Land Suitability Evaluation of Cocoa (*Theobroma cacao* L.) Production Areas in Davao City, Philippines

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Abstract

With the growing demand for cocoa, local farmers and other key players of the cocoa industry were encouraged to boost production to secure supply. However, after many decades of cocoa production, soil fertility and available cultivation areas are shrinking. Land suitability evaluation was conducted in areas grown with cocoa in Davao City, Philippines to determine the current suitability and soil-related constraints for cocoa production intensification and expansion. Using the environmental lapse rate, temperature of the area was determined and suitability were evaluated using Food and Agriculture Organization framework with the aid of QGIS software. Based on the result, six soil series were identified as suitable for cocoa. These included the Cabantian, Bolinao (Inayangan), Bolinao (Paquibato), Miral, Tugbok and undifferentiated soil. Cabantian, Miral and Bolinao (Inayangan) were moderately suitable with limitations in slope and soil fertility. Bolinao (Paquibato) was moderately suitable with limitations in soil depth and sloping topography. Tugbok was marginally suitable due to low soil fertility and slight limitation in slope. Undifferentiated soil was moderately suitable with sloping topography, shallow depth and soil fertility constraints. The six suitable soil series had moderate to marginal limitations. The constraints to cocoa production are manageable to some extent.

Keywords: current suitability, environmental lapse rate, intensification, land evaluation, production constraints

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1. Introduction

Climate has profound effects on cocoa production (Daymond and Hadley, 2004; Carr and Lockwood, 2011; Adjaloo *et al.*, 2012; Afoakwa, 2014; van Vliet *et al.*, 2015; Medina and Laliberte, 2017; Santosa *et al.*, 2018) and the primary determining factor for cocoa growth (Nair, 2021). Temperature and rainfall beyond cocoa's range decreases pod and bean yield (Daymond and Hadley, 2008) as it decreases pod development due to reduced population of the pollinators (Santosa *et al.*, 2018; Nair, 2021); decreases biomass accumulation (Hebbar *et al.*, 2020); lower the light interception (De Almeida and Valle, 2007; Carr and Lockwood, 2011); decrease net photosynthesis (Gateau-Rey *et al.*, 2018; Lahive *et al.*, 2019); affects regular stomatal conductance; and increase transpiration rate (De Almeida and Valle, 2007; Zakariyya and Indradewa, 2018; Kongor *et al.*, 2019; Lahive *et al.*, 2019). Unfavorable climate can also increase diseases and mortality rate in cocoa (Gateau-Rey *et al.*, 2018).

In determining options for sustainable cocoa production, edaphic and crop management, in addition to climate, are the key factors to consider (Medina and Laliberte, 2017; Santosa *et al.*, 2018). Soil texture and depth are important parameters to consider in the establishment of cocoa as cocoa roots require less root restriction from poor drainage and stoniness (Kongor *et al.*, 2019; Lahive *et al.*, 2019). Cocoa roots extend to > 1 m and active root zone at 0-0.5 m (De Almeida and Valle, 2007; Carr and Lockwood, 2011; van Vliet *et al.*, 2015; Snoeck *et al.*, 2016). Like other crops, cocoa removes nutrients from the soil (Hartemink, 2005), and management of soil fertility is a determinant in cocoa bean production (Wood and Lass, 2001; Kongor *et al.*, 2019; Voora *et al.*, 2019; Hebbar *et al.*, 2020; Marrocos *et al.*, 2020).

Cocoa (*Theobroma cocoa*) is a native humid tropical crop cultivated for its beans (Daymond and Hadley, 2008; Carr and Lockwood, 2011). It is one of the important crops in the world, with an estimated bean output of 5.6 million tons in 2019 (Food and Agriculture Organization [FAO], 2020). It has a global cocoa market value of around 8.6 billion in 2017 and a compound growth rate of 7.3%. The global cocoa market value is estimated to reach 189.89 billion by 2026 (Voora *et al.*, 2019).

Countries within 18 °N and 15 °S of the equator, known as the cocoa belt (Wood and Lass, 2001), produces the majority of cocoa beans. The top cocoa-producing country is Côte d'Ivoire in Africa, which accounted for 39% of the total cocoa bean production of the world. Other countries in Asia, America, and other parts of Africa produce the remaining 61% of the total cocoa bean production of the world 2019 (FAO, 2020). These cocoa-producing countries have humid tropical climate and rainforests where cocoa are suitable.

The Philippines is a cocoa-growing country with great potential for production intensification and expansion as it lies within the cocoa belt. However, data processed from the database of the Philippine Statistics Authority (PSA) (PSA) (2021) revealed that the average cocoa yield is 0.3 mt per ha in 2020 lower than the yield potential of 0.8 to 2.5 mt per ha (Sys *et al.*, 1993). This shows that there is a wide gap between the potential yield and the actual yield of cocoa in Philippine, thus land suitability evaluation for cocoa is needed in order to identify the constraints in production and the potential area for expansion of cocoa.

Despite the gap in yield and other supply issues, the local cocoa industry in Davao City has positioned itself in the international market as one of the best producers of high-quality cocoa beans. To contribute to the continuing efforts for poverty reduction and for inclusive growth in rural areas, the local cocoa industry should leverage opportunities such as those offered by the country's domestic and foreign cocoa markets. Increased production will simply mean supplying a bigger share of the existing demand and improving farmer's income. Increasing the current level of production could be started by conducting a proper land evaluation.

Land evaluation provides a rational basis for making land-use decisions based on the analysis of the relationship between land use and land, giving estimates of required input and projected outputs (Ahukaemere, 2018). The objective of land evaluation is to select the optimum land-use for each defined land unit, taking into consideration both physical and socio-economic considerations and the conservation of environmental resources for future use. Proper land suitability evaluation will result in the identification of area suited for specific uses (Ceballos-Silva and López-Blanco, 2003; Bandyopadhyay *et al.*, 2009; Akinci *et al.*, 2013; Ahukaemere, 2018); determination of soil constraints (Akinci *et al.*, 2013; Adeyolanu *et al.*, 2017; Ahukaemere, 2018; Neswati *et al.*, 2019; Syarif *et al.*, 2020); delineation of areas to avoid conflicts (Chen, 2014); and support for the decision-making in any land-use plans and policymakers (Brinkman and Young, 1976).

One of the evaluation methods to evaluate the land use system and determine the crop suitability is adapting the FAO framework (FAO, 1976), which is a method use to assess the land use system components and its compatibility – the land use type and the land unit. The land unit is described based on its characteristics that indicate land qualities. This is matched with the land use requirement of the land use type (existing or for development) (Rossiter, 1996). The FAO framework for land evaluation can identify the most limiting land qualities for specific land utilization types and suitability of crops (Chinene, 1992; Alemu *et al.*, 2013; Ashraf and Normohannadan, 2011; Aini *et al.*, 2020) and recognize mitigation strategies to crop limitations and soil conservation practices (Ashraf and Normohannadan, 2011).

In the Philippines, no published land suitability evaluation study has been carried out for cocoa. Thus, this study aimed to determine the suitability of land for cocoa production by evaluating relevant soil characteristics and land qualities using the FAO framework. Cocoa production-related constraints were determined as well as the corresponding corrective measures for future production intensification and expansion.

2. Methodology

2.1 Description of the Study Area

Davao City, Philippines is located at 6° 58’ N to 7° 34’ N and 125° 14’ to 125° 45’ E. It is bounded in the north and east by the Province of Davao del Norte, in the west by North Cotabato Province, and in the south by Davao del Sur Province and Davao Gulf. It has a land area of 244,000 hectares (Figure 1).

The climate of Davao City is Type IV based on modified Corona classification. Rainfall in the area has an annual average of 1,968 mm and the average mean annual temperature 31.8 °C maximum and 24.0 °C minimum (2006-2015) (Philippine Statistics Authority [PSA], 2016).

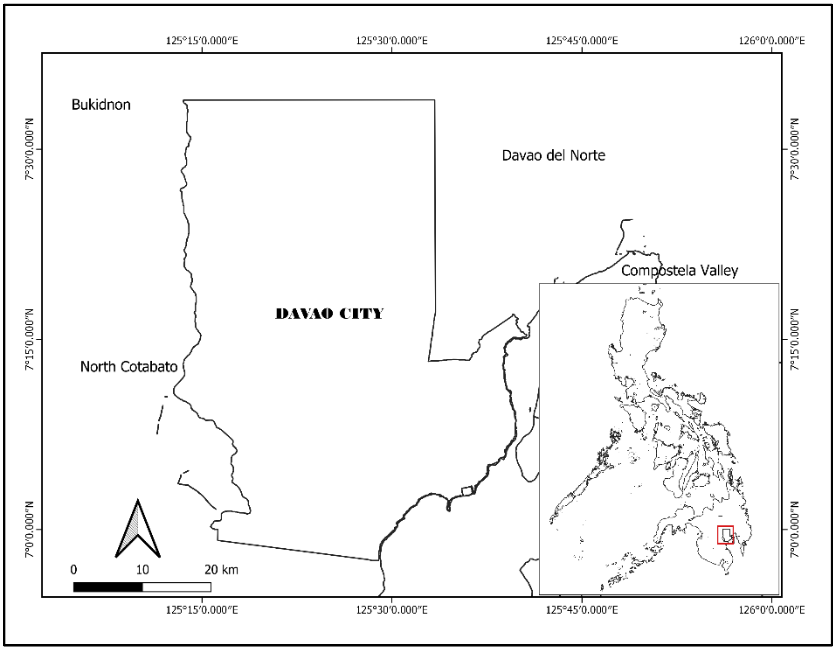

Figure 1. Location of the study area

2.2 Data Gathering and Sourcing

Map on soil type was extracted in PhilGIS website (PhilGIS, n.d.). For elevation, digital elevation model (DEM) data was acquired from Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global of United States Geological Survey (USGS) with spatial resolution of 30.8 m pixel size (USGS, n.d.) A 10-year annual temperature data (2006-2015) of Davao City published by PSA 2016 was used. The spatial data were processed using QGIS program (GSIS Association, 2021) and was checked to coincide with UTM Zone 51N of WGS 1984.

2.3 Delineation of Temperature Suitable Areas for Cocoa Production

The data on temperature (Table 1) was gathered at an elevation of 18 masl (elevation of the Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA] Davao City Monitoring Station) (PSA, 2016). However, the temperature of the landscape varies with the elevation (Arya, 2001). Adiabatic lapse rate explains the rate at which temperature changes in response to elevation change (Hemond and Fechner, 2014).

Furthermore, the environmental lapse rate measures the actual rate at which atmospheric temperature changes from the ground (Shuttleworth, 2012) and is 6.5 °C km^{-1} (Pratap *et al.*, 2013). Thus, temperature of the area was determined based on elevation using the environmental lapse rate at 6.5 °C km^{-1}. This was spatially presented using QGIS program and highly suitable areas for cocoa (S1) based on temperature requirement using suitability classification by Sys *et al.* (1993). S1 area based on temperature (as function of elevation) was delineated by reclassifying the DEM image. The reclassified DEM was polygonised and geometric attributes were added.

Table 1. Temperature of Davao City from 2001 to 2015 (PSA, 2016)

Year	Temperature (°C)	
	Maximum	Minimum
2001	31.0	22.0
2002	31.7	21.2
2003	31.6	24.3
2004	32.2	24.5
2005	31.8	24.4
2006	31.7	24.5
2007	31.6	24.3
2008	31.4	24.0
2009	31.9	24.4
2010	32.2	24.4
2011	31.6	24.2
2012	31.8	24.3
2013	32.1	24.4
2014	32.3	24.8
2015	32.7	25.0
Average	31.8	24.0
SD	0.4	1.0

2.4 Soil Survey, Collection of Soil Samples, and Soil Physicochemical Analysis

A soil survey was conducted within the temperature suitable areas for cacao production in Davao City to identify the different land units. The individuality of the land units was determined based on the established soil series. A pedon was examined in every land unit and corresponding soil samples were collected for laboratory analysis to determine the physicochemical properties of the soil. The list of the physicochemical properties and the methods used in the analysis are shown in Table 2.

Table 2. Methods for soil physicochemical analysis

Soil Properties	Methods
Chemical analysis	
pH	1:1 Soil:water pH method
Electrical conductivity (EC) ds/m	1:1 Soil:water electrical conductivity method
OC %	Walkley and Black method (Walkley and Black, 1934)
N %	Modified Kjeldahl method (Campbell and Hanna, 1937)
CEC (cmol(+)	Ammonium acetate method at pH 7 (Chapman, 2016a)
Exchangeable bases (Ca, Mg, K and Na)	Ammonium acetate method (Chapman, 2016b)
Physical analysis	
Soil Texture type and particle size proportions	Hydrometer method (Gee and Bauder, 2018)

2.5 Land Suitability Classification Methods using Limitation Approach

Land suitability evaluation was done following FAO framework (1976) and Sys *et al.* (1993). This involved matching the established land qualities and crop requirements. Soil quality attributes was based on the physicochemical properties of soil. The crop requirements for cacao were based on Sys *et al.* (1993) as shown in Table 3. Evaluation of soil quality attributes for cocoa production suitability was done through a relative limitation scale or the limitation approach by Sys *et al.* (1993). The suitability classes are divided into the following: S1 – highly suitable; S2 – moderately suitable; S3 – marginally suitable; N1 – currently unsuitable but potentially suitable; and N2 – permanently unsuitable. The crop requirement for cocoa is the basis for its suitability as presented in Table 3.

Using the limitation approach by FAO framework (Sys *et al.*, 1993), with reference on the matching of the land characteristics of the different soil series (Table 3) and the land quality requirement of cocoa (Table 2), the existing land suitability of the soil series for cocoa production in Davao City were determined.

Table 3. Land quality requirements of cocoa plants (Sys *et al.*, 1993)

Land characteristics		Degree of limitation S1	S2	S3	N1	N2
Topography (t)	Slope	0-4	4-8	8-16	16-30	30-50
Wetness (w)	Drainage	Good	Good	Moderate	Imperfect	Poor to very poor
	Flooding	None	-	-	Slight	Moderate
Soil (s)	Texture	C > 60s, L, SC SiCL, CL, SiL	SCL, C < 60v	C > 60v, LfS, SL	Cm, SiCm, LS, LcS, fS, S, Cs	C > 60s, L, SC
	Soil depth	> 200-150	150-100	100-50	-	< 50
Fertility (f)	Soil pH	6.4-6.2 6.6-7.0	6.0-5.5 7.0-7.6	5.5-5.0 7.6-8.2	< 5.0	-
	% OC	> 2.4	2.4-1.5	1.5-0.8	< 0.8	-
	CEC_t ($cmol^+$ kg $soil^{-1}$)	> 24-16	<16 (-)	< 16 (+)	-	-
	Base saturation (%)	> 50-35	35-20	< 20	-	-
	EC(ds/m)	0-1.1	1.1-1.8	1.8-2.2	-	> 2.2

3. Results and Discussion

3.1 Delineation of Suitable Area for Cocoa based on Temperature

Using environment lapse rate calculation, highly suitable (S1) temperature was attained at an elevation of 400-850 masl having a maximum temperature of 26-29 °C and annual average temperature of 23-25 °C. Based on temperature, 66% of the land area in Davao was suitable in cacao production which include Baguio, Calinan, Marilog, Paquibato, Toril and Tugbok District. Furthermore, 58% of the suitable areas was highly suitable (estimated to be 70,281 ha), majority of which were located in Marilog and Paquibato Districts covering about 22% of the total land area or estimated to be 52,490 ha (Figure 2 and Table 4). There were six soil series that was identified in areas with temperature highly suitable for cocoa. These included Bolinao

(Inayangan) (290.09 ha), Bolinao (Paquibato) (4,133.14 ha), Cabantian (14,447.87 ha), Miral (33,908.63 ha), Tugbok (15,847.72 ha) and undifferentiated soil in Calinan (1,654.12 ha) (Figure 3 and Table 4).

Temperature of the area decreased with increasing elevation. Cocoa suitability varied with elevation as temperature changes with elevation. Cocoa was highly suitable in high elevation areas (400-850 masl) with annual maximum temperature of 26-29 °C and annual average temperature of 2325 °C.

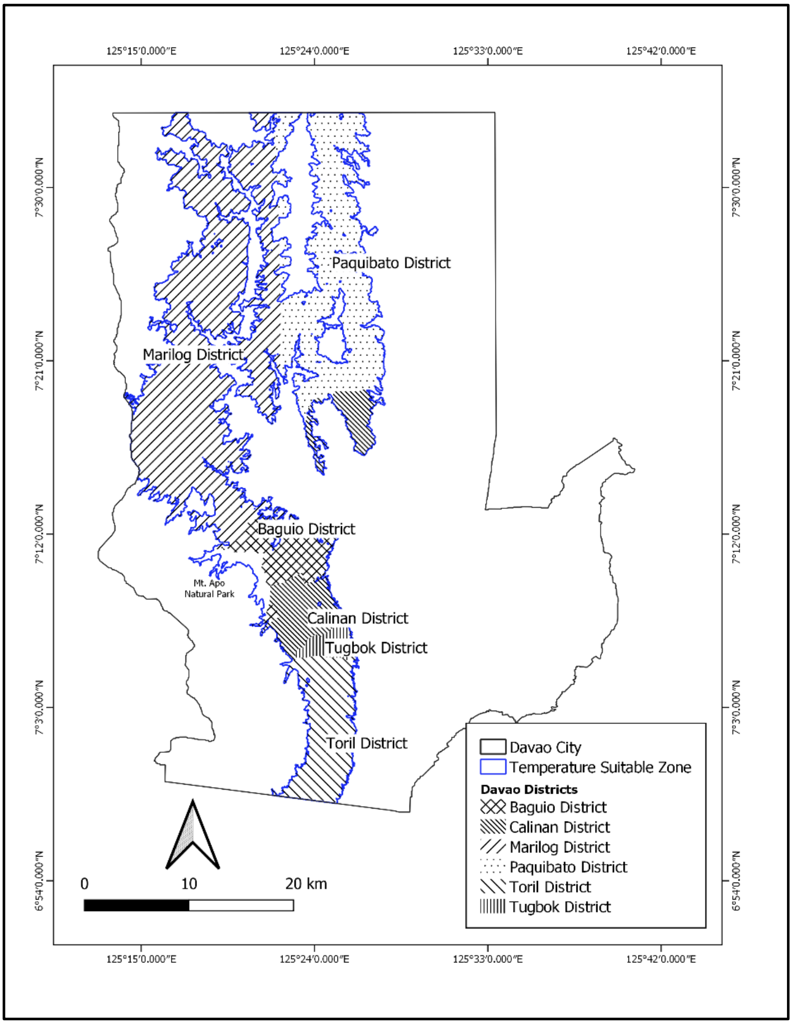

Figure 2. Highly suitable temperature areas for cocoa production in Davao City

Other studies showed that highly suitable temperature for cocoa was 25-28 °C annual average temperature (Aini *et al.*, 2020; Syahri *et al.*, 2020). Furthermore, based on Sys *et al.* (1993), highly suitable temperature is 23 to 25 °C, and the mean annual maximum temperature is < 30. According to Daymond and Hadley (2004), warm temperature (26.6 °C) results in higher wilting proportion from Cherelle disease and low fruit development. As the temperature increases, the respiration rates also increase and reduce the maintenance capacity of the cocoa tree for fruit loading.

Table 4. Soil series and their land area within highly suitable temperature zones for cocoa in Davao City

Soil series	Davao City District	Area (ha)
Bolinao (Inayangan)	Calinan	290.09
Bolinao Series (Paquibato)	Paquibato	4,133.14
Cabantian	Paquibato	14,447.87
Miral	Marilog	33,908.63
Tugbok	Calinan	7,872.58
Tugbok	Toril	6,841.04
Tugbok	Tugbok	1,134.10
Soil undifferentiated	Calinan	1,653.12
Total		70,280.56

3.2 Physicochemical Properties of Soil Series within Highly Suitable Temperature Zones for Cocoa

Identified soil found in highly suitable temperature zone of Davao City were as follows, Bolinao (two variants: Inayangan and Paquibato), Cabantian, Miral, Tugbok, and undifferentiated soil. The soil physicochemical properties of the different soil series in temperature suitable zone for cocoa is presented in Table 5. Based on standard laboratory result ranges, values revealed that soil pH level of Cabantian, Miral, Tugbok and undifferentiated soil were generally acidic for cocoa production (5.76, 5.69, 5.26, and 5.62, respectively). On the other hand, Bolinao (Inayangan) was neutral (6.72) which also reflected its electrical conductivity (EC) (0.88 ds/m). Organic carbon was moderately limited, and N was below optimum level in Miral (1.18 and 0.13%), Bolinao (Inayangan) (1.39 and 0.19%), and undifferentiated soil (1.18 and 0.13%), while very severe limitation on the percent base saturation was recorded in Tugbok (10.44 $cmol^{+}$ kg^{-1} soil). Depth of soil was very shallow for cocoa in Bolinao (Paquibato). No limitations were found in soil texture (Table 5).

Table 5. Physicochemical properties of soil series in temperature-suitable zones for cacao in Davao City

Soil properties	Soil series					
	Cabantian	Bolinao (Paquibato)	Miral	Tugbok	Bolinao (Inayangan)	Undiff. Soil
pH	5.76	6.64	5.69	5.26	6.72	5.62
EC ds/m	0.27	0.30	0.15	0.12	0.88	0.18
OC (%)	2.97	3.34	1.18	3.13	1.39	1.18
N (%)	0.26	0.32	0.13	0.24	0.19	0.13
CEC ($cmol^{+}$ kg^{-1})	54.45	41.36	22.12	30.41	58.95	55.00
Exchangeable cations ($cmol^{+}$ kg^{-1})						
K	0.95	0.20	0.40	0.59	0.59	0.83
Na	0.24	0.31	0.36	0.33	0.43	0.32
Ca	18.89	19.66	3.64	1.27	39.95	16.15
Mg	15.48	0.99	3.85	1.13	7.79	16.66
Base saturation (%)	65.15	50.88	37.14	10.44	82.96	61.75
% Sand	32.38	41.84	26.75	29.82	20.56	24.05
% Silt	39.15	36.35	41.86	18.47	17.27	41.43
% Clay	28.47	21.81	31.39	51.71	62.17	34.52
Texture type	Clay loam	Loam	Clay loam	Clay	Heavy clay	Loam
Soil depth (cm)	88.00	42.00	84.00	>107.00	112.00	60.00
Slope (%)	6-13	6-13	13-25	0-6	6-13	0-16

Samples analyzed were taken at the effective feeding root depth for cacao (> 20 cm).

3.3 Existing Suitability of Soil Series for Cocoa Production

Cocoa production was moderately suitable to Bolinao, Miral, Cabantian and undifferentiated soil. Bolinao (Inayangan) was slightly alkaline while Cabantian and Miral had soil acidity constraints for cocoa production. The moderate constraints of Cabantian and Miral were the sloping topography and the low nutrient level. For Bolinao (Paquibato), moderate constraints for cocoa production were the shallow rooting depth for anchorage and susceptibility of the soil to drought. Cocoa was found marginally suitable in Tugbok due to the very low levels of nutrient and acidic condition of the soil (Table 6 and Figure 3).

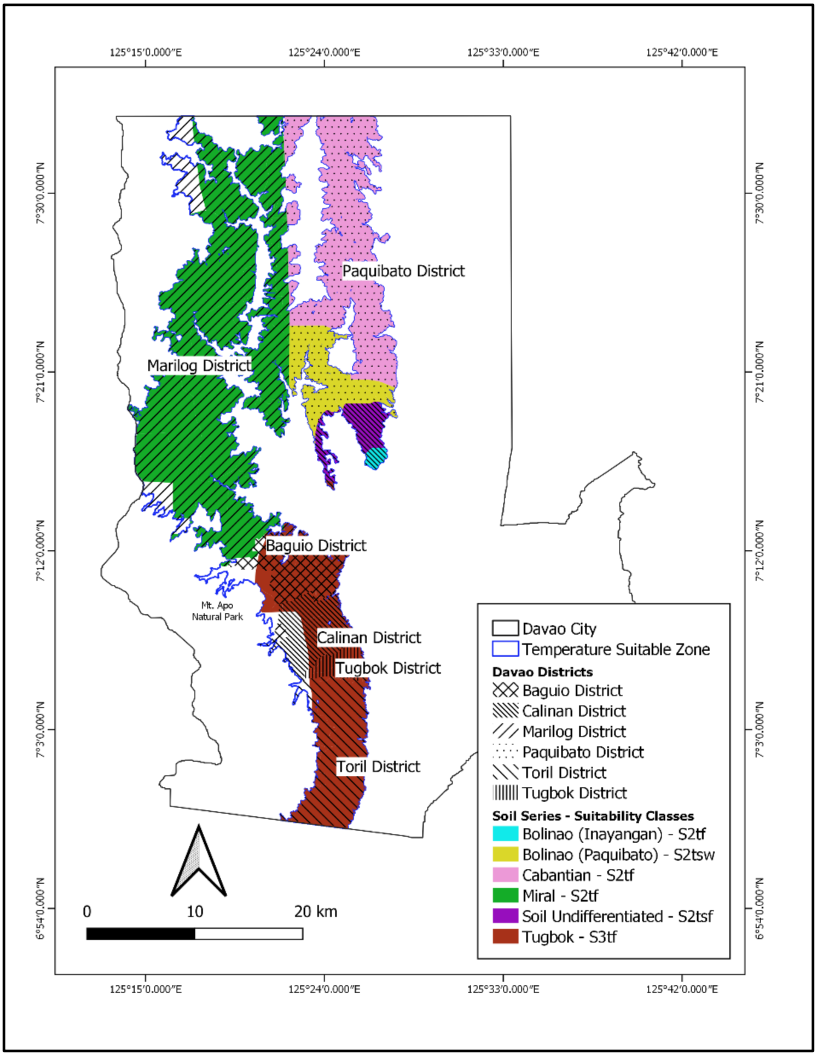

Figure 3. Suitability map for cacao

Nonetheless, these constraints to cocoa production are manageable to some extent. Effective conservation and sustainable farming practices are some of the techniques to manage the constraints brought about by the sloping topography of the soil. In addition, intercropping of cocoa is encouraged specifically in sloping areas to promote diversity and soil protection.

Table 6. Current suitability of soil series for cocoa production in temperature-suitable areas in Davao City

Soil series	Suitability rating	Production constraints			
		Topography (t)	Wetness (w)	Physical characteristics (s)	Fertility (f)
Cabantian	S2tf	Sloping topography; moderate erosion			Acidic soil
Bolinao (Paquibato)	S2tws	Gently sloping topography; slight erosion	Susceptible to drought due to intermittent low-rainfall months and shallow solum	Shallow rooting depth for anchorage	
Miral	S2tf	Sloping topography; moderate erosion			Acidic soil; deficient in OC and N; low exchangeable cations.
Tugbok	S3tf	Gently sloping topography; slight erosion			Acidic soil; very low base saturation
Bolinao (Inayangan)	S2tf	Sloping topography; moderate erosion			Deficient in OC and N
Undifferentiated soil (Saloy-Calinan)	S2tsf	Gently sloping topography; slight erosion		Shallow rooting depth for anchorage	Acidic soil; OC and N deficient

S2 – moderately suitable; S3 – marginally suitable; t – topography constraints; w – wetness constraints; s – physical characteristics constraints; f – fertility constraints

The application of organic amendments, green manuring and reliable irrigation techniques are recommended for land units with low organic carbon and shallow solum. Organic matter improves water retention of the soil, thus reducing the risk of drought. Similarly, organic matter improves aggregate stability, aeration and tillage (Weil and Brady, 2017). Nutrient and pH of the soil should be maintained at the optimum level for cocoa growth through judicious application of correct fertilizer and amendments.

4. Conclusion and Recommendation

This study identified and evaluated the suitable areas for cocoa production based on climate and soil quality of different soil series within the temperature suitable areas in Davao City. Temperature-suitable areas (annual average temperature of 23-25 °C) for cocoa production in the city were found at 400 to 850 masl elevation based on the environmental lapse rate estimation. A total of six soil series were identified in the temperature suitable area. These included the two variants of Bolinao, Cabantian, Miral, Tugbok, and the undifferentiated soil. Limitations of the soil for cocoa production were identified which were moderate (Bolinao, Cabantian, Miral, and undifferentiated soil) to marginal (Tugbok). Establishment of soil conservation measures, reliable irrigation facilities, and application of correct fertilizer and soil amendments are the common corrective and improvement measures. Nonetheless, these constraints to cocoa production are manageable to some extent. The results of the evaluation revealed that cocoa production in the city can be increased through intensification and possible expansion of the production area by properly managing the limitations identified in the different soil series.

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