Characterization, Classification, and Crop Suitability Assessment of Selected Soil Series in Ilocos Norte, Philippines

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Abstract

A land evaluation was conducted on selected soil series in the Province of Ilocos Norte using the Food and Agriculture Organization land suitability framework. Seven different soil profiles were studied to determine physicochemical properties, soil morphology, and land suitability for selected crops. The soil series studied were San Fernando (Typic Epiaqualfs), San Manuel (Typic Eutrudepts), Umingan (Typic Epiaquepts), Bantog (Typic Hapludalfs), Cervantes (Typic Hapludalfs), Pedon 6 (Typic Dystrudepts), and Pedon 7 (Typic Udifluvents). The results indicated that San Fernando was highly suitable (S1) for irrigated rice and maize, with suitability scores of 83 and 82, respectively, while San Manuel was highly suitable (S1) for garlic, irrigated rice, maize, onion, and tomato, with suitability scores ranging from 75 to 93. The Bantog series was predominantly classified as S1, except for robusta coffee and sugarcane, which were moderately suitable (S2cf) due to climate and fertility limitations. The Cervantes series was classified as S2w for garlic, onion, and rainfed upland rice, but with limitations due to wetness. For Pedon 6 and Pedon 7, most crops were moderately suitable (S2). To address soil fertility issues, proper phosphate fertilization (P_2O_5) is recommended for San Fernado, Bantog, and Cervantes, while the addition of organic fertilizers is recommended for San Fernando, San Manuel, Bantog, Pedon 6, and Pedon 7. Flooding is a concern in Umingan, while the Cervantes exhibits undulating to rolling slopes, which contributes to rill erosion. Appropriate interventions for these constraints must be integrated into the production process to maintain soil health and crop productivity.

Keywords: crop suitability, land evaluation, soil survey, soil taxonomy

1. Introduction

Global food security in the 21st century faces multifaceted challenges driven by population growth, climate change, and resource scarcity (Tariq, 2024). At the same time, global agriculture depends on climate conditions but is undergoing rapid changes due to technological advancements, socioeconomics factors, shifting consumption patterns, and threats from environmental degradation (Mrabet, 2023). In the Philippines, climate change and inefficient land use contribute to declining soil fertility, reduced crop yields, and increased vulnerability to extreme weather events such as droughts and typhoons. These challenges threaten rural livelihoods and exacerbate food insecurity. Accurate weather forecasting and a deeper understanding of soil characteristics for specific crops are essential for enhancing agricultural productivity and resilience (Stuecker *et al.*, 2018). Region 1, particularly Ilocos Norte, a key producer of rice, bulb crops, and other high-value commercial crops, underscores the urgent need for land optimization strategies to sustain long-term agricultural productivity (Dela Rosa *et al.*, 2004).

Concerns about productivity and land degradation in land management can be tackled through land suitability evaluation and assessment (Dela Rosa *et al.*, 2004). This evaluation and assessment system offers a rational foundation for decision support systems in land use by analyzing the relationship between land and its utilization based on inputs and outputs (Sys *et al.*, 1991). It also evaluates land capability for specific agricultural uses (Littleboy *et al.*, 1996), aligning with land use planning goals (Food and Agriculture Organization [FAO], 1989).

Soil characterization offers valuable information for land evaluation and provides insights into soil genesis, classification, and spatial distribution within a specific area (Deckers *et al.*, 2009). Optimizing agricultural land use is essential for enhancing the capacity and stability of agricultural production (Dornik *et al.*, 2022) and promoting sustainable practices in agriculture. This can be achieved through land suitability assessment (LSA) methods (Mendas and Delali, 2012; Akpoti *et al.*, 2019). Additionally, land suitability assessment (LSA) facilitates decision-making by providing information to guide the selection and implementation of optimal land use options (Khaki *et al.*, 2023; Tapia *et al.*, 2021; Mazahreh *et al.*, 2018; Yamada *et al.*, 2016).

A declining trend in crop production was recorded for several crops in Ilocos Norte. Sugarcane production decreased from 10,811 metric tons in 2020 to 10,485 metric tons in 2024. Garlic (dried bulb) declined from 4,464 metric tons in 2020 to 4,028 metric tons in 2024, while tomato production dropped from 27,456 metric tons in 2020 to 21,727 metric tons in 2024. Additionally, Robusta coffee production fell from 1.32 metric tons to zero in 2024 (Philippine Statistics Authority [PSA], 2025a). Meanwhile, rainfed rice production also declined from 52,129 metric tons in 2020 to 49,053 metric tons in 2024. However, both irrigated rice and corn maintained stable yields, reaching 292,835 metric tons and 69,918 metric tons in 2024, respectively (PSA, 2025b).

A research gap persists in the site-specific regions of the Philippines, including Ilocos Norte, despite the acknowledged benefits of soil surveys and crop suitability (Stuecker *et al*., 2018). Addressing this gap necessitates an understanding of soil characteristics, distribution, suitability, and limitations for various crops while considering physical, socio-economic, and environmental resource conservation. A concrete example is the land resource information system in Cagayan Valley, Philippines, which has served as a support tool for sustainable agricultural production (Martin, 2014). This land resource information system aids technicians and farmers in making informed decisions about which crops to cultivate in specific soil series based on crop suitability ratings. Furthermore, this initiative should also be adopted in Ilocos Norte. Despite the recognized advantages of soil surveys and land resource information systems in other regions like Cagayan Valley, Ilocos Norte lacks a comprehensive database that integrates soil characteristics with crop suitability and environmental resource conservation.

This study aims to characterize and classify specific soil series in Ilocos Norte, Philippines, and evaluate their suitability for crops such as irrigated rice, upland rainfed rice, maize, onion, garlic, sugarcane, coffee robusta, and tomato. Understanding the agricultural potential and limitations of these identified soil series in Ilocos Norte will provide valuable insights for farmers and policymakers, enabling them to make informed decisions regarding land management options. This will also help farmers identify soil problems, choose suitable crops, and implement proper interventions for the challenges encountered.

2. Methodology

2.1 Time and Place

This study was conducted from February to September 2020 in the Province of Ilocos Norte, Philippines. It is geographically situated in the northeastern corner of Luzon between 17° 43’ to 18° 29’ North latitude and 120° 25’ to 120° 58’ East longitude.

2.2 Sampling Area

The site selection and delineation of land units was guided by the existing Soil Survey Report (SSR) and the Bureau of Soils and Water Management (BSWM) soil series map of the province. Soil samples were collected from seven soil profiles each representing a different soil series namely, San Manuel (SnM), San Fernando (SnF), Cervantes (Crv), Bantog (Btg), Umingan (Umg), and two undifferentiated soil series; Pedon 6 (Pdn6), and Pedon 7 (Pdn7). The geographical locations (Figure 1) of the study sites were determined using Geographical Positioning System (Table 1). The highest elevation is the Cervantes series with 85 meters above sea level (masl) while the lowest is the San Fernando series with 10 masl.

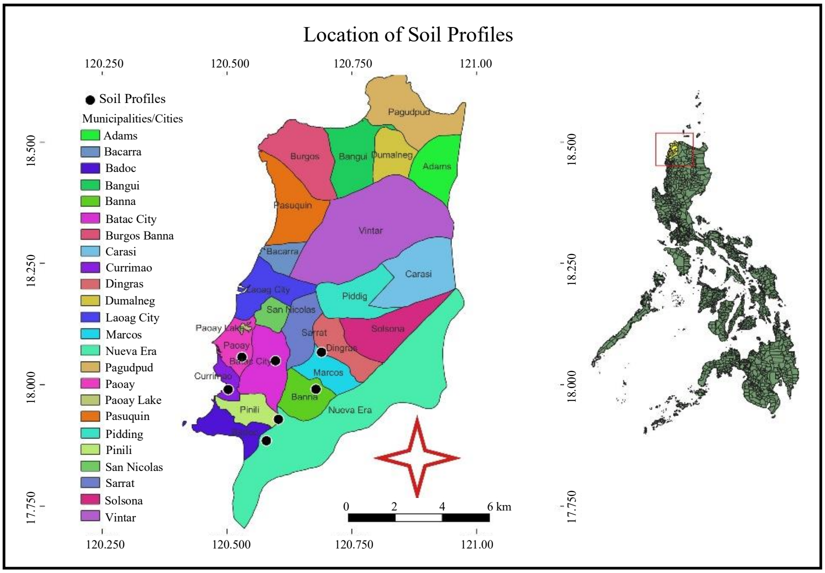

Figure 1. Location of Soil Profiles

Table 1. Geographic Locations of the Soil Series/Land Units

Pedon	Latitude (N)	Longitude (E)	Elevation (masl)
San Fernando (SnF)	18° 3' 24.24"	120° 31' 47.59"	10
San Manuel (SnM)	18° 2' 57.42"	120° 35' 49.94"	47
Umingan (Umg)	18° 4' 0.79"	120° 41' 22.37"	42
Cervantes (Crv)	17° 55' 42.57"	120° 36' 11.13"	85
Bantog (Btg)	17° 53' 3.72"	120° 34' 44.49"	72
Pedon6 (Pdn6)	17° 59' 26.31"	120° 40' 42.16"	57
Pedon7 (Pdn7)	17° 59' 23.67"	120° 30' 8.49"	18

2.3 Soil Morphology Examination and Description

The soil morphological evaluation was conducted across seven (7) study sites. A 1 m2 pit was dug at a depth of > 1 m. The soil horizons were identified and marked after the soil pit was dug and cleared. Soil morphological data such as matrix color, structure, consistence, horizon boundary, roots, and pores were taken in situ. Soil samples from each horizon identified were gathered for physical and chemical analyses.

2.4 Soil Sample Preparation and Analysis

An air-dried, ground, and sieved soil sample from each horizon was submitted to the Agricultural Systems Institute, College of Agriculture and Food Science, University of the Philippines Los Baños, Laguna for soil physicochemical analyses. The list of physicochemical analyses and the methods used are shown in Table 2.

Table 2. Methods for Physicochemical Analysis

Parameters	Methods
Chemical	
Cation Exchange Capacity	Ammonium Acetate Method (Chapman, 1965)
Soil pH	Potentiometric method
Organic Matter	Walkley and Black, 1934
Exchangeable Bases (Ca, Mg, Na, & K)	Ammonium Acetate Method (Black, 1982)
Available Phosphorus	Olsen-P (Olsen *et al.*, 1954)
Physical	
Particle Size Distribution	Hydrometer method (Bouyoucos, 1962)
Moisture Content (%)	Gravimetric method (Blake, 1965)

2.5 Climate Data Acquisition

The climate data such as rainfall, relative humidity, and mean temperature was collected from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) weather station in Laoag City, from 1991 to 2020 (Figure 2). The region has two climate types based on the modified Corona classification. Municipalities of Pagudpud and Adams located in the northernmost part of the region are classified under Type III, characterized by less pronounced maximum rain with a short dry period lasting from 1 to 3 months. The rest of the region is classified under Type I having pronounced wet (May to October) and dry (November to April) seasons. The mean annual rainfall is 2,221.7 mm/year. The mean annual temperature is 27.10°C, with November to February being the coldest months and May to August the hottest months. The climate data was used to assess crop suitability under the specified agroclimatic conditions.

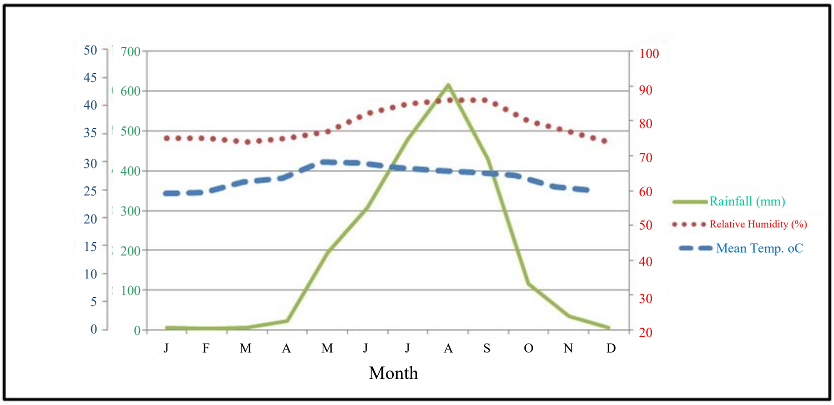

Figure 2. A 29-year summary distribution of rainfall, relative humidity, and mean temperature

2.6 Soil Classification

The soil taxonomic framework was carried out using the United States Department of Agriculture (USDA) "Keys to Soil Taxonomic," 12th edition (Soil Survey Staff, 2014).

2.7 Crop Suitability Assessment

The evaluation process includes identifying and matching Land Use Requirements (LUR) and Land Qualities (LQ) (Table 8a and 8b) to generate with sound and viable recommendations (Sys *et al*., 1993). Climate and land indices are calculated using weighing factor (1). It was carried out using the Square Root Method (Khiddir, 1986) and is expressed in Equation 1;

$$I = R_{min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \frac{C}{100}} \ldots \tag{1}$$

where I: index; Rmin: minimum rating; A, B, C . . . : other rating besides the minimum rating. The land suitability classification has three categories that were adapted from Food and Agriculture Organization (1976) framework namely: order, class, and subclass. The order/class includes highly suitable (S1, suitability index of 100-75), moderately suitable (S2, suitability index 75-50), marginally suitable (S3, suitability index 50-25), permanently not suitable (N, suitability index < 25. Subclasses were limited due to topography or slope (t), drainage and flooding (w), texture, coarse fragments and soil depth(s), soil fertility (f), soil salinity (n), and climate (c).

Table 3. Sample Table of Land Use Requirement for Onion

Climatic Characteristics	Class, degree of limitation, and rating scale					
	S1	S2		S3		N
	0	1		2	3	4
	100	95	85	60	40	25
Precipitation of the growing cycle (mm)	450-500 450-400	500-600 400-350	600-800 350-300	800-1600 300-250	- -	> 1600 < 250
Mean temp. of growing cycle (°C)	19-20 19-18	20-22 18-16	22-23 16-13	23-25 13-10	- -	> 25 < 10
Mean temp. at germination (°C)	18-15 18-20	15-10 20-25	10-5 25-30	5-2 30-35	- -	< 2 > 35
Daylength during Yield form. Period (h)	12.5-12 12.5-13	12-11 13-14	11-10 14-15	10-9 15-16	- -	< 9 > 16

Land Characteristics	Class, degree of limitation and rating scale					
	S1		S2	S3		N
	0	1	2	3		4
	100	95	85	60	40	25
Topography (t)						
Slope (%)	0-1	1-2	2-4	4-6	-	> 6
	0-2	2-4	4-8	8-16	-	> 16
	0-8	4-8	8-16	16-30	30-50	> 50
Wetness (w)						

Table continued.

Flooding	Fo	-	-	-	-	F1+
Drainage	good imperfect	moder. moder.	imperfect good	poor and aeric	poor, but drainab	poor, not drainab
Physical soil Characteristics (s)	L, SC	SiCs, Si	C<60v,	C>60v,	-	Cm,
Texture/struct.	SCL	SL, SiCl C<60s, Co	C>60s, fs, LS, LfS	S		SiCm
Coarse	0-3	3-15	15-35	35-55	-	> 55
fragments (%)	> 75	75-50	50-30	30-20	-	< 20
Soil depth (cm)	0-3	3-5	5-10	10-20	-	> 20
$CaCO_3$ (%)	0-1	1-2	2-3	3-5	-	> 5
Gypsum (%)						
Soil fertility Characteristics (f)	> 24	24-16	< 16 (-)	< 16 (+)	-	-
Apparent CEC (cmol(+)/kg clay)						
Base saturation (%)	> 50	50-35	35-20	< 20	-	-
Sum of basic cations (cmol(+)/kg soil)	> 2	2-1.2	1.2-0.8	< 0.8	-	-
pH H_2O	6.7-6.2	6.2-6.0	6.0-5.8	5.8-5.5	< 5.5	-
	6.7-7.2	7.2-7.8	7.8-8.0	8.0-8.2	-	> 8.2
Organic carbon (%)	> 2	2-1.2	1.2-0.8	< 0.8	-	-
Salinity and Alkalinity (n)						
ECe (dS/m)	0-1	1-2	2-3	3-5	-	> 5
ESP (%)	0-10	10-20	20-35	35-50	-	> 50

3. Results and Discussion

3.1 Morphological Properties of the Pedon

The images of the seven soil profiles are shown in Figure 3. These pedons indicate that the topsoil has been disturbed by plowing (Ap horizon), suggesting previous agricultural activities (Table 4). The SnF, SnM, and Btg series had an illuvial clay accumulation (Bt) while SnM, Umg, and Pdn6 had Cambic subsurface horizons. Lithological discontinuities were observed at a depth of 58 cm for the Umg series because of the removal and addition of materials by mass movement (Timbas *et al*., 2016). The soil color for SnF, SnM, Umg series and Pdn6 ranged from very dark brown to yellowish brown while Btg, Crv and Pdn7 ranged from very reddish black to yellowish red. Soil color varies with moisture levels, usually appearing darker when wet due to higher light absorption (Pillinger *et al*, 2023). Most pedons had clay to loam texture which is generally ideal for a wide range of crop cultivation. The surface structure was characterized by weak, fine granular to moderate medium blocky, and columnar structure in the subsoils. The presence of this soil structure influences aeration, root permeability, and the drainage for most crops (Msanya *et al*., 2018). Furthermore, soil consistency ranged from slightly sticky to sticky and slightly plastic to plastic. The relationships among soil moisture vary by climate, vegetation, and soil texture and tend to decrease with depth (Li *et al*., 2024). The horizon boundary was clear and abrupt and eventually became diffuse in the subsoil. Roots and pore spaces are abundant in the upper layers and decreased significantly with depth.

3.2 Physical Properties of the Pedon

Table 5 presents the physical properties of different soil profiles in Ilocos Norte, Philippines. Clay-dominant soils were prevalent in three soil series, SnF, SnM and Crv. An increase in clay content with depth to illuviation processes and the influence of the underlying geology through weathering (Idoga *et al*., 2005). In relation to organic carbon, a 2:1 expanding and limited-expanding clay minerals positively contributes to the sequestration and stabilization of labile carbon in soil (Das *et al*., 2023). These soils have higher water-holding capacity, but poor drainage is one of the characteristics of clayey soils. Loamy soils found in the Btg series and parts of Pdn6 and Pdn7 offer balanced texture. This is generally characterized by having good drainage and an indicator of high nutrient retention. Lastly, the clay loam texture which was observed in the Umg series had poor drainage, which is associated with low hydraulic conductivity, and exhibit mottled characteristics.

3.3 Chemical Properties of the Pedon

The soil pH of the seven soil profiles ranged from slightly acidic to moderate alkaline (pH 6.0-8.5) with most soils being slightly alkaline except the Btg series, Crv series, and Pdn6 (Table 6). These soils are suitable for a wide range of crops (Redmon *et al*., 2024). Slightly acidic soils may require lime for pH adjustment. The organic carbon in the surface and subsoils of all profiles was less than 1.84% and decreased with depth. The low soil organic carbon (SOC) in all soil profiles is due to the intensive tillage operation which disturb the soil structure and destabilize soil aggregates (Pires *et al*., 2017; Conant *et al*., 2007). Most soil profiles studied had a high amount of available P_2O_5 except for the SnF and Crv series that exhibit high Phosphorus fixing capacity. Agronomic optimum concentrations of available phosphorus in the topsoil would guarantee that yields are not constrained by the availability of phosphorus in the soil (McDowell *et al*., 2024). Moreover, all profiles had high base saturation which indicates good nutrient retention due to the abundance of fine particles and weatherable minerals present (Yli-Halla and Räty, 2024). Notably, this high base saturation extends throughout the entire subsoil as well. This implies that a higher base saturation is good for agricultural crop production.

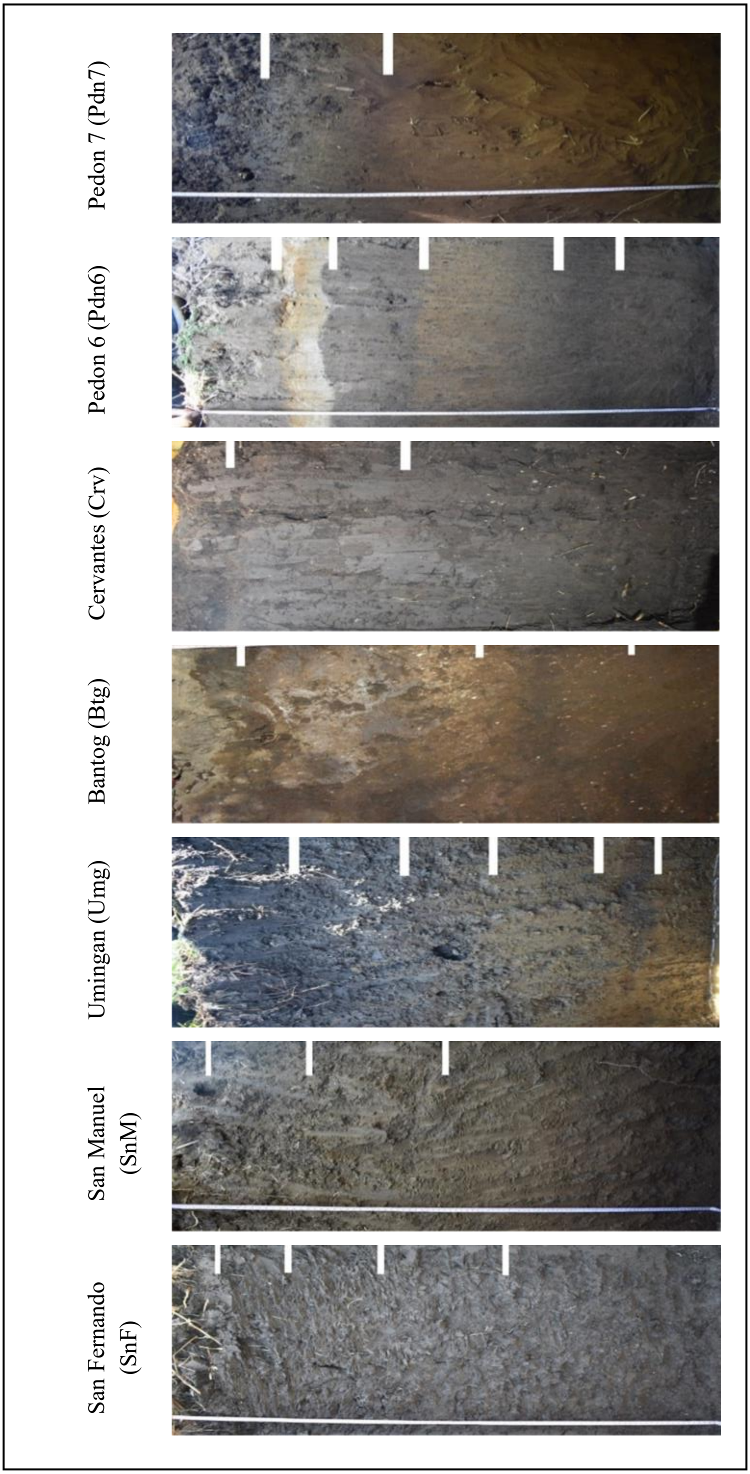

Figure 3. Images of the Different Soil Profiles/Pedon

Table 4. Morphological Characteristics of the Soil Profile/Pedon

Horizon	Depth (cm)	Matrix color (moist)	Texture	Structure	Consistence	Boundary	Roots	Pores
				SnF				
Ap	0-10	10YR 4/6 dark yellowish brow	C	wk, f, gr	s, p	ab, w	mn, c	mn, co, ir
Bt1	11-23	10YR 3/3 dark brown	C	wk, med, gr	s, p	cl, sm	fw, f	c, f, ve
Bt2	24-40	10YR 3/3 dark brown	C	wk, f, ab	s, p	cl, sm	fw, f	fw, f, ir
Bt3	41-63	7.5YR 2/4 very dark brown	C	mod, med, b	s, p	cl, w	f, vf	fw, f, ir
BC	64-102	7.5YR 4/3 brown	C	mod, med, b	s, p	cl, sm	vf, vf	fw, f, ir
				SnM				
Ap	0-8	10YR 2/4 very dark brown	CL	wk, f, gr	ss, sp	ab, sm	mn, med	cm, fw, ir
Bt	9-22	10YR 2/2 very dark	C	mod, co, gr	s, p	cl, wv	fw,f	fw, vf, t
Bw1	23-43	7.5YR 3/4 dark brown	CL	mod, co, gr	ss, sp	ab, sm	vfw,vf	fw, vf, t
Bw2	44-105	7.5YR 4/6	CL	wk, f, b	ss, sp	cl, sm	vfw,vf	fw, vf, ve
				Umg				
Ap	0-11	7.5YR 2/1 black	CL	mod, f, gr	ss, sp	cl, sm	mn, co	mn, co, t
Bw1	12-25	7.5YR dark brown	CL	mod, f, gr	ss, sp	gr, sm	mn, co	mn, co, t
Bw2	26-39	7.5YR 3/3 reddish brown	CL	mod, med, gr	ss, sp	gr, sm	cm, fw	cm, med, t
Bw3	40-57	5YR 6/6 yellowish red	CL	st, med, gr	ss, sp	gr, wv	fw, f	cm, fw, ir
2B	58-62	2.5YR 3/6 dark red	LS	sg	ns, np	cl, wv	vfw, vf	fw, f, ir
2C	63+	2.5YR 6/8	SL	wk, gr	ss, sp	ab, br	vfw, vf	fw, f, ir
				Btg				
Ap	0-14	2.5YR 2/2 very dusky red	L	wk, co, ab	ss, sp	ab, sm	cm, f	cm, med, t
AB	15-46	2.5YR 2/1 reddish black	L	wk, gr	ss, sp	cl, sm	fw, vf	fw, f, ir
Bt1	47-70	2.5YR 3/3 dark reddish brown	L	wk, gr	ss, sp	gr, wv	cm, f	fw, vf, ir

Table continued.

Bt2	71-100	5YR 3/4 dark reddish brown	L	wk, gr	ss, sp	gr, wv	cm, f	fw, vf, ir
				Crv				
Ap	0-14	2.5YR 2/2 very dusky red	C	wk, co, m	s,p	ab, sm	cm, f	cm, med, t
B1	15-37	2.5YR 2/1 very reddish black	C	mod, co, sb	s,p	cl, sm	fw, vf	fw, f, ir
B2	38-100	2.5YR 3/3 Dark reddish brown	C	st, co, sb	s,p	gr, wv	cm, med	fw, vf, ir
				Pdn6				
Ap	0-15	7.5YR 4/6 strong brown	SL	wk, f, gr	ss, sp	ab, sm	mn, f	cm, co, ir
Bw	16-23	5YR 5/4 strong brown	SiL	wk, f, gr	ss, sp	ab, wv	cm, f	fw, f, ir
B1	24-38	10YR 3/4 dark yellowish brown	SiL	mod, co, sb	ss, sp	cl, wv	vfw, vf	cm, f, t
B2	39-71	10YR 4/6 strong brown	SiL	mod, med, sb	ss, sp	gr, wv	vfw, vf	fw, f, ir
B3	72-83	7.5YR 7/10 strong brown	SiL	st, f, sb	ss, sp	gr, sm	vfw, vf	-
BC	84-108	7.5YR 3/6 strong brown	SiL	st, f, b	ss, sp	cl, sm	vfw, vf	-
				Pdn7				
Ap	0-19	5YR 3/4 dark reddish brown	L	mod, f, gr	s, p	ab, sm	cm, f	cm, med, t
C1	20-39	5YR 2/4 dark reddish brown	SL	st, f, gr	ss, sp	cl, sm	fw, vf	fw, f, ir
C2	40-105	5YR 4/6 yellowish red	S	sg	ns, np	gr, wv	cm, med	fw, vf, ir

S- sand, L-loam, C-clay, SiL-silt loam, LS- loamy sand, CL- clay loam, SL-sandy loam, wk- weak, mod- moderate, st- strong, f-fine, med- medium, gr-granular, co-columnar, sb-subangular, sg -single- grained, ss- slightly sticky, ns- non-sticky, sp, slightly plastic, s-sticky, p- plastic, ab-arupt, cl-clear, gr-gradual, sm-smooth, wv-wavy, br-broken, m- many, fw-few, vfw- very few, cm- common, vf-very fine, f-fine, ir- irregular, t-tubular, ve-vesicular.

Table 5. Physical Properties of the Soil Profile/Pedon

Horizon	Depth (cm)	Moisture Content (%)	Particle Size Distribution (%)			Textural Classes
			%Sand	%Silt	%Clay	
			SnF			
Ap	0-10	36.08	20	39	42	Clay
Bt1	11-23	34.96	14	17	69	Clay
Bt2	24-40	34.36	13	15	73	Clay
Bt3	41-63	34.68	13	12	75	Clay
BC	64-102	34.96	17	20	63	Clay
			SnM			
Ap	0-8	36.64	21	44	35	Clay loam
Bt	9-22	35.60	21	14	65	Clay
Bw1	23-43	36.40	23	38	38	Clay loam
Bw2	44-105	36.16	20	47	33	Clay loam
			Umg			
Ap	0-11	36.50	30	34	41	Clay
Bw1	12-25	36.32	28	33	39	Clay loam
Bw2	26-39	36.04	28	33	39	Clay loam
Bw3	40-57	35.32	29	37	34	Clay loam
2B	58-62	37.32	76	19	5	Loamy sand
2C	63+	35.96	22	53	25	Silt loam
			Btg			
Ap	0-14	37.04	46	38	16	Loam
AB	15-46	36.48	45	36	19	Loam
Bt1	47-70	35.84	36	42	22	Loam
Bt2	71-100	35.88	39	42	20	Loam
			Crv			
Ap	0-14	34.44	27	20	52	Loam
B1	15-37	35.60	24	20	56	Clay
B2	38-100	35.76	27	22	50	Clay
			Pdn6			
Ap	0-15	36.44	53	27	19	Sandy loam
Bw	16-23	35.00	48	51	1	Silt loam
B1	24-38	37.96	29	53	18	Silt loam
B2	39-71	37.76	34	50	16	Silt loam
B3	72-83	37.72	26	61	13	Silt loam
BC	84-108	37.92	24	61	16	Silt loam
			Pdn7			
Ap	0-19	38.16	24	50	26	Clay
C1	20-39	38.96	82	5	13	Loam
C2	40-105	39.48	90	4	6	Sandy loam

Table 6. Chemical Properties of the Soil Profile/ Pedon

Horizon	Depth (cm)	pH (H20)	%OM	%OC	P (mg/kg)	Exchangeable (cmol(+)/kg) Ca	Mg	Bases Na	K	CEC (cmol (+) /kg)
SnF										
Ap	0-10	8.5	1.4	0.81	5	32.54	9.06	1.87	0.67	37.23
Bt1	11-23	7.8	1.01	0.59	n.d*	34.01	16.07	3.11	0.64	47.71
Bt2	24-40	7.8	0.88	0.51	1	31.81	18.51	4.4	0.51	51.61
Bt3	41-63	7.7	0.65	0.38	n.d*	34.66	21.14	5.04	0.52	48.09
BC	64-102	7.6	0.63	0.37	n.d*	31.92	19.8	5.36	0.59	54.14
SnM										
Ap	0-8	7.5	2.33	1.35	25	32.93	8.04	2.02	1.75	42.94
Bt	9-22	7.1	2.98	1.73	5	30.62	18.33	1.4	1.81	43.59
Bw1	23-43	7.8	0.71	0.41	7	33.48	7.72	1.51	0.46	40.75
Bw2	44-105	7.9	0.21	0.12	n.d*	30.89	4.67	1.4	0.28	34.59
Umg										
Ap	0-11	7.1	n.d.	n.d.	26	29.51	9.68	0.9	3.63	41.2
Bw1	12-25	7.2	3.18	1.84	36	29.75	7.3	0.64	2.21	41.33
Bw2	26-39	7.7	0.99	0.57	7	29.56	6.42	0.69	1	44.87
Bw3	40-57	7.8	0.71	0.41	3	29.11	6.58	0.86	0.66	41.06
2B	58-62	7.7	n.d.	n.d.	10	26.24	4.36	1.07	0.76	30.58
2C	63+	7.8	0.57	0.33	6	26.74	5.65	0.94	0.6	48.43
Btg										
Ap	0-14	6.6	1.39	0.81	2	38.04	11.24	3.86	0.52	51.41
AB	15-46	6.7	0.79	0.46	5	34.49	12.64	1.87	0.4	48.25
Bt1	47-70	6.7	0.85	0.49	12	33.86	12.87	1.69	0.43	50.99
Bt2	71-100	6.7	0.46	0.27	13	33.98	12.76	1.91	0.43	51.28
Crv										
Ap	0-14	5.7	1.7	0.99	3.97	26.19	12.72	0.71	1.13	32.07
B1	15-37	6.0	0.82	0.48	2.62	30.49	15.45	0.88	0.38	43.25
B2	38-100	7.4	0.49	0.28	7	36.99	12.8	1.37	0.73	52.06
Pdn6										
Ap	0-15	6.5	0.52	0.30	55	30.12	7.9	1.12	0.59	39
Bw	16-23	6.5	0.1	0.06	3	10.55	3.01	1.14	0.62	18.52
B1	24-38	6.5	0.58	0.34	2	12.38	4.49	0.92	0.07	17.28
B2	39-71	6.7	0.63	0.37	0	13.63	4.28	1.22	0.07	19.6
B3	72-83	6.5	0.39	0.23	1	15.45	5.16	1.42	0.08	23.41
BC	84-108	6.7	0.54	0.31	1	16.1	6.24	1.54	0.08	23.56
Pdn7										
Ap	0-19	7.3	1.57	0.91	21	19.68	4.81	0.97	0.72	25.79
C1	20-39	7.5	0.12	0.07	8	11.46	2.18	0.47	0.23	14.78
C2	40-105	7.5	n.d.	n.d.	7	4.82	1.45	0.22	0.1	6.54

**n.d.-not detected*

2.4 Taxonomic Framework of the Soil Series

The soil classification of the seven study sites is presented in Table 7. Three of the pedons, the SnF series (Typic Epiaqualfs), Btg series (Typic Hapludalfs), Crv series (Typic Hapludalfs) were classified under the order Alfisols. These soils were characterized by high base saturation with CEC of >24 cmol (+)/kg of soil having an ochric epipedon where organic matter decreases with depth. However, these soils differ in certain characteristics. The SnF series had an aquic soil moisture regime implying higher water retention and potential for waterlogging while the Btg and Crv series had a udic soil moisture regime with distinct wet and dry season suggesting lower water retention and drought stress.

Table 7. Soil Classification using the USDA Framework (Soil Survey Staff, 2014)

Pedon	Soil Order	Subgroup	Great Group	Subgroup	Classification
San Fernando (SnF)	-Ochric epipedon -Argillic horizon - %BS within 125cm is >50% (Alfisol)	-Isohyperthermic TR -Aquic SMR (Aqualf)	-BS is >50% -Have episaturation (Epiaqualfs)	-CEC values of >24 cmol/kg - OC decreases with depth - other epiaqulafs (Typic epiaqualfs)	Typic Epiaqualfs
Family: Fine-clayey, Isohyperthermic, Typic Epiaqualfs					
San Manuel (SnM)	-Ochric epipedon -Cambic horizon (Inceptisol)	-Isohyperthermic TR -Udept SMR -No plaggen (Udept)	-BS is >50% -Irregular decrease of OC between 25cm to 125cm -other udepts (Eutrudepts)	-CEC values of >24 cmol/kg -slope of <25% -<50cm human-transported material at surface -Irregular decrease of OC -other Eutrudepts Typic eutrudepts	Typic Eutrudepts
Family: Fine clayey, Mixed, Isohyperthermic, Typic Eutrudepts					
Umingan (Umg)	-Ochric epipedon -Cambic	-Isohyperthermic TR -Aquic SMR	-BS is >50% -Have episaturation	-CEC values of >24 cmol/kg	Typic Epiaquepts

Table continued.

	(Inceptisol)	(Aquepts)	(Epiaquepts)	-OC decreases with depth -with mottles -Other aquepts that have episaturation (Typic epiaquepts)	
Family: Fine loamy, Mixed, Isohyperthermic, Typic Epiaquepts					
Bantog (Btg)	-Ochric epipedon -Argillic (Alfisols)	-Isohyperthermic TR -Udic SMR (Udalfs)	-No sulfide material -60% BS between 25 and 75 cm from mineral soil surface -Other udalfs (Hapludalfs)	-CEC values of >24 cmol/kg -%BS is >50% - color value <3 moist and <5 dry of throughout the upper 18cm mineral soil -other halpudalfs (Typic hapludalfs)	Typic Hapludalfs
Family: Loamy, Isohyperthermic, Typic Hapludalfs					
Cervantes (Crv)	-Ochric epipedon (>50% clay but not more than 60%) (Alfisols)	-Isohyperthermic TR -Udic SMR (Udalfs)	-BS% >50% -no natric -no glossic -no kandic -other udalfs (Hapludalfs)	-CEC values of >24 cmol/kg -Organic Carbon decreases with depth -other hapludalfs (Typic hapludalfs)	Typic Hapludalfs
Family: Fine clayey, Mixed, Isohyperthermic, Typic Hapludalfs					
Pedon6 (Pdn6)	-Ochric -Cambic (Inceptisol)	-Isohyperthermic TR -Udic SMR (Udepts)	-No sulfuride material at 50cm -no duripan or fragipan -other udepts (Dystrudepts)	-CEC values of <24 cmol/kg in the subsoil -BS% is >50 -other dystrudepts (Typic dystrudepts)	Typic Dystrudepts

Table continued.

Family: Fine loamy, mixed, Isohyperthermic, Typic Dystrudepts					
Pedon7 (Pdn7)	-Ochric -Cambic (Entisols)	-Isohyperthermic TR -Udic SMR (fluvents)	-BS% >50% -No calcic or duripan within 100cm -BS% >50% -other fluvents (udifluvents)	-CEC values of <24 cmol/kg in the subsoil -OC decreases with depth -%BS is >50% -other udifluvents (Typic udifluvents)	Typic Udifluvents
Family: Loamy Mixed, Isohyperthermic, Typic Udifluvents					

Table 8a. Land Quality and Climatic Characteristics of the Soil Series in Ilocos Norte

Land Characteristics	San Fernando (SnF)	San Manuel (SnM)	Umingan (Umg)	Pedon 6 (Pdn6)
Topography (t)				
Slope (%)	level to nearly level (1-3%)	level to nearly level (1-3%)	level to nearly level (1-3%)	level to nearly level (1-3%)
Wetness (w)				
Flooding	F0, F11	F0, F11	F2, F12	F0
Drainage	Moderate	Good	Poor	Good
Physical soil characteristics (s)				
Texture/ structure	C+60, s	C-60, v	CL	SiL
Coarse fragments (vol %)	1	0	2	1
Rooting depth (cm)	102	105	70	108
Soil fertility (f)				
CEC (cmol+/kg)	47.76	40.47	41.25	23.56
Base Saturation (%)	114	109	92	97
Organic Carbon (%)	1.57	2.68	2.34	0.79
Alkalinity (n)				
ESP (%)	8.09	3.92	2.13	5.53
Climatic Characteristics (c)				
Rainfall (mm)	Annual: 2,221.7	Annual: 2,221.7	Annual: 2,221.7	Jan-Mar: 14.4 Annual: 2,221.7
Temperature (°C)				
Ave. of max. and min. temp	24 – 30	24– 30	24– 30	24– 30
Relative humidity (%)	74-86	74-86	74-86	74-86

Table 8b. Land Quality and Climatic Characteristics of the Soil Series in Ilocos Norte continuation.

Land Characteristics	Pedon 7 (Pdn7)	Cervantes (Crv)	Bantog (Btg)
Topography (t)			
Slope (%)	level to nearly level (1-3%)	gently sloping to undulating (3-8%)	level to nearly level (1-3%)
Wetness (w)			
Flooding	F0	F0	F0
Drainage	Good	Imperfect	Good
Physical soil characteristics (s)			
Texture/ structure	L	C+60, s	L
Coarse fragments (vol %)	1	0	1
Rooting depth (cm)	105	100	100
Soil fertility (f)			
CEC (cmol+/kg)	15.70	42.46	50.48
Base Saturation (%)	99	111	99
Organic Carbon (%)	1.45	1.73	1.50
Alkalinity (n)			
ESP (%)	3.44	2.29	4.61
Climatic Characteristics (c)			
Rainfall (mm)	Jan-Mar: 14.4 Apr-Jun: 525 Jul-Sep: 1,524 Oct-Dec: 158.3 Annual: 2,221.7	Jan-Mar: 14.4 Apr-Jun: 525 Jul-Sep: 1,524 Oct-Dec: 158.3 Annual: 2,221.7	Jan-Mar: 14.4 Apr-Jun: 525 Jul-Sep: 1,524 Oct-Dec: 158.3 Annual: 2,221.7
Temperature (°C)			
Ave. of max. and min. temp	24– 30	24– 30	24– 30
Relative humidity (%)	74-86	74-86	74-86

Textural sequence: Cm: Clay, massive; SiCm: silty clay, massive; C+60,v: clay, more 60% 0-2μ, vertisol structure; C+60,s : clay, more 60% 0-2μ, blocky structure; C-60, v : clay, less 60% 0-2μ, vertisol structure; C-60,s : clay, less 60% 0-2μ, blocky structure; SiCs : silty clay, blocky structure; Co : clay, oxisol structure; SiCL: silty clay loam; CL : clay loam; Si : silt ; SiL : silt loam; SC: sandy clay ; L: loam; SCL: sandy clay loam; SL: sandy loam: LfS: loamy dine sand; Lms: loamy medium sand; LcS : loamy coarse sand; fS: fine Sand; mS: medium sand; cS: coarse sand

F0: no flooding

An argillic horizon is evident in the SnF and Btg series, while the former has an episaturation. The Btg series includes no sulfide materials present in the subsurface horizon. Light color value both moist and dry in the upper layer indicates low organic matter content. This might require additional amendments for optimal agricultural productivity. For Crv series, it is usually found in the rolling areas. It has an ochric epipedon due to its low organic matter content, with a clay content of between 50% and 60%. Challenges that arise from this soil include water retention and susceptibility to compaction. It has udic moisture regime. The absence of calcic, duripan, lithic contacts, and cracking within 125 cm of mineral soils suggest relative uniformity and good drainage potential.

The SnM series (Typic Eutrudepts), Umg series (Typic Epiaquepts), Pdn6 (Typic Dystrudepts) were classified under Inceptisols. This is a young soil with incipient soil development. It is found in places with high temperature (> 22°C). It also has a good capacity to retain nutrients with CEC values greater than 24 cmol(+)/kg of soil. Organic matter decreases with depth. For the Umg series, episaturation was observed having saturation for a significant part of the year. Mottles were also found which subjected the soil to alternate wetting and drying. Pdn6 was classified as Typic Dystrudepts. SnM and Pdn6 found the presence of cambic subsurface horizons indicates some development but not enough to be considered mature soil. Moreover, the absence of duripans or fragipans that allow good drainage and root penetration was evident. SnM was high in CEC (greater than 24 cmol (+)/ kg of soil) which indicates higher nutrient retention. On the other hand, Pdn6 has lower CEC (less than 24 cmol (+)/kg of soil) in the subsoil which is a constraint in agricultural production for deep-rooted crops.

Pdn7 (Typic Ustifluvents) belongs to the order Entisols. This order indicates a very young soil with minimal development. The base saturation exceeded 50%. The absence of calcic or duripan within 100 cm indicates good drainage and root penetration. This soil's main challenge is the low CEC values (less than 24 cmol (+)/ kg of soil) on the subsoils which may require additional fertilization to maintain soil fertility. Like other pedons discussed, the organic matter content decreased also with depth.

3.5 Crop Suitability Assessment

A comprehensive crop suitability assessment was done utilizing the LURs with LQs methodology (Sys *et al.*, 1993). Optimal areas for various crops such as irrigated rice, upland rice, maize, tomato, sugarcane, onion, garlic and robusta coffee were mapped (Figures 4 to 10) from the resulting crop suitability assessment.

The SnF series was highly suitable (S1) for irrigated rice and maize with scores of 83 and 82, respectively (Table 9a and b). Garlic, onion, rainfed upland rice and sugarcane were found to be moderately suitable. Fertility status of the soil (S2f) limits these crops in this soil series. Robusta coffee and tomato were marginally suitable because of fertility limitations (S3f), however, with much intense requirement for soil fertility program as compared to other crops.

SnM series were found to be highly suitable for five crops studied namely garlic, irrigated rice, maize, onion and tomato with score ranging from 75 to 93. Rainfed upland rice and sugarcane were moderately suitable while robusta coffee remained marginally suitable due to persistent fertility constraint.

The Umg series was not suitable for robusta coffee, rainfed upland rice and sugarcane. Other crops were found to be of varying suitability ranging from moderately to marginally suitable. Wetness limitations were the reason for this crop suitability assessment. In this soil condition, irrigated rice is the best option to be planted due to limitation identified. In contrast, Btg series was predominantly S1 for most crops except robusta coffee and sugarcane. These crops were moderately suitable due to climate and fertility limitations (S2cf).

Table 9a. Land Suitability Index (LSI) by Land Units

Crops	San Fernando	San Manuel	Umingan	Bantog	Cervantes	Pedon 6	Pedon 7
Robusta Coffee	45	41	18	63	18	50	49
Garlic	73	79	41	83	56	64	56
Irrigated Rice	83	93	63	82	48	66	61
Maize	82	82	35	86	41	93	84
Onion	73	79	41	83	56	64	56
Rainfed Upland Rice	65	75	44	90	52	72	73
Sugarcane	60	61	16	68	25	69	64
Tomato	53	78	31	83	32	64	87

Table 9b. Land Suitability Classification by Land Units

Crops	San Fernando	San Manuel	Umingan	Bantog	Cervantes	Pedon 6	Pedon 7
Robusta Coffee	S3f	S3sf	N	S2f	N	S2f	S3f
Garlic	S2	S1	S3w	S1	S2w	S2f	S2
Irrigated Rice	S1	S1	S2w	S1	S3t	S2f	S2f
Maize	S1	S1	S3w	S1	S3w	S1	S1
Onion	S2	S1	S3w	S1	S2w	S2f	S2
Rainfed Upland Rice	S2f	S2	N	S1	S2w	S2f	S2f
Sugarcane	S2cf	S2c	N	S2c	N	S2cf	S2cf
Tomato	S3f	S1	S3w	S1	S3w	S2f	S1

The Crv series showed moderately suitable for garlic, onion, and rainfed upland rice due to wetness limitations (S2w). Wetness and topography limitations deemed irrigated rice, maize and tomato to be marginally suitable (S3wt). Robusta coffee and sugarcane were not suitable in this kind of soil.

Pdn6 and Pdn7 were moderately suitable for most crops with ratings ranging from 50 to 73. Maize was highly suitable with ratings of 84 and 93 for Pdn7 and Pdn6, respectively. However, robusta coffee was found marginally suitable for Pdn7 due to fertility issues.

4. Conclusion and Recommendation

The study sites vary in geomorphic and physicochemical properties. Among the seven land units studied, three soils belong to inceptisols, namely SnM, Umg, and Pdn6; three belong to alfisols, specifically SnF, Btg, and Crv; and one belongs to entisols, which is Pdn7. The overall land suitability rating for all study sites ranges from highly suitable (S1) to permanently not suitable (N). The SnF and SnM series are highly to moderately suitable for crops such as irrigated rice, onion, rainfed upland rice, maize, garlic, and sugarcane. To address soil fertility issues, proper phosphate fertilization (P_2O_5) is recommended for SnF, Btg, and Crv, while the addition of organic fertilizers is recommended for SnF, SnM, Btg, Pdn6, and Pdn7. For the Umg series, the suitability rating ranges from moderate to marginal, with limitations due to wetness, certain physical properties, and fertility. To maintain crop productivity, interventions such as raised beds, the creation of water canals or flood control systems, optimal planting timing, and the use of combined inorganic and organic fertilizers should be considered. The Btg series is highly suitable for rainfed upland rice, irrigated rice, and maize. The Crv soil is suited for irrigated rice, though some areas have limitations due to topography. For crops like onion, garlic, maize, tomato, and sugarcane, it is advised to use judicious fertilization, practice close-growing crops, employ contour tillage, and consider cover cropping and terracing with proper drainage outlets.

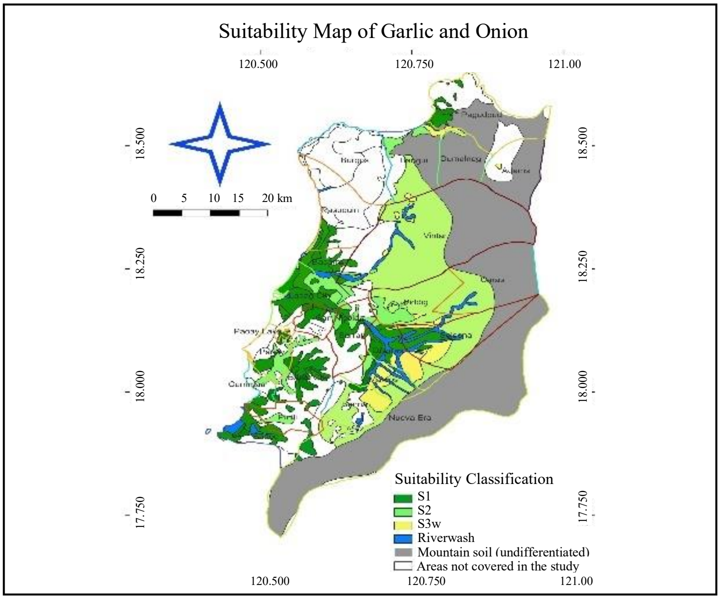

Figure 4. Suitability map of Garlic and Onion

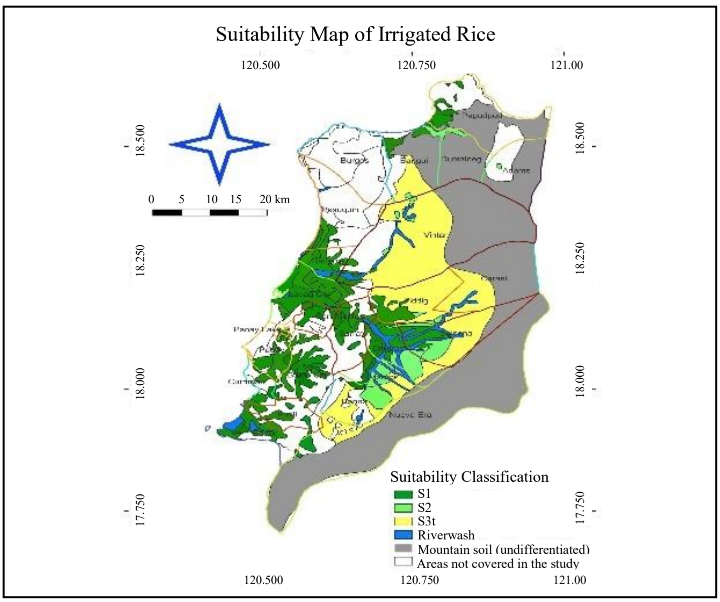

Figure 5. Suitability map of Irrigated Rice

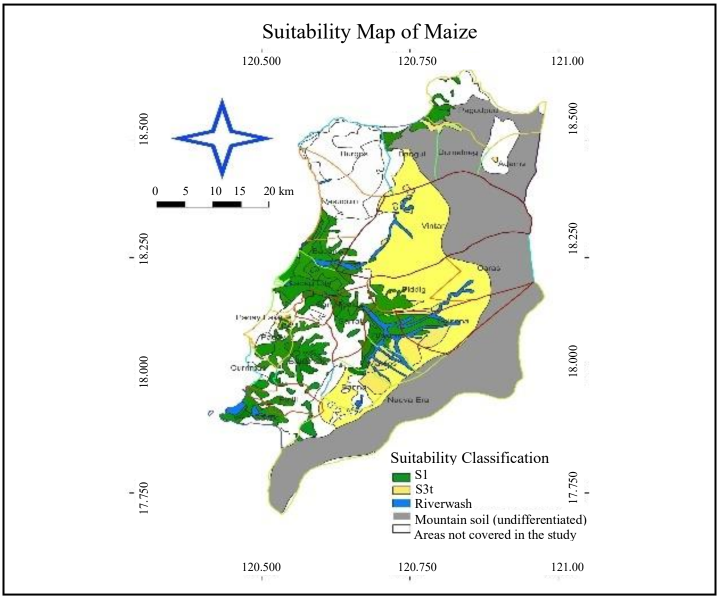

Figure 6. Suitability map of Maize

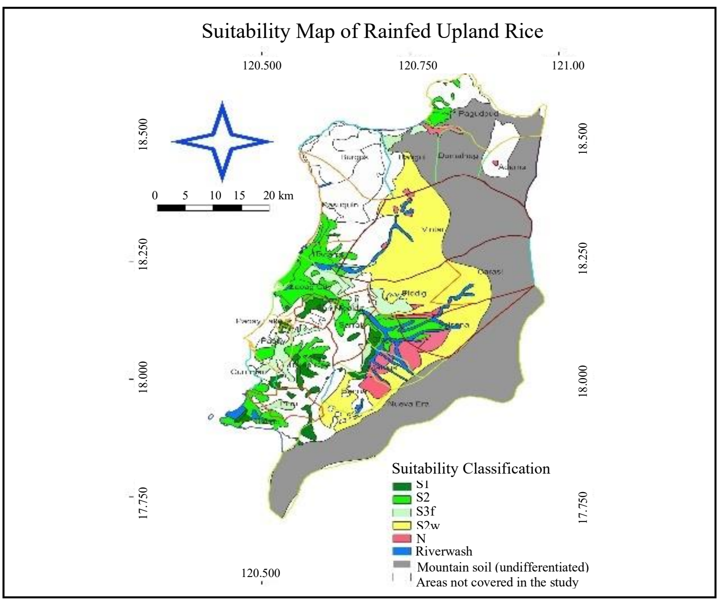

Figure 7. Suitability map of Rainfed Upland Rice

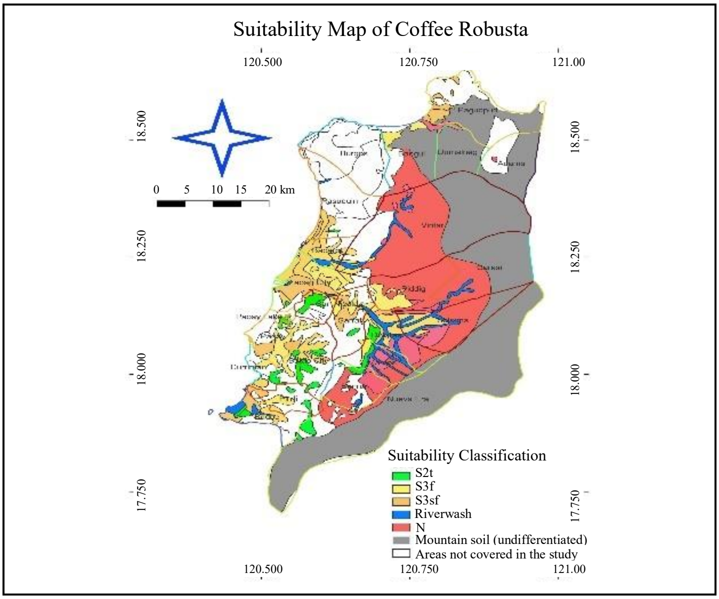

Figure 8. Suitability map of Robusta Coffee

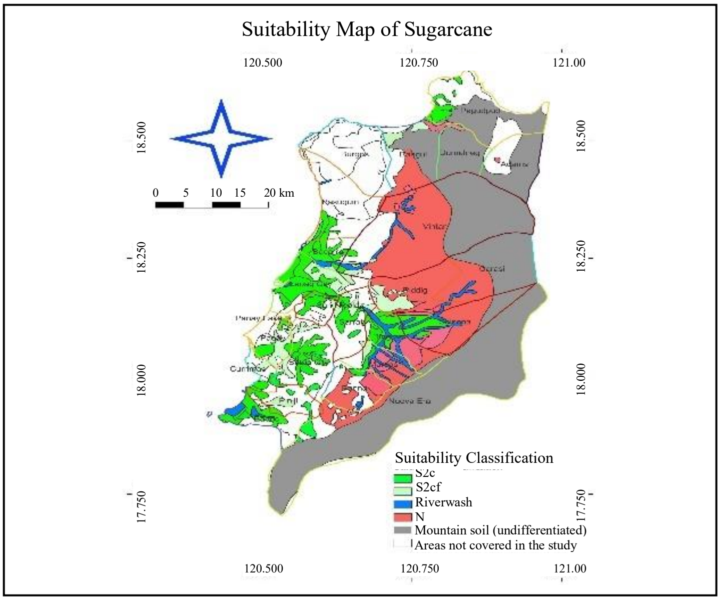

Figure 9. Suitability map of Sugarcane

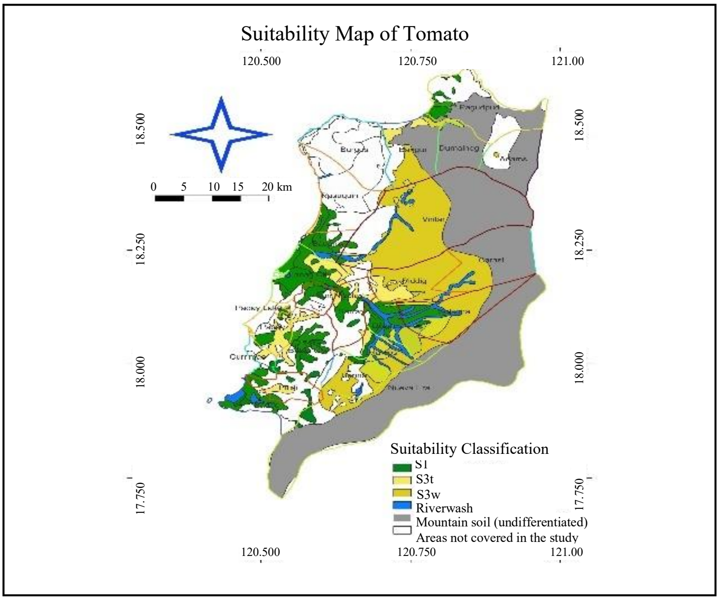

Figure 10. Suitability map of Tomato

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