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Physico-Chemical Characteristics of Soils under Cacao Production System in Davao de Oro, Philippines

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Abstract

The study was conducted to understand the physico-chemical characteristics of the soils under cacao production system in Davao de Oro, Philippines. Eight (8) cacao farms were selected for detailed field characterization and sampling of soils for various nutrient analyses. Fertility status of each selected farm was determined by comparing the fertility properties of each soil with the critical nutrient level requirement for cacao. Results showed that most of the soils have a dark brown soil color in the upper horizons, and dark, yellowish-brown in the lower horizons. They range from moderately deep to very deep soil profile (19 to 150 cm), with very friable to extremely firm when moist, slightly sticky to very sticky, and slightly plastic to very plastic when soil consistence is wet. Lower elevations had shallow solum with high water table, resulting in the development of mottles and redoximorphic properties. The amount of clay ranged from 9 to 37%, with 18 to 40% for silt, and 30 to 68% for sand. Most of the cacao farms were intercropped with coconut, durian, lanzones, rubber, and banana. Most of the soils are moderate to slightly acidic, with pH values < 6.5 and CEC ranging from 10 to 34 meq/100g. Moreover, most of the areas have low organic matter (1.66%) except for the areas which continually applied organic matter during fertilization (4.60%). The amount of nitrogen (N) is optimum; however, phosphorus (P) was generally deficient in the soils of most cacao farms surveyed, while amount of potassium (K) ranges from 41.30 to 375.60 mg/kg.

Keywords: cation exchange capacity, soil properties, nutrient status, soil profile

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Cacao (*Theobroma cacao L.*) is grown in the tropics in a band between 10 to 20 degrees north and south of the equator, sometimes called the “Cocoa Belt”. It grows most notably in Central and South America, West Africa and Southeast Asia, specifically Malaysia, Indonesia, and the Philippines.

The global demand for cacao is estimated to reach between 4.7 million to 5 million metric tons by 2020, but a global cacao shortage is also predicted at 1 million MT the same year, as reported by the Department of Agriculture (BPI, 2017). In the Philippines, local consumption is at 50,000 MT every year, yet local supply is only around 10,000 MT. To avoid this impending deficit, the Philippines committed to produce 100,000 MT of fermented beans for export and domestic markets through a projected 40% annual increase in production by 2020 (DTI, 2018). However, this challenging commitment of the cacao industry will become more challenging given various constraints.

Based on the study of Mensah et al. (2013), the main constraints on the establishment and rehabilitation of cacao farms are poor soil nutrients, scarcity of early-bearing and high-yield cacao seeds and seedlings, inappropriate watering application rate at the nursery period, and poor agro-chemical application technology. There is a strong cycling of nutrients within cacao systems, and the amounts of nutrients removed through harvest are relatively small. Yet in the long term, cacao production has led to the depletion of soil nutrients. Although the soils on which cacao were planted used to be fertile, many of them are no longer able to provide the nutrients required to obtain good yield. However, there is a large variability in yield and fertilizer response, and in some cases, fertilizers show little effect. The effects of fertilizers depend on the cacao tree requirements and current nutrient availability from the soil. Most cacao researchers agree that the largest cacao yields can be obtained in systems with little shade and high fertilizer rates under good management, but that yield shows a sharp decline after 10 years of full production (van Vliet et al., 2015).

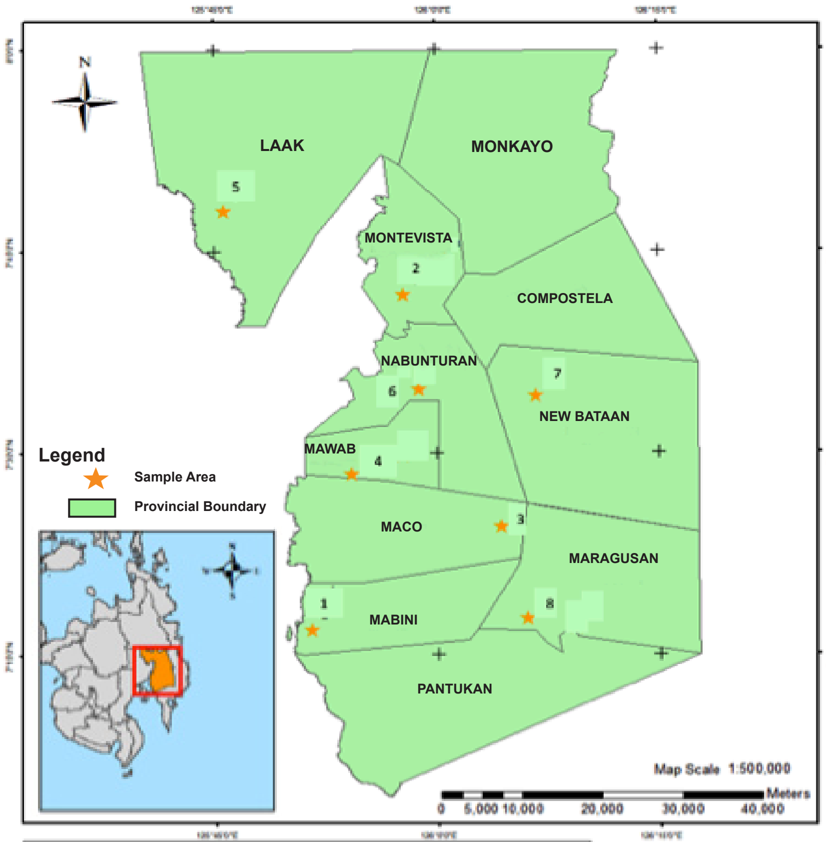
In modern cacao cultivation, the aim is to maximize early growth, obtain high early yields, and sustain peak yields subsequently. To achieve this, it is necessary to have a good understanding of the factors affecting cacao growth and yield and to apply the necessary management practices on time required by the cacao plant. An essential ingredient in most cacao growing situations is the right type and amount of fertilizer input, but most of the areas planted with cacao have varying types of soil, and must be managed differently depending on their fertility. Therefore, it is important to assess and understand the different soil properties and nutrient status of productive cacao areas.

This study aims to investigate the current soil properties and nutrient status of cacao production area in Davao de Oro to obtain baseline data as basis for management. Specifically, it aims to determine the physico-chemical characteristics of the soils under cacao production system, and evaluate nutrient status and corresponding management of the soils in cacao production systems in Davao de Oro, Philippines.

Materials and Methods

Site sampling selection and duration of the study

Eight (8) different locations of cacao production area across Davao de Oro were selected through the aide of Municipal Agriculturist Offices to serve as sampling sites (Figure 1). The field study was conducted in selected productive cacao farms across Davao de Oro from January to March 2019, with physical and chemical analyses of the soil samples conducted in April 2019.



Site 1 Pindasan, Mabini N 07°28'122 E 125°85'940 13m asl	**Site 5** Emilda, Laak N 7°48'05.134" E 125°45'44.038" 163m asl
Site 2 Lebanon, Montevista N 7°41'45.945" E 125°57'48.852" 259m asl	**Site 6** Sta. Maria, Nabunturan N 7°34'45.425" E 125°58'51.050" 78 m asl
Site 3 New Leyte, Maco N 7'24'34.107" E 126'04'23.459" 919m asl	**Site 7** Cogonon, New Bataan N 7°34'16.861" E 126°06'45.687" 149m asl
Site 4 Sawangan, Mawab N7°28'30.568" E 125°54'16.197" 189 m asl	**Site 8** Bagong Silang, Maragusan N 7°17'43.291" E 126°06'06.632" 712m asl

Figure 1. Map of Davao de Oro, Philippines showing the location of the sampling sites

Profile description and soil sample collection

Soil profile characterization was done following the standard procedure of FAO (2006). A pit with a dimension of 1 m x 1 m with a depth of at least 1 m was dug manually in each site to examine the physico-chemical characteristics. Sampling was done in each site by collecting 1 kg of composite soil sample from 30 subsamples at a 30 cm depth.

Soil sample preparation

Soil samples were air-dried, pulverized using a wooden mallet, and sieved in a 2-mm wire mesh to get the fine earth for the determination of the soils' physical and chemical properties. The samples were then brought to an analytical laboratory for processing and analyses of soil properties, such as particle size distribution, soil consistence, soil pH, organic matter, cation exchange capacity, total nitrogen, available phosphorus, and exchangeable K.

Analysis and interpretation of data

Soil properties were evaluated to understand the genesis, fertility, and constraints of the soils in the study. The soils' characteristics in the different cacao production systems were compared, and the relationship between properties was evaluated through descriptive assessment. The soil constraints to crop production were determined by comparing the soil properties with the physico-chemical requirements of cacao (Table 1).

Table 1. Physical and chemical requirements of cacao plant.

SOIL PROPERTIES	CACAO PLANT REQUIREMENT	SOURCE
Texture	50% sand; 30-40% clay; 10-20% silt	PCARRD (1989), BPI (2015)
Consistence	fr, np; ns	FAO (1968)
Soil Deep	>100cm	Njukeng & Baligar (2016), Ajiboye et al. (2015)
Drainage	Well-drained	PCA (no year), Ajiboye *et al.* (2015)
CEC (me/100g)	12	Njukeng & Baligar (2016) PCARRD (1989)
pH	5.0-6.5	PCARRD (1989), BPI (2015)
OM (%)	>3.5	Njukeng & Baligar (2016)
Total N (%)	>0.09	Njukeng & Baligar (2016), Ritung et al. (2007)
Available P (ppm)	10	Ritung et al. (2007)
Exch K (mg/kg)	117.3	Ritung et al. (2007)

fr-friable; np-non-plastic; ns-non-sticky

Results

Characteristics of sampling sites and their soil morpho-physical properties

The study selected eight (8) sampling sites across Davao de Oro with unique characteristics (Table 2) which were surveyed and sampled. These areas are considered the best cacao orchards in the province and received recognition in local and national competitions.

Site 1 has a plain landform with nearly level gradient in Pindasan, Mabini, developed from alluvial soil with an elevation of 13 m asl. It is characterized as having a lithological discontinuity, a result of different series of depositions through flooding. It has a shallow water table that caused the development of redoximorphic properties below 75 cm. Most of the vegetation was cacao intercropped under coconut trees.

Sites 2, 3, and 4 were located in the middle slopes of high-gradient mountains in Lebanon, Montevista, New Leyte, Maco, and Sawangan, Mawab, with elevations of 259 m, 919 m, and 189 m asl respectively. Site 2's soil possessed high clay content, while Site 3's soil was shallow, well-drained and developed with about 43 cm lying in unsorted sand, and Site 4's soil developed from basaltic-andesitic volcanic parent material. The primary vegetation for these sites is cacao intercropped with other fruit trees, such as coconut, rubber, lanzones, and durian.

Sites 5 and 8 are located in the middle slopes of medium-gradient mountains in Imelda, Laak and Bagong Silang, Maragusan with elevations of 163 m and 712 m asl, respectively. Site 5's soil possesses a strongly sloping gradient and is rich in clay that developed from basaltic-andesitic volcanic parent material, while Site 8's soil is well drained, with only a 19 cm depth of developed soil underlying in similar parent material as that of Site 5. Both areas are primarily planted with cacao; but while Site 5 is intercropped with a small number of coconuts, rubber, and bananas, Site 8 is intercropped with bananas and corn, the latter being the case after fungus-infested plants were eradicated.

Site 6 is in the valley floor of a nearly level area in Sta. Maria, Nabunturan with an elevation of 78 m asl. The site developed from alluvial soil through flooding and is characterized by its lithological discontinuity. The area was widely planted with cacao intercropped between coconuts. The soil developed in this area is more than 100 cm deep; it generally has a dark, yellowish-brown color with dusty red in the lowest horizon.

Site 7 is in the toeslope of a very gently sloping area in Cogonon, New Bataan with an elevation of 149 m asl. The site is characterized by well-drained condition and shallow A horizon (10 cm) overlying a coarse textured alluvial deposit. Most vegetation of the area is cacao, intercropped with coconut, and a few hills of banana.

The elevation of surveyed areas ranges between 13 m and 919 m asl, implying that cacao orchards in Davao de Oro can be established within this range of elevation. The increasing elevation is associated with a prominent superb fruiting performance of cacao. Most of the cacao trees were intercropped between coconut and fruit trees, while some orchards were planted simultaneously with other tree crops like rubber and durian, with varying planting distances ranging from 2.5m x 2.5m or 3m x 3m to 5m x 5m. The shade requirement of cacao is a controversial issue, but well-maintained unshaded cacao with a closed canopy can give high yields over a long period (Beer et al.,1998; de Almeida and Valle, 2007).

Table 2. Morphological characteristics of soils under cacao production system in Davao de Oro.

Characteristics						
	Site 1		Site 2		Site 3	
Location	Pindasan, Mabini		Lebanon, Montevista		New Leyte, Maco	
Soil Horizon	Ap - 0-30		Ap – 0-25		Ap – 0-28	
	BC - 30-50		BA_1 – 25-55		AB – 28-43	
	C - 50-72		BA_2 – 55-86		CB – 43-84	
	B - 72-110		Bw – 86-127		C – 84-110	
			CB – 127-150			
Soil Color (Munsell Color Chart)	7.5YR 2.5/2 (very dark brown)		10YR 3/6 (dark yellowish brown)		10YR 3/3 (dark brown)	
	2.5Y 4/3 (grayish dark brown)		10YR 4/6 (dark yellowish brown)		10YR 4/6 (dark yellowish brown)	
	2.5Y 4/3 (olive brown)		10YR 4/6 (dark yellowish brown)		10YR 5/8 (yellowish brown)	
	5Y 4/1 (dark gray)		10YR 4/6 (dark yellowish brown)		10YR 7/4 (very pale brown)	
			10YR 3/6 (dark yellowish brown)			
Soil Texture at 30 cm depth	Clay loam 30% Clay, 40% silt, 30% sand		Clay loam 36% Clay, 30% silt, 34% sand		Loam 9% Clay, 39% silt, 52% sand	
Soil Texture	SL (clay rich)		SiC		SCL	
	VFS		SCL		SL	
	FS		SCL		FS	
	C		SL (clay rich)		L	
			SL (clay poor)			
Soil Structure	m/f-c/sbk		s/vf-vc/sbk		m/f-c/sbk	
	w-m/m-c/sbk		s/f-c/sbk		m/vf-m/sbk	
	w/f-c/sbk		s/f-c/sbk		w/vf-m/sbk	
	m/m-c/sbk		s/f-c/sbk		sg	
			m/f-m/sbk			
Soil Consistence (moist & wet)	fr	sst-st & spl-pl	fi	st & pl	fr	sst & spl
	fr	sst & spl	fi	st & pl	vfr	Sst & npl
	vfr	nst &npl	fi	st & pl	vfr	nst & npl
	fr	s & p	fi	sst-st & spl-pl	Unsortedsand	nst & npl
			fi	sst & spl		

A. Soil Texture

LS – loamy sand
SL – sandy loam
SCL – sandy clay loam
S – sand
Si – silt
C - clay
VFS – very fine sand
FS – fine sand
CS - coarse sand
SiC – silty clay

B. Soil Structure

B.1. Grade
w - weak
w-m - weak to moderate
m - moderate
m-s – moderate to strong
s - strong

B.2. Size
f - fine
f-m – fine to medium
f-c – fine to coarse
f-vc – fine to very coarse
vf-m – very fine to medium
m - medium
c- coarse
vc – very coarse

B.3. Type
sg – single grain
abk – angular blocky
sbk - subangular blocky

Site 4	Site 5	Site 6	Site 7	Site 8
Sawangan, Mawab	Emilda, Laak	Sta. Maria, Nabunturan	Cogonon, New Bataan	Bagong Silang, Maragusan
Ap – 0-14	Ap – 0-12	Ap – 0-19	Ap – 0-10	AC – 0-19
B – 14-61	Bw – 12-31	CB_1 – 19-45	C_1 – 10-19	C – 19-120
BC – 61-74	BC – 31-57	C_1 – 45-62	CB – 19-41	
C – 74-100	CB – 57-84	CB_2 – 62-78	C_2 – 41-74	
	C – 84-110	C_2 – 78-110	C_3 – 74-110	
10YR 3/3 (dark brown)	10YR 3/6 (dark yellowish brown)	10YR 3/6 (dark yellowish brown)	10YR 3/4 (dark yellowish brown)	10YR 2/2 (very dark brown)
10YR 3/4 (dark yellowish brown)	10YR 4/6 (dark yellowish brown)	10YR 5/6 (yellowish brown)	2.5Y 4/3 (olive brown)	
10YR 4/6 (dark yellowish brown)	10YR 4/6 (dark yellowish brown)	10YR 3/6 (dark yellowish brown)	10YR 3/4 (dark yellowish brown)	
Saprolite	10YR 5/4 (yellowish brown)	10YR 5/6 (yellowish brown)	7.5YR 3/4 (dark brown)	
	5YR 4/6 (yellowish red)	10R3/4 (dusty red)	10YR 3/6 (dark yellowish brown)	
Clay loam 37% Clay, 29% silt, 34% sand	Clay loam 38% Clay, 27% silt, 34% sand	Sandy Clay loam 24% Clay, 23% silt, 53% sand	Sandy loam 9% Clay, 27% silt, 64% sand	Sandy loam 14% Clay, 18% silt, 68% sand
L	C	LS	LS (clay poor)	SL
SiC	SiC	VFS	VFS	
SC	SC	S	Si	
	SCL	SiL	VFS	
	Saprolite	S	S	
m-s/f-c/sbk	m-s/f-c/sbk	m/f-c/sbk	m/f-m/sbk	sg
s/f-c/sbk	m-s/f-c/sbk	vw/f-vf/sbk	w/f-vf/sbk	
s/f-c/sbk	m-s/f-c/sbk	sg	m/f-m/sbk	
	m-s/f-c/sbk	m/f-vf/abk	w/vf-f/sbk	
		sg	sg	

efi	st & vpl	fi	st-vst & pl-vpl	fi	sst &spl	fi	sst & spl	l	nst & npl
efi	st & vpl	fi	st-vst & pl-vpl	vfr	nst & npl	l	nst & npl		
efi	st & vpl	fi	st & pl	l	nst & npl	fr	sst & spl		
		fi-vfi	st & pl	fr	sst & spl	l	nst & npl		
				l	nst & npl	l	nst & npl		

C. Soil Consistency

C.1. Moist
vfr - very friable
fr - friable
fi- firm
vfi - very firm
efi - extremely firm

C.2. Wet (Stickiness and Plasticity)
nst - non-sticky
st - sticky
sst - slightly sticky
vst - very sticky

npl - non-plastic
pl - plastic
spl - slightly plastic
vpl - very plastic

In areas where forest environment was wiped out due to progressive deforestation, over-exposure to sun and wind along with drought, pests, and diseases may cause an early degeneration and devastation of productive cacao orchards (Wessel, 1971). This can be a challenging issue for cacao orchards in Davao de Oro, particularly in areas situated in medium to high elevations. Moreover, growing cacao in an agroforestry system, where most of the sampled orchards employed this farming system generates an intensive, productive use of the land and maintaining and improving the properties of tropical soils, which play an important role in improving cocoa production and the fertility of degraded tropical soils (Gardini et al., 2017).

In recent development of research in cacao, there is a strong growing context that yield is greatly affected by physical conditions rather than the nutrient content in the soil. Among many climatic and edaphic crop production constraints, substantial reduction in the production capacity of rainfed areas could be attributed to soils' physical constraints, like surface crusting and hardening, subsurface hard pan and compactness, high and slow permeability, extremes of consistence, soil water-related constraints, and wind and water erosion (Indoria et al. 2016). Thus, knowledge on the physical properties of soil like regolith depth, soil color, texture, structure, consistence, redoximorphic properties, and presence of rock fragments are essential in improving soil characteristics and achieving optimum cacao production.

The relief or elevation in which the soil profile is situated has no direct effect on the development of soil horizon. However, slope position has a relation to the thickness of the soil developed. In general, soils in valley floors deposited from alluvial soils tend to have discontinuous horizonation and have deeper solum development. Upper horizon soil color varies from very dark brown (Sites 1 and 8), dark brown (Sites 3 and 4), and dark, yellowish brown (Sites 2, 5, 6 and 7). As recorded, Site 8 has a very dark brown color with 4.87% organic matter. The dark colors are the result of having a high amount of organic matter derived from accumulation and decomposition in the topsoil (Schaetzl and Anderson, 2005). Some soils were poorly drained and most profiles located in sloping areas have less than 100m of soil depth.

At 30 cm deep, four (4) out of eight (8) cacao soils surveyed had clay loam type of soil while the other orchards had a higher amount of sand ranging from 52% to 68% and clay content of only 9% to 14% characterized as sandy loam (refer back to Table 2). The orchards having this soil texture had a higher volume of production compared to the other farms surveyed, contradicting the report of PCARRD (1989) that ideal soil for cacao orchard contains 30% to 40% clay. These farms were located in New Leyte (Maco) with an elevation of 919 m asl, Bagong Silang which has an elevation of 712 m asl, and Cogonon (New

Bataan) with an elevation of 149 m asl. This also further contradicts the claim of available literature that cacao has a wide range of elevation suitability with an optimum elevation starting with about 300 m asl, since the current study reveals that it can go beyond this stipulated elevation in maintaining good production.

Soil structure is described in terms of grade, size, and aggregate types. Common in soils with Ap (plowed) horizon have weak to moderate structures because of the influence of human activity, except for soils in Sites 4 and 5, which had strong structures. Orchards having strong upper horizon structures typically also have strong lower horizon structures. Aggregate size weakly correlates to structure grade. Surveyed soils varied in their aggregates' sizes from very fine to very coarse, measuring from less than 5 mm to greater than 50 mm. The discontinuous horizonation of soils in Sites 1 and 6 having a clayey portion in the middle horizon is the major factor of having poorly drained soil, a result of seasonal flooding. Most aggregate types were sub-angular and blocky.

Soil consistence in all orchards varies from very friable to extremely friable when moist. In wet conditions, they vary from non-sticky to very sticky and non-plastic to very plastic. In moist conditions, soils in Site 2 were firm, which means that soil material crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable. Soils in Site 4 have an extremely firm consistence, in which soil material crushes only under very strong pressure. Soils in these cacao orchards also have very plastic and very sticky lower horizons.

This only implies that soil firmness when in moist condition is dictated by its plasticity and the amount of clay present, while soils in remaining orchards were at a very friable to friable condition. The soil in Site 5 was sticky and plastic, while alluvial soils of Sites 1, 6, and 7 had slightly sticky and slightly plastic soils in upper horizon, with non-sticky and non-plastic soils in the lower horizons when wet.

Generally, the prime reason for having no mottles in their soil profile was because cacao orchards were established in sloping or medium- to highly-elevated areas. This means that the soils were well-drained and not subjected to alternate wetting (reducing) and drying (oxidizing) conditions, except for the soils in Sites 1 and 6. Site 1 having an elevation of 13 m asl had a presence of mottles from a 30-72 cm depth implicating poorly drained conditions that lead to alternate wetting and drying. At 72 cm downward, redoximorphic features are observed with dark grey color when wet. This means that permanent wetting occurs in this particular horizon. On the other hand, soils in Site 6 have few mottles in second horizon because it overlies in a poorly drained soil deposited through flooding. Development of roots was influenced by the firmness and depth of true soils developed. Root systems can extend up to 130 to 150 cm, which can be noticed in the soil of Site 2. This is congruent with the report of Wessel (1971) that cacao trees usually form a thick taproot up to a depth of 1.5m or more. Cacao roots tend to root deeper in soils with a sandy topsoil than with a clayey topsoil, as sandy soils dry out to a greater depth during dry months. However, in the absence of a dry season, roots are similar in both sandy and clayey soils (Wessel, 1971). The excessive quantities of stones and gravel in the soil of Site 8 impede root penetration and poor development of cacao roots, especially the taproot.

Few rock fragments were present in the topsoil of Sites 5, 7, and 8, but for Site 8, the upper horizon at 19 cm deep was composed of medium and coarse gravel. Its lower horizon was primarily composed of sub-rounded medium and coarse gravel, making for more pore spaces. The soils deposited in various time periods made for a clear boundary of the soil profile in Sites 1, 6, and 7.

Nutrient status of soil under cacao production system

The selected cacao orchards faced serious crop production and management issues such as soil fertility, particularly nutrient availability. There is no simple solution to these problems plaguing the cacao industry in Davao de Oro in particular and Davao region in general. However, it can be addressed by understanding the soil nutrient status, which is one of the means in solving the many soil fertility problems in cacao orchards.

In Site 1, OM and P were the major nutrient components identified as limiting factors, with a minor deficiency of K. The adequate clay content in the orchard is the cause of a higher presence of CEC that can hold exchangeable bases (Table 4). The minor deficiency of K was attributed only to the limited supplementation of K-containing fertilizers.

In Site 2, OM and P were deficient. The high clay content of the area led to high levels of CEC (Table 3), which meant the exchangeable bases were also high. Adding P-containing fertilizer is essential to effectively balance the nutrient status of the orchard.

In Site 3, most elements were deficient, except for N and CEC (Table 4). The adequate levels of N and CEC in the orchard are mainly attributed to the higher amount of OM. The OM content in the area is the product of the regular application of organic fertilizers. The 9% clay content in the area was low, meaning exchangeable bases and other nutrients will be leached if OM is not regularly incorporated. Adding most of the crucial elements is necessary for having high production.

The high clay content of Site 4 was responsible for the level of CEC despite the low content of OM (Table 4), meaning exchangeable bases were sufficiently present in the orchard. Meanwhile, P was the element observed to be of lower amount in the area. This was attributed to the low supplementation of these elements. Applying OM and deficient elements were still recommended to ensure a well-balanced fertilization.

The same with the other areas, the high level of CEC in Site 5 was mainly attributed to the high clay content. Due to the high clay level, the exchangeable bases were not affected despite the low amount of OM. OM and P were the only elements deficit in this orchard, while pH was observed to be at critical levels (Table 4). This suggests that the application of liming materials in this site can aid in balancing pH levels to complement the available nutrients.

In Site 6, OM, P and K were identified to have insufficient amounts in the orchard. The hardpan in the mid portion of the profile (refer back to Table 2) meant that some exchangeable bases did not leach due to poor drainage, despite having only an average amount of clay and a low amount of OM that will hold these nutrients. Deep plowing and the establishment of drainage canals in the area are important to increase the water infiltration rate and reduce the surface run-off of certain nutrients. The orchard's poor drainage gave rise to a significant amount of Fe accumulated in the area. This only indicates that the site has regularly endured from alternate wetting and drying.

The low clay content and OM in Site 7 means a lower level of CEC, with the low amount of OM complemented by the low amount of N (Table 3). Due to the low clay content that can hold nutrients, the application of organic matter is highly recommended to increase the capacity of holding cations.

Site 8 has very low content of clay, though the high level of CEC was compensated by the high amount of OM (Table 3). In addition, the N supply was doubled from its optimum requirement, and exchangeable bases are sufficiently supplied in the area.

Table 3. Soil nutrient status of selected cacao orchards in Davao de Oro Province.

CHEMICAL PROPERTIES	1	2	3	4	5	6	7	8
pH (H20)	6.42	5.85	5.73	6.10	5.05	5.86	5.89	6.08
OM (%)	1.92	2.06	4.32	1.65	1.85	1.72	0.82	4.87
CEC (me/100g)	25.61	25.21	14.61	34.02	33.42	15.21	10.81	25.21
Total N (%)	0.13	0.13	0.23	0.12	0.13	0.12	0.05	0.26
Exch K (mg/kg)	112.30	261.40	101.80	375.60	178.80	57.30	41.30	175.10
Avail P (mg/kg)	4.58	2.20	5.52	6.52	1.71	3.38	12.83	15.52

Legend:

1	2	3	4
Pindasan, Mabini	Lebanon, Montevista	New Leyte, Maco	Sawangan, Mawab
5	**6**	**7**	**8**
Imelda, Laak	Sta. Maria, Nabunturan	Cogonon, New Bataan	Bagong Silang, Maragusan

Table 4. Summary of the soil fertility status of the selected cacao orchards in Davao de Oro.

SOIL PROPERTIES	SOURCE	THRESHOLD SOIL PROFILE VALUE	SOIL PROFILE							
			1	2	3	4	5	6	7	8
Texture	BPI (2015)	50% sand; 30-40% clay; 10-20%silt	-	-	-	-	-	-	-	-
Consistence	FAO (1968)	fr, np; ns	+	-	+	-	-	+	+	+
Depth	Njukeng & Baligar (2016), Ajiboye *et al.,* (2015)	>100cm	+	+	-	-	-	+	+	-
Drainage	PCA (no year), Ajiboye Ajiboye *et al*., (2015)	Well-drained	-	-	+	-	-	-	+	+
CEC (me/100g)	Njukeng & Baligar (2016)	12	+	+	+	+	+	+	-	+
pH	BPI (2015)	5.0-6.5	+	+	+	+	+	+	+	+
OM (%)	Njukeng & Baligar (2016)	>3.5	-	-	+	-	-	-	-	+
Total N (%)	Njukeng & Baligar (2016), Ritung et al., (2007)	>0.09	+	+	+	+	+	+	-	+
Available P (ppm)	Ritung et al., (2007)	10	-	-	-	-	-	-	+	+
Available K (mg/kg)	Ritung et al., (2007)	117.3	-	+	-	+	+	-	-	+

Plus sign (+) indicates that soil property is favorable for cacao growth; minus sign (-), soil property is a constraint to cacao growth;

Discussion

The result of soil analysis reflects the status of the soil nutrients in selected cacao orchards of Davao de Oro. The soil pH of the cacao orchards ranged from strongly acidic to slightly acidic. According to the Bureau of Plant Industry, the ideal soil pH for cacao production ranges from 5.0 to 6.5, where the selected orchards fall under. According to the Philippine Coconut Authority, under coconut intercropping, cacao can tolerate soils ranging from extremely acidic to slightly alkaline. This also supports Wood's argument (1985) that "cocoa is tolerant to acidic conditions as long as the soil provides enough nutrients". Having this pH status is normal for soils of humid tropical regions where soils are subjected to frequent leaching of bases (Alloway, 1996). Soils under cacao became acidic due to long-term cultivation, lack of proper levels of fertilizer and lime addition, and loss of nutrients through erosion (McCauley, Jones, and Olsun-Rut, 2017).

Low-CEC soils are more likely to develop potassium (and other cation) deficiency, while high-CEC soils are less susceptible to cation loss from leaching (CUCE, 2007). For sandy soils, a large one-time addition of cations can lead to large leaching losses, as observed in the sandy soil of Site 7, the only site that has a lower CEC value than the minimum requirement of 12me/100g as the critical level set by Njukeng and Baligar (2016). Higher CEC means either clay or organic matter is present in the soil in high amounts, as reflected in the soil of Site 8, where clay content is very low while organic matter is high. This also suggests that high (clay) CEC soils have a greater water holding capacity than low (sandy) CEC soils (Njukeng and Baligar, 2016).

Soils in Sites 3 and 8 have a sufficient amount of organic matter, exceeding the minimum requirement of 3% (Njukeng and VBaligar, 2016). The amount of nitrogen correlates to the amount of organic matter because humus is a valuable reservoir of nitrogen, and should be built up and/or maintained. Humus is formed from raw organic matter by soil organisms, binding soil particles together to form aggregates. This ensures the correct oxygen level in the soil, as well as water penetration and root development (Kerr, 2014).

The critical value for N in cacao production is 0.09% (Njukeng and Baligar, 2016; Ritung et al., 2007), wherein almost all sites are sufficient, except for Site 7's sandy loam soil which comprised of 64% sand. In sandy soils, water can easily wash away or move down soluble nutrients such as N and K. The premise that the soil's N content in most cacao orchards was generally above the critical level can be attributed to nitrogen present in annual litter fall, which is about 20% to 45% of the total N in the vegetation, and 2% to 3% of the total N in the soil (Njukeng and Baligar, 2016).

The available phosphorus was generally low for cacao soil except for Sites 7 and 8, where it was higher than the critical level of 10mg/kg (Njukeng and Baligar, 2016). This can be attributed to the coarse textured parent materials that lead to the leaching of P. Njukeng and Baligar (2016) gave emphasis that a large part of the P in a cacao ecosystem is found in vegetation and litter, while the amount of P in the soil itself is low. It was reported by Ogunlade and Aikpokpodion (2006) that leaf litter fall in cacao plantation was not sufficient to supply the phosphorus required for optimal yields, and the application of P fertilizer is a practical intervention to address this constraint.

Potassium is a major nutrient in mature cacao (Hartemink, 2005). Potassium levels vary with the location, with Sites 2 and 4 having very high exchangeable potassium content, Sites 5 and 8 having optimum levels, and Sites 3 and 1, 6 and 7 (the latter being alluvial soils) having deficient levels. Based on the range of exchangeable K values observed in some soils, the addition of K-containing fertilizer is needed to achieve optimal cacao yields, particularly in areas with a deficient K content (refer back to Table 4). Gattward et al. (2012) reported that if potassium is limited, sodium can partially replace potassium in the nutrition of clonal cacao, with significant improvements on photosynthesis.

According to Jadin and Snoeck (1985), optimum proportions for cacao are 68% Ca, 24% Mg and 8% K of the total exchangeable bases in the soil. The evaluated soils were generally inadequate in these required nutrients (see Table 4 again), and could become more deficient in nutrient content in the near future without proper fertilization. Further production of cacao beans might deplete the remaining essential nutrients and lead to serious soil fertility constraints, so formulating and following the best nutrient management strategies is essential for sustainable cacao bean production.

Conclusion and Recommendation

Study results showed that the soil under cacao production system in Davao de Oro is characterized by shallow to very deep solum: dark brown in the upper horizons and dark, yellowish-brown in the lower horizons. The soil additionally has the following characteristics: for soil consistence, friable to very firm when moist; slightly sticky to very sticky; slight to very high plasticity; and silty clay loam to loam soil texture.

Futher, the soils under the production system generally had moderately acidic to slightly acidic pH, low organic matter content (except in orchards applied with organic fertilizer), adequate amount of nitrogen, low phosphorus content, and low potassium content (in some areas). With this, appropriate fertilization based on site-specific recommendation and proper cultural management is needed.

To alleviate constraints, improving nutrient status, minimizing soil degradation, and appropriate soil fertility management strategies should be employed. These include the regular monitoring and evaluation of fertilizer use, minor agricultural lime application of the soil in Site 5 (Imelda, Laak) to slightly increase the pH, and application of organic fertilizer to increase organic matter content in all sites, except in Sites 3 and 8.

Results taken are deemed useful for sustainable cacao production and nutrient management of cacao production areas in Davao De Oro, Philippines.

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