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Soil classification, suitability assessment, and constraints analyses of major soil series grown to sugarcane in Negros Occidental, Philippines

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ABSTRACT

Five major soil series (Guimbalaon, Isabela, Luisiana, San Manuel, and Silay) in Negros Occidental were evaluated to assess the suitability of major soil series grown to sugarcane and identify possible constraints of the soils for sugarcane production. Specifically, the study assessed the morphological, physical, and chemical properties of soils associated with the growing of sugarcane; evaluated the land quality requirements for major soil series grown to sugarcane; determined the suitability of major soil series for sugarcane production; and evaluated the possible soil constraints to sugarcane production.

Soil pH, total N, percent organic C, and available P were found highest in Isabela series; exchangeable K in Guimbalaon series; exchangeable Na, Ca, and Mg, extractable Fe, and CEC in San Manuel series; and exchangeable Al in Luisiana series. All of the soil series evaluated were classified as marginally suitable (S3) for sugarcane production, although soil constraints varied across soil series. Topography and wetness were the severe constraints common to all soil series. Limitations on fertility and physical soil characteristics were considered moderate and manageable.

Keywords: soil classification, soil suitability, soil constraints, sugarcane production

INTRODUCTION

Sugarcane production is a key economic activity in over 100 countries, particularly in developing countries with high proportion of poor and unemployed groups. As a provider of income and employment, sugarcane-based agriculture has an important role to play in the economic growth of developing economies, especially in the upliftment of financial condition of under-skilled rural people (Meyer et al 2013). The sugarcane industry has expanded enormously over the

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for ethanol production. Sugarcane production is becoming more concentrated within countries, with the top ten sugarcane-producing countries increasing their share from 56% in 1980 to around 70% in 2010 (Meyer et al 2013). The main driver for this expansion is increased world sugar consumption resulting from rising incomes and changes in food consumption patterns, particularly in Asia and Africa (Meyer et al 2013).

Given that more than 20 million hectares of land are cropped to sugarcane mostly as a monoculture, sugarcane production continues to raise concerns about environmental impact and sustainability due to intensive use of agricultural chemicals such as fertilizer, herbicides and ripeners coupled with greater reliance on heavier mechanical harvesters and infield haulage equipment. Sugarcane is listed as one of the four crops to be investigated in terms of its impact on biodiversity as part of the International Finance Corporation's Biodiversity Agricultural Commodities Program (IFC-BACP). It is also widely acknowledged that commercial agriculture such as sugarcane production has the potential to impose severe hydrological, soil degradation, and biodiversity impacts on the natural environment. An estimated 1.5 billion people, or a quarter of the global population, depend directly on land that is being degraded (FAO 2009). Globally, about one tenth of the world's arable area (1.2 billion ha) is affected by serious degradation with about 300m ha now unusable (UNEP 1997). If agriculture does move to embrace an ecologically-sympathetic approach, the great scientific challenge for the coming years will be to understand more fully the life in our soils and how it may be better managed for food production and environmental renewal (Cribb 2006).

Soil classification arose a long time ago when humans noticed and tried to explain differences in the suitability of soils for different crops (Brady & Weil 2002). Scientists have developed different systems of soil classification to group soils of similar properties in one class, allowing them to exchange information on soils found in different areas. Soil classification also helps in determining the best possible use and management of soils. This system of classification is strictly qualitative and hierarchical, wherein a soil is classified based on the existence of diagnostic soil horizons and diagnostic soil properties as well as threshold values for measurable soil properties measured up to a maximum soil depth of 200cm. Hence, classification enables the user to see relationships among and between soils and their environment as well as formulate principles of prediction value (Soil Survey Staff 1951 as cited by Beinroth et al 1978).

The effective and sustainable use of land involves matching site conditions with the specific requirements and potential impacts of different land uses. Significant costs to the environment and society in general may result where land is used for purposes that it is not physically capable of supporting. Suitability analysis is used to determine the appropriateness of a given area for a particular use. The basic premise of suitability analysis is that each aspect of the landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned. It is used extensively to find and maintain good cropland as well as ensure proper crop rotation. Hence, in the process it helps to ensure that land resources are used in the most productive and sustainable ways because different crops require different land types and growing conditions. Consequently, the productive potential of a soil is limited by its inherent

constraints. Identifying and managing these constraints is fundamental to sustainable production systems.

Generally this study aimed to assess the suitability of major soil series grown to sugarcane in Negros Occidental and identify possible constraints of the soils for sugarcane production using soil classification. Specifically, the study intended to: assess the morphological, physical, chemical, and mineralogical properties of soils associated with the growing of sugarcane; identify the taxonomic classification of major sugarcane soils in Negros Occidental; know the land quality requirements for major soil series grown to sugarcane; determine the suitability of major soil series for sugarcane production; evaluate the possible soil constraints in sugarcane management; and utilize soil classification in soil fertility assessment and fertilizer management.

MATERIALS AND METHODS

Survey, Assessment and Selection of the Study Sites

A comprehensive assessment on sugarcane areas was conducted. Topographic, geologic, and soil maps as well as other publications were used as materials in identifying the sampling sites. Major soil series of the province that were mostly grown to sugarcane were identified and utilized in this study. Of the nine soil series that were mostly planted to sugarcane in Negros Occidental, five soil series (Guimbalaon, Luisiana, Isabela, San Manuel, Silay), were comprehensively assessed and utilized in this study since these were the most widespread soil series found in the province (Figure 1).

Soil Data and Climatic Characteristics Collection

Data on soil and climatic characteristics of the major soil series grown for sugarcane were collected from available references. Simplified Keys to Soil Series of Negros Occidental (PhilRice 2014) and Soil Survey Reports of Negros Occidental (Alicante et al 1951) were used as references for most of the soil characteristics. Climatic characteristics of each soil series were obtained from www.en.climate-data.org.

Suitability Evaluation and Constraint Analyses

Soil and climatic characteristics of the five soil series (Guimbalaon, Isabela, Luisiana, San Manuel, Silay) were matched with the criteria set by Sys et al (1993) for sugarcane requirements to determine their suitability class. Matching was done using the FAO land evaluation system (FAO 1976) with the following interpretations of suitability classes:

- S1 – soils without limitations or with 2 or 3 slight limitations.
- S2 – soils with 2 or 3 slight limitations and no more than 2 moderate limitations.
- S3 – soils with more than 2 moderate limitations and/or no more than 1 severe limitation that however does not exclude the use of the land.

- N1 – soils with one severe limitation that excludes the use of the land or more than one severe limitation that can be corrected.
- N2 – soils with severe or very severe limitations excluding the use of the land and that cannot be corrected.

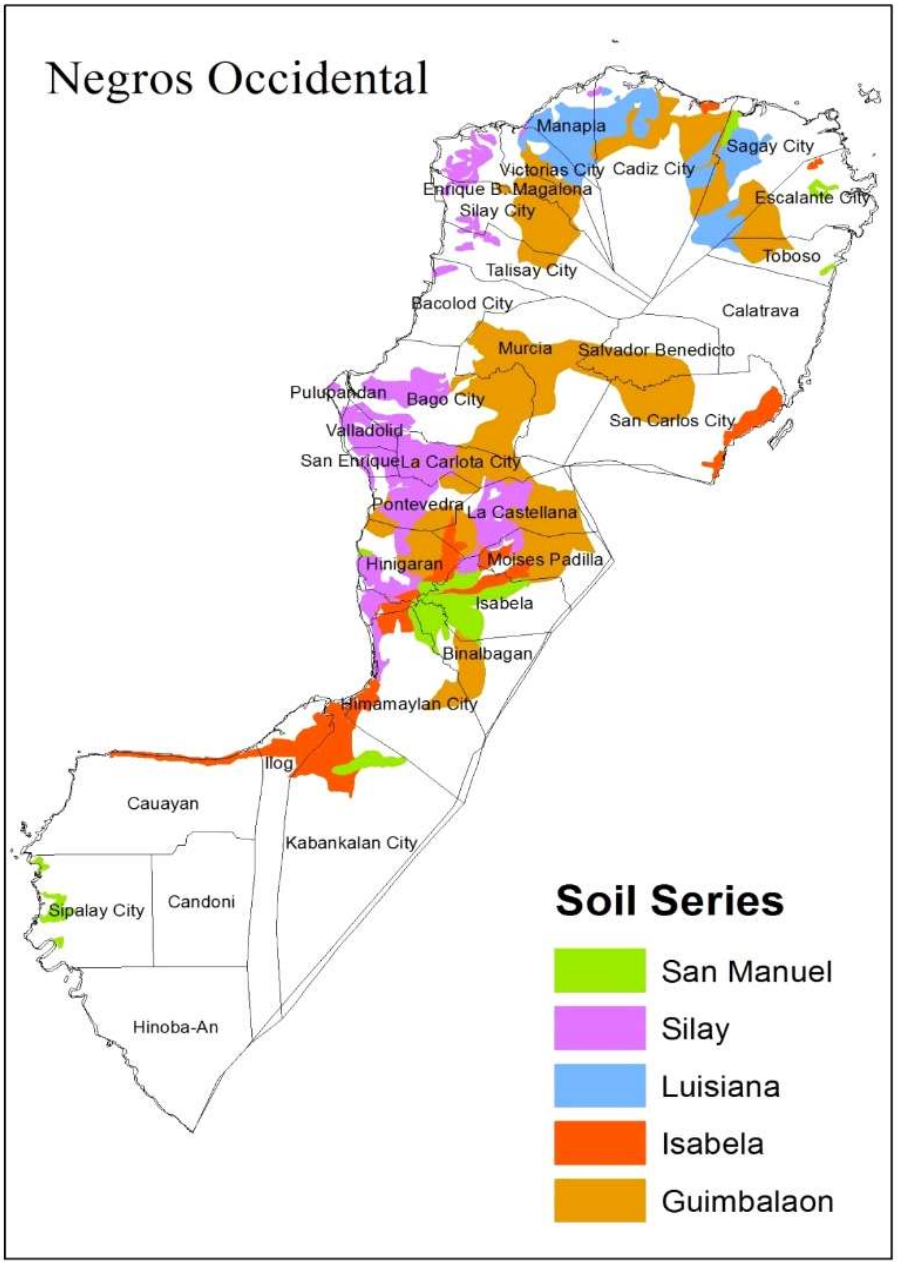

Figure1. Distribution of the five major soil series grown to sugarcane in Negros Occidental

Accordingly, land suitability indicates whether the land unit is suitable (S) or not suitable (N) for a specified use. Classes spell the degree of suitability. Subclass reflects the kinds of limitation due to topography, soil wetness (flooding and drainage), soil physical properties (texture, coarse fragments and soil depth), soil fertility (apparent CEC, base saturation, and soil pH) and climate (annual precipitation and mean monthly temperature). Letter suffixes were assigned to each subclass: "t" for topography, "w" for wetness, "s" for physical properties, "f" for fertility, and "c" for climate. Soil parameters that were identified to limit production after determining the suitability of the soils were considered constraints. Suitability and Constraints Maps were made thereafter.

Soil Collection and Laboratory Analysis

Twenty soil samples were collected from representative sites and were processed and analyzed in the laboratory for soil pH, total N, available P, exchangeable bases, percent organic carbon, extractable Fe, exchangeable Al, particle size distribution, and cation exchange capacity following standard procedures.

RESULTS AND DISCUSSION

Morphological, Physical, and Chemical Characteristics of Major Soil Series Grown to Sugarcane

Buol et al (1997) stated that soil morphology reflects the important properties observed, described, and studied in the field where the soil is in its natural state. The differences in soil characteristics associated with landscape position are usually attributed to differences in the runoff, erosion, and deposition processes which affect soil genesis (Canton et al 2003, Dengiz 2010). Hence, assessment of the potentials and limitations of soil for the different land uses provides the basis for formulating the appropriate management strategies which target specific management problems to improve crop production and soil and water conservation strategies (Karuma et al 2015).

Five major soil series namely Guimbalaon, Luisiana, Isabela, San Manuel, and Silay grown to sugarcane in Negros Occidental were assessed. These five soil series were described in the Simplified Keys to Soil Series Guidebook (PhilRice 2014). Guimbalaon soil was formed from older alluviums, which are country rocks and washed out materials from the upper slopes. It is described as a young soil in its incipient development stage but has not yet fully developed its diagnostic horizons. Isabela soil was formed from alluvial deposits and is described as an old soil with high base status and alluvial accumulation of clay in the subsoil horizons from underlying horizons that exhibits minimum complexity in its horizonation. Luisiana soil developed from highly weathered basaltic volcanicro ck materials and is described as a highly leached old soil with accumulation of clay in the lower horizon and has low base status. San Manuel soil is a non-calcareous soil that formed in recent water-deposited sediments mainly in flood plains which are frequently subjected to flooding. Silay soil is described as a fine loamy-textured soil with more than 15% fine sand including gravels and 18 – 35% clay composed of different minerals (mixed).

Based on the results of the soil chemical analyses of the different soil series, Isabela series obtained the highest value on pH (both in H_2O and $CaCl_2$), total nitrogen, percent organic carbon, and available phosphorus among other soil series. Exchangeable K was found to be highest in Guimbalaon series while exchangeable Na, Ca, Mg as well as extractable Fe and cation exchange capacity were highest in San Manuel series. Exchangeable Al was highest in Luisiana series as compared to other soil series. However, Luisiana series was found to be low in most of the chemical properties evaluated in the soil pH in both in H2O and CaCl2, percent total N, exchangeable K, Na, Ca, and Mg, CEC, and extractable Fe while Silay series were low in percent organic carbon, available P and Isabela series for exchangeable Al. Morphological, physical, and chemical characteristics of these soils are shown in Table 1.

Land Qualities/Land Characteristics of Major Soil Series Grown to Sugarcane

According to Sys et al (1991), land characteristics are measurable properties of the physical environment directly related to land use while land qualities are measurable, calculable, or estimable attributes, representing the immediate requirements of the land utilization types and are in fact the consequences of land characteristics. In addition, both land characteristics and land qualities influence the suitability of land that will depend on the fact whether some of these characteristics/qualities are optimal, marginal, or suitable. Therefore, evaluation of characteristics and qualities, for specific land use, is an essential stage in the overall evaluation work (Sys et al 1991). The summary of the land characteristics of major soil series, namely, Guimbalaon, Isabela, Luisiana, San Manuel, and Silay are presented in Table 2.

Land Quality Requirements of Sugarcane

Land Quality Requirements can be synthesized from the analysis of the behavior of crop yields as influenced by temperature, moisture regime, and soil properties including effective rooting depth, texture, internal drainage, CEC, pH, and salinity.

In this study, the land quality requirement of sugarcane was analyzed. The standard crop requirement information was based on Land Evaluation of Sys et al (1993) involving climate, landscape, and soil conditions. The evaluation applies the information on topography (t), wetness (w), physical soil characteristics (s), soil fertility characteristics (f), and climate (c) of the different major soil series under study. Each parameter measured for the different soil series were rated as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2). Land suitability classes were made thereafter as shown in table 3. Based on the results, the soil series have different suitability with respect to the different parameters mentioned. Results revealed that all soil series namely Guimbalaon, Isabela, Luisiana, San Manuel, and Silay were classified as marginally suitable (S3); however, limitation for sugarcane production varies in each soil series. A suitability map was then prepared (Figure 2). Soils that were not studied and found in the map were indicated as others.

Table 1.Morphological, Physical, and Chemical Characteristics of Major Soil Series Grown to Sugarcane in Negros Occidental

Soil Characteristics	Soil Series				
	Guimbalaon	**Isabela**	**Luisana**	**San Manuel**	**Silay**
	Morphological and Physical Characteristics				
Taxonomic Name	*Typic Hapludands*	*Vertic Hapludolls*	*Orthoxic Palehumults*	*Fluventic Eutropepts*	*Aquic Hapludalfs*
Relief	Rolling to Hilly	Level	Rolling to Mountainous	Level to Slightly Undulating	Level
Soil Parent Material	Older Alluvium	Alluvial deposits	Highly Weathered Volcanic Basaltic Rock Materials	Recent water-deposited sediments mainly floodplains; weakly stratified alluvium	Old Alluvium
Mineralogy	Significant amounts of amorphous minerals and Al-OH complexes	Composed mostly of minerals which have shrink-and-swell capacity	Kaolinite materials	Composed of different clay minerals	Composed of different minerals (mixed)
Oxygen availability to roots (Drainage) a. Depth of mottles b. Soil Drainage Class	Black and Red spot mottles at 30-60 cm depth	Black / Red / Gray spot mottles at 30-60 cm depth	Red specks and Black spots at topsoil (0-30 cm depth) and subsoil (30-60 cm depth)	Brown and Gray spot mottles at 30-60 cm depth	Yellowish-brown spot mottles at 30-60 cm depth

Table 1. Continuation

Soil Characteristics	Soil Series: Guimbalaon	Isabela	Luisana	San Manuel	Silay
Morphological and Physical Characteristics					
Coarse Fragments	Reddish and angular gravels at the surface; soft powdery – red and black fragments; weathered andesite and basalts; partially weathered rock outcrops in some places	None	None	None	None
Water Retention	Low to Moderate	Very High	Moderate to High	Moderate	Moderate
Permeability	Moderate to Rapid	Slow	Moderate	Moderate to Rapid	Slow to Moderate
Workability/ Tilth	Moderate to Easy	Hard to Moderate	Moderate	Easy	Easy
Conditions for Germination					
a. Gravel Content	Reddish and angular gravels at the surface	None	None	None	None
b. Erosion Status	Severe	None	Moderate to Severe	None	None
Flooding	None	Seasonal River Flooding	None	Seasonal River Flooding	Slight Seasonal Run-off Flooding
Clay (%)	25.40	23.00	48.80	40.80	26.00
Silt (%)	19.40	15.00	14.20	24.60	17.60
Sand (%)	55.20	62.00	37.00	34.60	56.40
Soil Types	Clay / Fine Sandy Loam / Gravelly Loam	Clay / Sandy Loam	Clay	Loam / Fine Sandy Loam	Fine Sandy Loam / Loam / Clay

Table 1 continued….

Table 1. Continuation

Soil Characteristics	Soil Series				
	Guimbalaon	Isabela	Luisana	San Manuel	Silay
Chemical Characteristics					
pH (H_2O)	6.07	6.45	4.86	5.76	5.54
pH ($CaCl_2$)	5.22	5.82	4.16	5.17	4.76
Total N (%)	0.10	0.13	0.10	0.12	0.11
Organic C (%)	1.03	1.20	1.13	1.08	0.83
Available P (mg/kg)	40.69	82.45	13.47	46.83	11.45
Exchangeable K (me/100g)	0.95	0.39	0.04	0.21	0.14
Exchangeable Na (me/100g)	0.09	0.06	0.01	0.17	0.10
Exchangeable Ca (me/100g)	11.01	17.71	2.22	27.23	8.10
Exchangeable Mg (me/100g)	1.10	1.65	0.15	2.31	1.16
CEC (cmol/kg)	9.72	15.79	7.65	19.06	8.14
Exchangeable Al (me/100g)	0.02	0.01	0.28	0.02	0.02
Extractable Fe (mg/kg)	78.29	98.11	37.06	139.93	94.60

Table 2. Land Characteristics of Major Soil Series Grown to Sugarcane in Negros Occidental

Soil Series	Soil Physical and Chemical Characteristics										Climatic Characteristics		
	Slope	Flooding	Drainage	Texture	Coarse Fragment	Effective Rooting Depth	Apparent CEC (cmol/kg)	Base Saturation (%)	pH	Organic Carbon (%)	Temperature (°C)	Rainfall (mm)	RH (%)
Guimbalaon	18 - 40	None	Moderate to Good	Clay / Fine Sandy Loam / Gravelly Loam	Outcrops and pebbles	Shallow (0.5m)	45.96	130.38	6.07	1.03	26.9	2,513	82
Isabela	0 - 2	Seasonal flooding	Poor to moderate	Clay / Sandy Loam	None	Deep (>1.0 m)	195.94	134.59	6.45	1.20	27.3	2,243	82
Luisiana	18 – 25	None	Good	Clay	None	Very Deep (>2.0 m)	16.20	34.51	4.86	1.13	27.4	2,156	82
San Manuel	0 - 5	Seasonal flooding	Good	Loam / Fine Sandy Loam	None	Deep (>1.0 m)	49.00	157.50	5.76	1.08	27.2	2,374	82
Silay	0 - 2	Seasonal flooding	Poor to moderate	Fine Sandy Loam / Loam / Clay	None	Moderate (0.8 m)	32.85	118.31	5.54	0.83	27.1	2,722	82

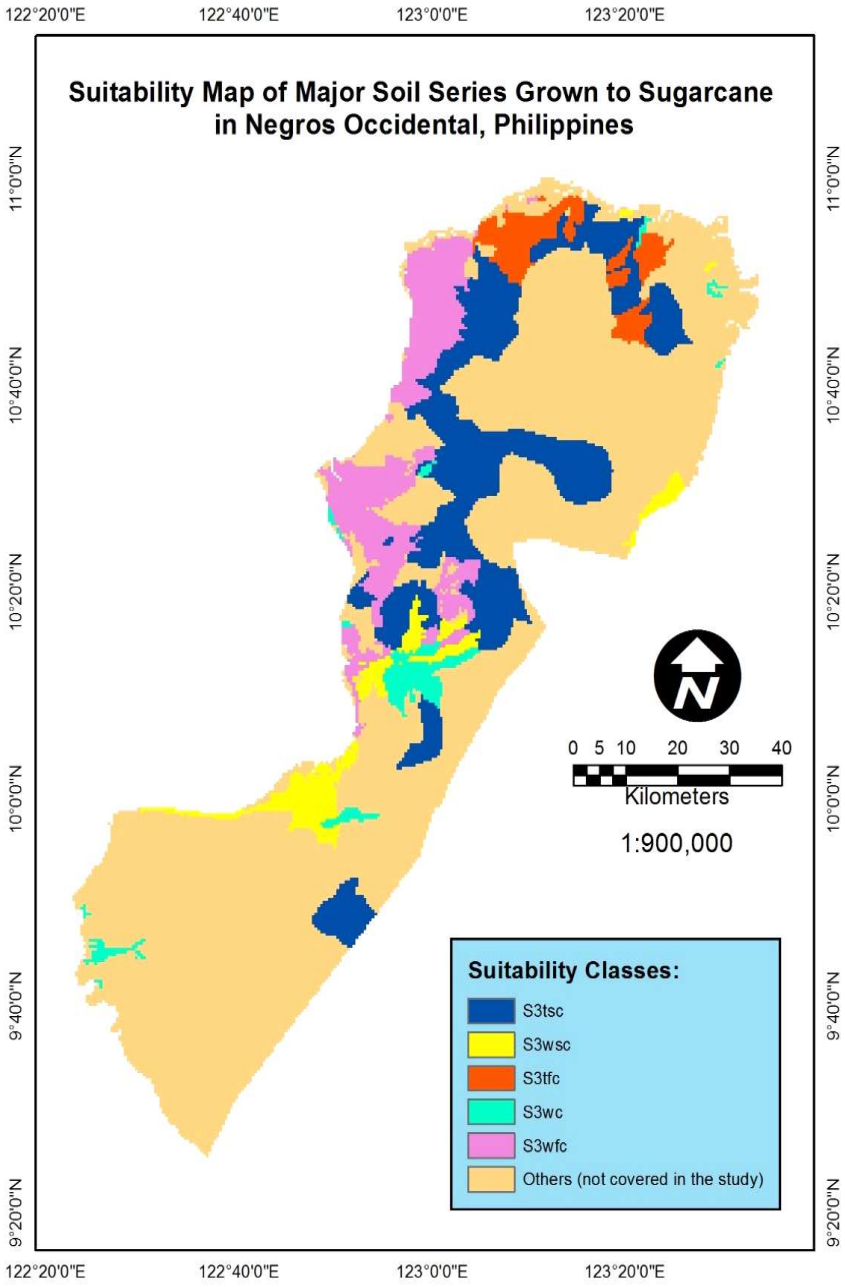

Figure 2. Suitability Map of Major Soil Series Grown to Sugarcane in Negros

Crop Constraints Analysis

The use of land limitations is a way of expressing the land characteristics or land qualities in a relative evaluation scale. Limitations are deviations from the optimal conditions of a land characteristics/land quality which adversely affect a kind of land-use (Sys et al 1991). The suitability ratings (Table 3) were utilized in the determination of the limitations or constraints of the crop from the different soil series under study. Based on the results, topography and wetness are the severe constraints for most of the soils. The influence of landscape on agricultural land use is multiple. Topography or relief is the expression of the interaction of the several different phenomena and processes within the earth's crust and on its surface. Its form and dimensions are primarily related to geological formations and to the climate, both past and present, which have either directly or indirectly acted upon these formations. On the other hand, wetness situation of a land unit is defined by drainage and flooding. Drainage is considered in almost every system of land capability classification. For instance, the suitability for upland crops decreases when drainage conditions become impeded. Likewise, flooding is also considered a serious limitation (Sys et al 1991).

Nevertheless, climate specifically relative humidity (RH) was observed to be the common factor for all soil series which moderately limited production of sugarcane since it had exceeded the maximum requirement of humidity needed by the crop. At specific crop development stages, a too high relative humidity may affect susceptibility to diseases. A too low relative humidity at seed formation may cause shrinkage of seeds and lower yields (Sys et al 1991).

Other factors noted were physical soil characteristics and fertility; however, limitation is moderate and manageable. Table 4 presents the summary of constraints of the major soil series for sugarcane production. Isabela, San Manuel, and Silay series have problems on wetness due to its seasonal flooding occurrences (Table 2). On the other hand, Guimbalaon and Luisiana series have constraint on topography because of its rolling to hilly to mountainous topographic position (Table 2). A constraints map is presented in Figure 3.

Table 3. Suitability Evaluation of Major Soil Series Grown to Sugarcane in Negros Occidental

Land Qualities / Land Characteristics	GUIMBALAON		ISABELA		LUISIANA		SAN MANUEL		SILAY	
	Qualities	Rating	Qualities	Rating	Qualities	Rating	Qualities	Rating	Qualities	Rating
Topography (t)										
Slope (%)	18 - 25	S3	0 - 2	S1	18 - 40	S3	0 - 5	S1	0 - 2	S1
Class		**S3**		**S1**		**S3**		**S1**		**S1**
Wetness (w)										
Flooding	None	S1	Seasonal flooding	S3	None	S1	Seasonal flooding	S3	Seasonal flooding	S3
Drainage	Moderate to Good	S1	Poor to moderate	S2	Good	S1	Good	S1	Poor to moderate	S2
Class		**S1**		**S3**		**S1**		**S3**		**S3**
Physical Soil Characteristics (s)										
Texture	C/FSL/GL	S1	C/SL	S2	C	S1	L /FSL	S1	FSL/L/C	S1
Coarse Fragment	Outcrops and pebbles	S2	None	S1	None	S1	None	S1	None	S1
Effective Rooting Depth (cm)	Shallow (0.5m)	S2	Deep (>1.0 m)	S1	Very Deep (>2.0 m)	S1	Deep (>1.0 m)	S1	Moderate (0.8 m)	S1
Class		**S2**		**S2**		**S1**		**S1**		**S1**

C – clay; FSL – fine sandy loam; GL - gravelly loam; SL – sandy loam; L – loam

Table 4. Soil Constraints of Major Soil Series for Sugarcane Production in Negros Occidental

Soil Series	Constraints to Crop Production				
	Topography	Wetness	Physical Soil Characteristics	Soil Fertility Characteristics	Climate
Guimbalaon	The topography is rolling to hilly with 18 – 25 % slope.	-	There is the presence of outcrops and pebbles and the effective rooting depth is shallow (0.5 m).	-	Relative humidity is more than the crop requirement.
Isabela	-	Seasonal flooding occurs with poor to moderate drainage.	The sandy loam soil texture is just moderately suitable for the crop.	-	Relative humidity is more than the crop requirement.
Luisiana	The topography is rolling to mountainous with 18 – 40 % slope.	-	-	Low base saturation and soil pH.	Relative humidity is more than the crop requirement.
San Manuel	-	Seasonal flooding occurs.	-	-	Relative humidity is more than the crop requirement.
Silay	-	Seasonal flooding occurs with poor to moderate drainage.	-	Low organic carbon content.	Relative humidity is more than the crop requirement.

Table 3. Suitability Evaluation of Major Soil Series Grown to Sugarcane in Negros Occidental

Land Qualities / Land Characteristics	GUIMBALAON		ISABELA		LUISIANA		SAN MANUEL		SILAY	
	Qualities	Rating	Qualities	Rating	Qualities	Rating	Qualities	Rating	Qualities	Rating
Topography (t)										
Slope (%)	18 - 25	S3	0 - 2	S1	18 - 40	S3	0 - 5	S1	0 - 2	S1
Class		**S3**		**S1**		**S3**		**S1**		**S1**
Wetness (w)										
Flooding	None	S1	Seasonal flooding	S3	None	S1	Seasonal flooding	S3	Seasonal flooding	S3
Drainage	Moderate to Good	S1	Poor to moderate	S2	Good	S1	Good	S1	Poor to moderate	S2
Class		**S1**		**S3**		**S1**		**S3**		**S3**
Physical Soil Characteristics (s)										
Texture	C/FSL/GL	S1	C/SL	S2	C	S1	L /FSL	S1	FSL/L/C	S1
Coarse Fragment	Outcrops and pebbles	S2	None	S1	None	S1	None	S1	None	S1
Effective Rooting Depth (cm)	Shallow (0.5m)	S2	Deep (>1.0 m)	S1	Very Deep (>2.0 m)	S1	Deep (>1.0 m)	S1	Moderate (0.8 m)	S1
Class		**S2**		**S2**		**S1**		**S1**		**S1**

C – clay; FSL – fine sandy loam; GL - gravelly loam; SL – sandy loam; L – loam

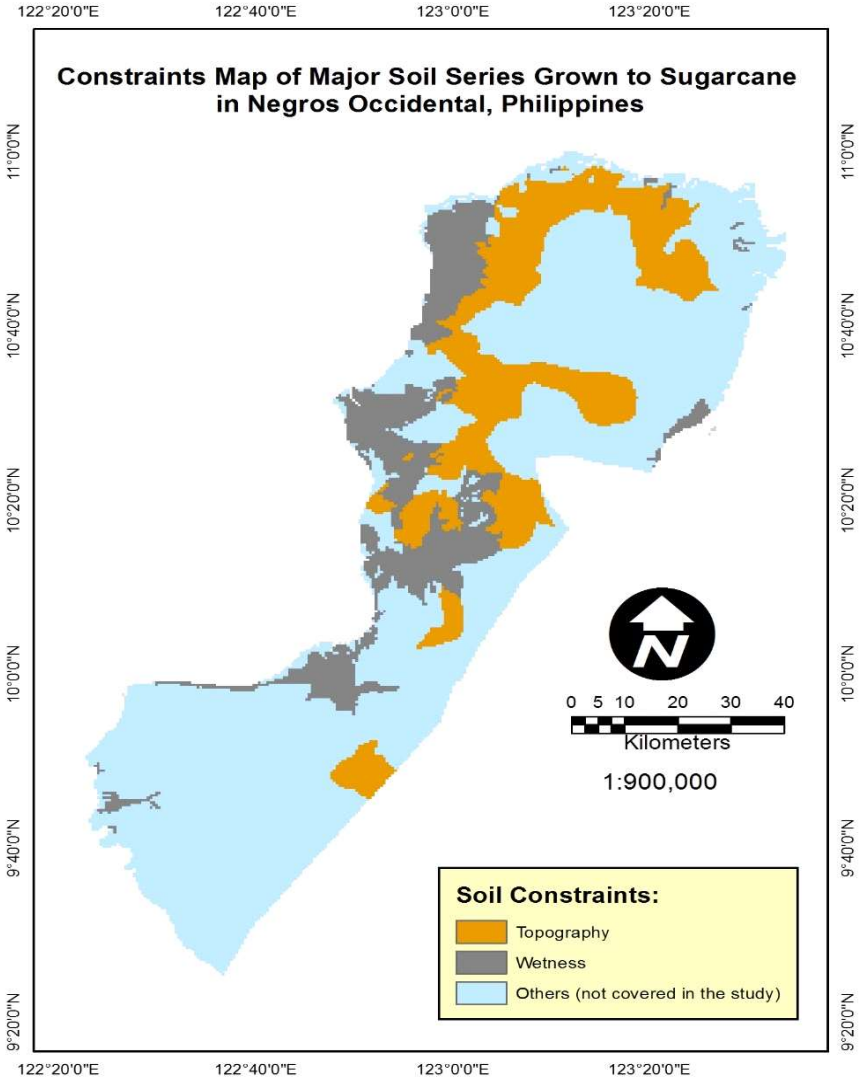

Figure 3. Constraints Map of Major Soil Series Grown to Sugarcane in Negros

CONCLUSIONS

Five major soil series (Guimbalaon, Isabela, Luisiana, San Manuel, and Silay) that were widely planted to sugarcane in Negros Occidental possess different morphological, physical, and chemical characteristics due to different soil factors (parent materials, topography, climate, living organisms, time) that affect soil genesis. Guimbalaon series, derived from older alluvium and described as young soil, have high exchangeable K. Isabela series, formed from alluvial deposits and

described as an old soil with high base status, obtained the highest chemical value on pH (both in H_2O and $CaCl_2$), total nitrogen, percent organic carbon, and available phosphorus among other soil series. Luisiana soil, developed from highly weathered basaltic volcanic rock materials and described as a highly leached old soil, was high in exchangeable Al. San Manuel series, a non-calcareous soil that formed in recent water-deposited sediments mainly in flood plains, was highest in exchangeable Na, Ca, Mg as well as extractable Fe and cation exchange capacity. Silay series, a fine loamy-textured soil which was derived from mixed mineral materials of more than 15% fine sand including gravels and 18 – 35% clay, was found to be low in percent organic carbon and available P. s. *Letters in Applied Microbiology*, 48:705-711.

Guimbalaon, Isabela, Luisiana, San Manuel, and Silay soil series were classified as marginally suitable (S3) for sugarcane production although, soil constraints varied across soil series. Topography and wetness were the severe constraints for most of the soils; however, limitation for fertility and physical soil characteristics were considered moderate and manageable.

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