	0.302		1					
Clay	-0.68*			1				
PD	-0.061				1			
BD						1		
OM	0.547						1	
pH	0.425							1

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

The correlation between soil properties and Cd content both in soil were done by using Pearson correlation analysis. The results of correlation analysis differed for each soil depth. The relationship between Cd concentrations in this study did not significantly correlate with soil densities and soil textures (except clay) in both of the soil depths, indicating these soil physical properties were not the major factors that affect the amounts of Cd in soil and uptake by plant in the area studied.

For the soil at depth 0-10 cm, Cd content in soil was strongly correlated to organic matter at 0 – 10 cm depth ($r = 0.83$, $P < 0.01$) which means the higher content of organic matter in soil at 0 – 10 cm depth leads to the increasing accumulation of Cd concentrations in cacao soil at 0 – 10 cm depth. This consistent with study who reported due to the high amount of organic matter in surface soil could enhance Cd bound to the organic particles [43]. Most soil Cd is adsorbed to organic matter thus promoting the accumulation Cd in soil [40], making these results different with similar study [39] [44]. This happen because various organic materials can be used to increase soil organic matter content, but in this research most farm used cacao leaves litter while cacao leaves accumulate a high concentration of Cd, thus piling out the Cd concentration to topsoil layer [45]. The correlation graphic can be seen in Figure 15:

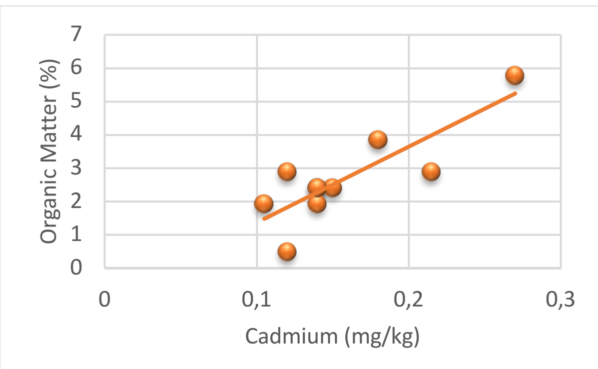

Figure 15 Correlation between cadmium and soil organic matter content in 0-10 cm soil depth

Where as at depth 10-20 cm, Cd content in soil was significantly negatively correlated with clay texture ($r = -0.68$, $P < 0.05$) which means high clay percentage in soil texture in soil of the areas studied leads to decrease of the concentration Cd in soil at 10 – 20 cm. Clay content, have been reported to control the presence of Cd in soil and Cd uptake by plants [46]. Clay contents may play a crucial role for retaining the Cd and restricting Cd movement in soil thereby reducing the absorption of Cd into plant tissues [47]. Clay particles can bind organic matter thus protecting it from being decomposed and keep the Cd content inside [23].

Contrary to these results, while farms with high percentage of clay tend to have a lower value of Cd content. Inconsistent results in correlation of cadmium content and clay percentage were also found in similar studies [38] [39], so further research is needed to ensure the correlation between cadmium and clay content in soil. The correlation graphic can be seen in Figure 16:

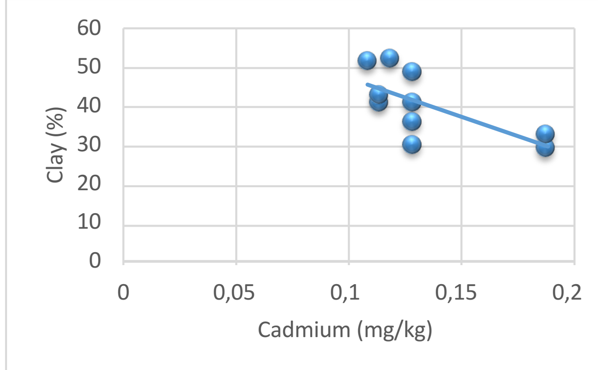

Figure 16 Correlation between cadmium and clay content in 10-20 cm soil depth

4. CONCLUSION

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

1. Soil properties that has been analyzed from 10 locations of cacao farm in Banjarharjo village were all an adequate environment for cacao plants to grow. Soil texture (silt, clay and sand) ranging from silt (26,82 %), clay (22,26 %) and sand (11.96 %) until silt (39.24 %), clay (52.09 %) and sand (49.04 %). Particle density ranging between 1.85 g/cm^3 until 2.52 g/cm^3 with the average value of 2.23 g/cm^3. Bulk density ranging between 0.66 g/cm^3 until 1.08 g/cm^3 with the average value of 0.9 g/cm^3. Organic matter ranging between 0.48 % until 5.76 % with the average value of 2.23 %. Soil pH ranging between 5.85 until 7.68 with the average value of 6.66.

2. Cadmium (Cd) contamination has been detected in the soil (0-10 cm and 10-20 cm deep) under cacao cultivations in the study areas in Banjarharjo village though at low to concentration. In the areas studied, Cd concentrations in soil ranging between 0.105 mg/kg until 0.27 mg/kg with an average value of 0.15 mg/kg. The highest concentrations of Cd in cacao soil 0 – 10 cm were found in location 6 and cacao soil in 10 – 20 cm were found in locations 6 and 9. The concentrations of Cd in all soil of study areas were below the maximum limit of Cd contents in agricultural soil, either established by EU (3.00 mg kg-1) and US EPA (0.43 mg kg-1), indicated no Cd contamination occurred at soil depths of 0-10 cm and 10-20 cm.

3. Coefficient correlation (r) between Cd in this study did not significantly correlate with soil densities and soil textures (except clay) in both of the soil depths as well indicated these soil physical properties were not the major factors that affect the amounts of Cd in soil and uptake by plant in the area studied. Nevertheless, Cd concentrations in the soil were significantly correlated with several soil properties. In this study, Cd concentration in soil 0 – 10 cm was strongly correlated with organic matter at soil depth of 0 - 10 cm ($r = 0.83$,

P < 0.01) and Cd content in 10 – 20 cm depth negatively correlated with clay percentage (r = -0.68, P < 0.05). Therefore, these results indicated that Cd concentration in soil (0 – 10 cm depth) affected by organic matter 0 – 10 cm depth meanwhile in soil (10-20 cm depth) was only affected by clay percentage.

AUTHORS' CONTRIBUTIONS

1. Ignatius Jovantheo: Collected the data, performed the analysis, wrote the paper.
2. Ngadisih: Conceived and designed the analysis, supervisor
3. Chandra Setyawan: Conceived and designed the analysis, supervisor
4. Katharina Keiblinger: Conceived and designed the analysis, supervisor

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