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Quality of Soils in Soybean Producing Areas in Caraga Region, Philippines

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ABSTRACT

This study aims to determine the soil quality of selected soybean producing farms in the Caraga region using soil quality index (SQI) measurements. Five sites were selected in the municipalities of San Miguel, Surigao del Sur and Trento, Agusan del Sur. Three 10×10 m soil monitoring plots were established within soybean fields in each site. Within each monitoring plot, three composite samples were collected coming from 10 subsamples using a soil probe. SQI was calculated following three general steps, (1) selection of minimum data set (MDS) via Principal Components Analysis (PCA), (2) Scoring of MDS via linear method, and (3) Calculation of weighted overall SQI. Out of the 16-soil property indicator, a total of five soil properties (exchangeable Ca, % sand, electrical conductivity, available P, and soil respiration) were extracted and used as the MDS for the calculation of SQI in each site. The main indicator properties for determining the quality of the soils in the area were Exchangeable Ca and % Sand contents offering a 68% and 26% weights over other soil properties, respectively. High SQI classification was found on four out of five sites evaluated, these were the two sites in the Municipality of Trento (Cebolin.M (61%) & Cebolin.T (54%)) and two sites in the Municipality of San Miguel (Libas-gua (68%) & Upper Carromata (93%)). One site in San Miguel revealed a low SQI (Lower Carromata (41%)). These SQI values indicate that in these areas, soils with very high Exchangeable Ca and Sand content could have a low-quality condition, and sites with optimal Exchangeable Ca (400 - 600 ppm) contents and loamy to sandy loam texture could be classified as high quality soils. Proper drainage system could be best done to manage the very high exchangeable Ca content in these soil and thus, could improve its quality.

Keywords: *Soil Quality Index (SQI), Principal Component Analysis (PCA), Minimum Dataset (MDS)*

1 Introduction

In the Caraga region, soybean is one of the commercial high-value crops produced, and historically, the region was recognized as the soybean capital of the Philippines. However, upon recent assessments, there is a decline in the production quantity and quality of the produced beans (Balanay & Laureta 2021). Most of the study focuses on the economics of soybean but very little to no study regarding the quality of the soil in the area (Balanay & Laureta 2021, Dela Cruz & Neric 2016).

The quality of the soil is a direct determinant of the quality and quantity of crop production. Soil quality is the ability of soils to function within the boundaries of a natural or handled ecosystem, to sustain the productivity of plants and animals, to maintain or improve the quality of air and water, and to sustain human health and habitat (Karlen et al. 2003). The soil quality cannot be measured directly, but soil properties that are sensitive to changes under environmental and/or anthropogenic influences could be used as indicators of its quality (Schloter et al. 2003).

Although knowledge of soil quality plays an essential role in the improvement of crop production and productivity, there is scarce scientific information available about the soil quality of soybean farms in the region. There is currently no agreement or established methodology for the selection of soil quality indicators. Many indicators of soil quality have been proposed, but few have been tested and validated (Ghaemi et al. 2014). For soybean plants, a good quality soybean should be high in crude protein (CP) and high yielding. These quality parameters are highly related to the capacity of the soil to function as a nutrient supplying and reservoir system. This capacity of the soil can be indicated by optimum levels of soil pH, soil nutrients, water holding capacity, etc. With a proper assessment of the quality status of the soil, specific measures can be made to alleviate any constraints that can be uncovered from the assessment process.

Hence, this study aims to determine the soil quality of selected soybean producing farms in the Caraga region. In this study, the quality of the soil was assessed following specific protocols and procedures as outlined for soil quality assessments. Moreover, these data could potentially provide recommendations to alleviate the constraints that will be uncovered and relevant information to improved soil quality in soybean producing farms.

2 Materials and Methods

Site Characterization

The sites were located in the municipalities of San Miguel, Surigao del Sur and Trento, Agusan del Sur. In San Miguel, three barangays were selected namely; Libas-gua, Upper Carromata (inside experimental station of SDSSU - Surigao del Sur State University, now NEMSU - North Eastern Mindanao State University) and, Lower Carromata. Manchuria variety was planted in Libas-gua and Lower Carromata while Tiwala variety was planted in Upper Carromata. One site in Trento was also planted with Manchuria and another site with Tudela Black variety. Both sites in Trento were located in Brgy. Cebolin. Both areas were closely situated along relatively huge river systems (Tago River – San Miguel and Sumilao River - Trento). Thus, seasonal flooding is expected to happen around October to July. The general parent material of the soil in these areas were alluvial deposits, primarily from the flooding events which is the common mechanism of formation for soils near flood plains or lowlands near river systems (Carating et al. 2014). These soils are considered economically important in the Philippines since most of the agricultural activities happen in this piece of land (Carating et al. 2014). The general soil type in San Miguel sites based on the soil series map in geoportal philippines (NAMRIA n.d.) belong to the San Manuel series while the sites in Trento belong to the Mambutay Series. A typical Silt Loam and Sandy Loam soil texture can be found in these areas respectively.

Soil Sampling Technique and Preparations

Three 10×10 m soil monitoring plots grown with soybeans were established in each site. Within each monitoring plot, three composite samples were collected coming from 10 subsamples at 20 cm depth using a soil probe. A total of nine composite samples were collected in each site. Each composite sample was air-dried, quartered and processed separately in relation to the laboratory analysis it would undergo.

Soil Laboratory Analysis

The physical analysis of the soil was conducted at the Soil and Plant Health Laboratory of the College of Agriculture and Agri-Industries – Caraga State University. For soil texture analysis, it was analyzed following the micro-pipette method (Miller & Miller 1987). Briefly, air-dried soil sample was pulverized and sieved to pass a 2 mm mesh. Around 4 g of this was placed in a falcon tube and was added with 40 ml dispersing solution (5% conc.) and then, was shaken for 20 mins in an end-to-end rotary shaker (60 rpm). After shaking, the samples were placed in a stable rack for 2 hours to allow settling process thereafter, around 2 ml aliquot was collected and oven dried to represent the clay contents of the soil, the remaining suspensions were passed through a 0.053 mm sieve to collect for the sand component. Silt was then computed as a proportion of clay and sand percentages. For Bulk density, after collecting in the field via core samplers (5 cm dia. and 5 cm depth), it was brought to the laboratory for oven-drying. For Aggregate stability analysis, a quarter of the air-dried sample was pass through a 1 mm mesh. This size class was subjected to aggregates stability analysis in wet condition following the methods outlines by Patton et al. (2001).

The chemical analysis of the soil was done at the Regional Soils Laboratory at Brgy. Taguibo, Butuan City. Organic matter (OM) was analyzed following the Walkley-Black Method (Nelson and Sommers 1996), Total Nitrogen by Kjeldahl Method (Bremner 1996), Available Phosphorus by Olsen Method and Exchangeable K, Ca, Mg, Na via Ammonium Acetate Extraction Method (Van Reeuwijik 2002).

Soil Quality Index (SQI) Calculation

This is primarily done using the procedures outlined by Ramirez et al (2022). We created a spreadsheet to semi-automate the process but briefly, it starts with a selection of the minimum data set (MDS) using the results of principal components analysis (PCA) of all variables. Only PCs with at least 1 eigenvalue, 1 standard deviation or the total cumulative proportion of variance explained was at least 75% were retained. Then soil properties with at least 30% or 0.3 factor loading (absolute value) were considered to be selected as one of the MDS parameters (Andrews & Carroll 2001). When more than two soil properties were in a PC, correlation analysis was done among those parameters and only those with the highest absolute total correlation coefficient (Pearson's method) was retained to avoid redundancy. In cases when no correlation is found, then those parameters were retained.

After that, the selected MDS were scored using a linear method following these principles; "More is better", "Less is better", and "Optimum is better". To score the "more is better" indicator, observed values were divided by the highest value under that parameter such that the highest observed value among them received a score of 1 and the rest was scored <1. For the "less is better" indicator, observed values were divided by the lowest value under that parameter such that the lowest observed value among them received a score of 1 and the rest was scored <1. Then, in scoring the "optimum is better" indicator, thresholds of more is better and less is better scoring was observed, thus, when a parameter observed value was beyond its threshold level, it will be scored based on "less is better" method, and when a parameter observed value is below its threshold level, it will be scored based on "more is better" method (Ramirez et al. 2022 p. 1160).

And lastly, the scores will be used to compute for the soil quality index (SQI) following the formula below:

$$SQI = \sum_{1}^{n} W_i S_i \qquad (1)$$

where; W is the weight of a parameter as indicated in the PCA. The weight was based on the ratio between the proportion of variance in that PC and the cumulative variance for all PCs with standard deviation of >1 (Table 3), and S is the indicator score using the linear method.

Statistical Analysis

All data were subjected to the analysis of variance to determine mean differences across the six sites against selected soil parameters. Post hoc for significant differences were conducted using Fisher Least Significant Difference (F-LSD). A T-test was also conducted to compare the mean difference between the two municipalities. Correlation analysis and Principal Component Analysis was also done on selected soil parameters. All statistical analyses was conducted in R Studio ver. 023.06.0+421.

3 Results and Discussion

Properties of the soil and its implication on soil quality

Understanding the properties of the soil could pave the way to properly managing its quality. Table 1 shows the selected physical, chemical and biological properties of the soils under three varieties planted in five locations in two municipalities. Results revealed that there were significant differences (n = 54, *p-values* = <0.05) across the five locations for all parameters determined. We could speculate that the areas planted to soybeans in the Caraga region were naturally different from one another. This entails that the management of these farms should be anchored to its salient soil properties and thus, the management of soil should be location and crop specific. Moreover, the analysis of variance also revealed that some of the parameter means were also statistically comparable (same letter subscript) thus, groupings or soil clustering would also be a good step before planning any intervention toward enhancing the quality of such soils.

A good clustering parameter would be soil textural class, as it is a static property thus, will not instantly change over time. As shown in Table 1, soil textural classes can be summarized into three clusters. First, the Loam Cluster, under which was the site in Libas-gua, San Miguel planted with Manchuria variety. Second is the Loamy Sand cluster, which was observed in Lower Carromata site in San Miguel grown with Manchuria variety as well. The third cluster is Sandy Loam, which was found to be under three sites, two in Trento Municipality – Cebolin.M planted with Manchuria and Cebolin.T planted with Tudela Black and one in San Miguel, Upper Carromata. In principle, those soils under the same textural cluster can be managed similarly however, with precaution as to the other set of dynamic parameters.

The dynamic physical parameters evaluated were bulk density (BD), aggregate stability (AS) and plant available water (PAW) content. These properties were known to indicate the degree of compaction, stability of the soil and capacity of the soil to retain moisture for plant use, respectively. Thus, it could indicate the effects of tillage, cultural management and water use efficiency of the soil. All of the BD means were within the optimal range for good root growth (Landon 1991). Moreover, the analysis of variance (*p-value* = 1.82e-11***) revealed that across sites, the lowest was observed in Upper Carromata. This could be due to the fact that this area was the experimental site of NEMSU thus, might receive intensive addition of soil amendments and cultivation to prepare the field for experimental purposes.

For soil AS in wet conditions, results revealed that all means in each location were below the optimal range (80-100%) (Weil & Brady 2017). This could indicate that the soil in all of the sites were poor in terms of stability against the action

Table 1. Mean values of soil properties under the different sites.

Parameters	**Manchuria**			**Tiwala**	**Tudela Black**	**Statistics**	
	San Miguel		**Trento**	**San Miguel**	**Trento**		
	Libas-gua	**Lower Carromata**	**Cebolin.M**	**Upper Carromata**	**Cebolin.T**	***p-value***	***CV(%)***
% Sand	33.6_c	86.3_a	62.1_b	64.3_b	60.1_b	2.75e-15***	14.1
% Silt	45.8_a	7.6_c	27.9_b	24.1_b	23.3_b	4.98e-11***	32.4
% Clay	20.7_a	6.2_c	10.0_{bc}	10.7_b	16.6_a	2.47e-07***	38.9
Textural Class-USDA	L	LS	SL	SL	SL	-	-
Bulk Density (g/cm3)	1.0_b	1.2_a	1.2_a	0.9_c	1.2_a	1.82e-11***	6.6
% Aggregate Stability	41.6_b	11.4_c	16.8_c	55.9_a	13.7_c	<2e-16***	20.7
Plant Available Water (%)	5.9_b	0.6_c	1.1_c	38.8_a	0.3_c	<2e-16***	23.6
pH in water (1:2.5)	6.8_b	7.5_a	6.1_c	4.65_d	6.2_c	<2e-16***	3.1
pH in CaCl2 (1:2.5)	6.2_b	7.2_a	5.8_c	4.3_d	6.1_{bc}	<2e-16***	6.0
EC (µS/cm)	55.2_b	230.2_a	24.9_d	41.8_c	36.7_{cd}	<2e-16***	20.3
Organic matter (%)	1.8_b	1.2_d	1.3_{cd}	2.4_a	1.4_c	<2e-16***	13.8
Total N (%)	0.1_b	0.0_d	0.1_c	0.2_a	0.1c	<2e-16***	9.6
Avail. P (ppm)	15.4_a	12.4_b	13.2_{ab}	7.6_c	11.7_b	1.39e-06***	28.0
Exch. K (ppm)	161.9_a	171.9_a	175.6_a	88.6_b	160.4_a	3.15e-05***	33.8
Exch. Ca (ppm)	5351.1_d	7649.1_a	6165.6_c	1789.2_d	6535.6_b	<2e-16***	5.3
Exch. Mg (ppm)	1776.7_a	522.0_b	551.1_b	229.7_c	550.0_b	<2e-16***	8.1
Exch. Na (ppm)	51.2_a	54.8_a	54.8_a	25.4_b	54.5_a	1.19e-15***	16.8
Soil Respiration (mg C/g)	1.2_a	1.0_a	0.7_b	1.2_a	0.9_{ab}	0.00233**	27.3

Note: Composite samples analyzed per parameter is n = 9, except for Bulk Density (n=5). Textural Class (L – Loam, LS – Loamy Sand, SL – Sandy Loam). Means followed with same letter subscript across sites is not significantly different at 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

of water (e.g. rainfall and irrigation) and could be prone to erosion and run-off. Moreover, based on the analysis of variance, the highest AS was observed in Upper Carromata and the lowest in Lower Carromata. These significant differences (<0.05) could be attributed primarily to the OM content of these soils since OM is one of the most important binding agents for soil aggregate formation and stability (Villasica et al. 2018). This can also be seen in the correlation analysis in Figure 1 wherein a positive and significant correlation was observed between AS and OM (r = 0.83). In terms of the PAW content of the soil, it also follows the same pattern for the highest content as to AS. The site in Upper Carromata revealed the highest PAW content and this could still be attributed to the OM content of the soil (see Figure 1) having a positive and significant correlation (r = 0.86). The OM content of the soil is very dynamic in nature and thus should be managed properly since it can affect several dynamic physical and chemical properties of the soil as well.

All chemical properties evaluated in this study were dynamic properties. The pH in water and pH in CaCl2 were considered to be very dynamic and could determine the availability of other nutrients in the soil. Results revealed that a near neutral pH in water and in CaCl2 was observed in Lower Carromata sites. This indicates that the soil could still have the basic cations in its soil solution. Moreover, the lowest pH in water and CaCl2 was observed in Upper Carromata site indicating that some of the bases might have leach over time. Correlation analysis between pH and the basic cations (Ca, Mg, Na) (Figure 1) shows a generally positive and significant (r = 0.91, 0.55, 0.77, respectively) correlation thus directly affecting each other. For EC or Electrical conductivity of the soil, this indicates the salinity or the relative contents of soluble salts in the soil solution. Results showed that the EC of the soils were all below the range of salinity or sodicity problems (Landon 1991). The highest across the sites is the one on Lower Carromata indicating that a source of soluble salt might be present in the area such as the seasonal flooding events of the proximate river systems. Similar to pH, EC is very dynamic and can also affect nutrient availability (Weil & Brady 2017).

For the nutrient status of the soil, OM plays a vital role as a nutrient supplying component in the soil. OM affects the contents of Nitrogen (N) and Phosphorus (P) in various degrees. Across all sites, the highest OM content was quantified under Upper Carromata site. This could be due to the management employed by the caretakers of this area. Based on the correlation analysis in Figure 1, OM and N contents were strongly

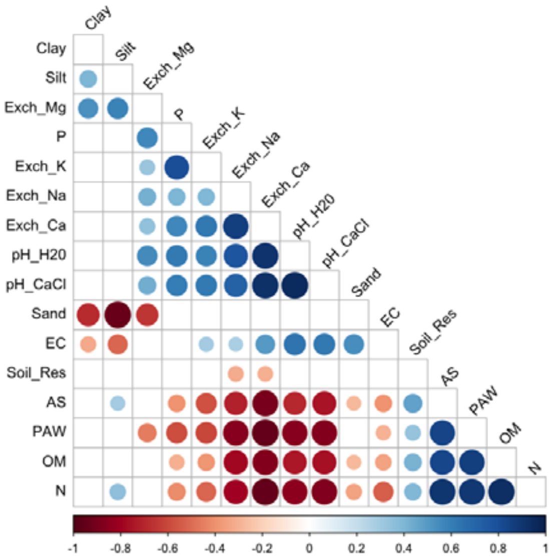

Figure 1. Correlation Matrix for pertinent data. *Note: Blue color – Positive significant correlation; Red Color – Negative significant correlation.*

related to one another (r = 0.93) indicating that N contents could be derived from the decomposition of OM in the soil. Moreover, N contents follows the same pattern as to the OM contents of the soil indicating a direct relationship, thus in terms of management, an active organic-based farming would be beneficial across all sites for the availability of N. Moreover, the available P across sites is within the range for optimal P contents (Landon 1991). Significant differences (*p value* = 1.39e-06***) were still observed across sites. For the Exchangeable cations determined in every site, exchangeable Ca shows the highest concentration among the cations, indicating that these soils experience loading of calcium-rich sediments and that leaching of this cation is not prominent. This could also imply that these soils are young and thus, should be managed more critically. The last property determined was basal soil respiration, which can indicate the biological property of the soil. Soil respiration is directly related to mineralization or decomposition of organic matter which in turn releases carbon from the soil in the form of CO2, thereby changing the chemical dynamics within the soil and the surrounding atmosphere. As shown in Figure 1, soil respiration was slightly correlated with PAW, OM, N showing its effect to the dynamics within the soil. In addition, the highest soil respiration was observed in the Upper Carromata area since it also has the highest OM contents (Table 1).

Soil Quality Evaluation and its Implications

Following the steps for SQI calculation using the 16-soil properties evaluated, 82% of the variance in the data was explained by the first three principal components (PCs). In Table 2 under PC1, seven soil properties show relevant factor loadings (>0.3) and thus, were pre-selected to be retained under PC1. Since the correlation analysis showed that all properties under PC1 are highly correlated to one another thus, the highest sum of the absolute value of its correlation coefficient was determined and the parameter with the highest absolute sum of correlation will be used as the minimum data set (MDS) for SQI calculation. Exchangeable Ca revealed the highest sum of absolute correlation coefficient compared with the other parameters (sum absolute r = 5.49) in PC1 hence, was selected to represent PC1. Following the

Table 2. Results from the PCA including the corresponding factor loading for each soil property

Soil Property	**PC1**	**PC2**	**PC3**
Clay	-0.007	**-0.407**	0.059
Silt	-0.075	**-0.453**	-0.188
Sand	0.062	**0.511**	0.125
AS	**-0.308**	-0.096	0.197
PAW	**-0.331**	0.087	0.106
pH_H20	**0.326**	-0.059	0.164
pH_CaCl	**0.328**	-0.019	0.163
EC	0.187	0.246	**0.415**
OM	**-0.305**	-0.092	0.241
N	**-0.334**	-0.113	0.096
P	0.211	-0.232	**0.335**
Exch_K	0.233	-0.123	0.195
Exch_Ca	**0.344**	-0.004	-0.024
Exch_Mg	0.129	**-0.434**	0.147
Exch_Na	0.292	-0.086	-0.194
Soil_Res	-0.119	-0.037	**0.626**
Standard Deviation	2.868	1.8613	1.20229
Proportion of Variance	0.514	0.2165	0.09034
Cumulative Proportion	0.514	0.7306	0.82092

Note: Values in bold and underline were considered to significantly contribute to the total explained variance under the PCs.

same approach employed under PC1, Percent Sand content was the only one retained under PC2 with significant factor loading while all three properties under PC3 with >0.3 factor loadings were retained since all of these properties were uncorrelated. A total of five soil properties were considered to contain significant amounts of variance (82%) that best represent the soil attributes of the sites (Table 2 & Table 3)

Table 3 shows the final minimum data set (MDS) of this study with its corresponding weights. The highest weight was assigned to Exchangeable Ca and the lowest weight was assigned to EC, Avail. P and Soil Respiration. The scoring principles were also indicated wherein Exchangeable Ca and Available P where scored based on “optimum” value, then % Sand, EC and Soil respiration where score as “less is better”. Results revealed that among the sites planted to soybean cultivars, the area in Upper Carromata showed the highest SQI (93%) and the area in Lower Carromata revealed the lowest SQI (41%) (Table 4). The reason for a very high SQI in Upper Carromata could be attributed to its optimal Exchangeable Ca contents, which was considered the most powerful indicator of the SQI. Specifically, Exchangeable Ca contributed 63% to the SQI of Upper Carromata and an average of 17.82% for the rest of the sites. The optimal contents of Exchangeable Ca in the soil ranges from 1000-2000 ppm, below those value can cause Ca deficiency to the plants, and above those value can cause fixation or alter the availability of other nutrients and cations in the soil (Landon 1991). The possible reason for very high contents of Exchangeable Ca to the other site could be due to its seasonal flooding events wherein Ca-rich deposits might be enriching the soil during those events. Upper Carromata area is relatively elevated compared to the other sites thus, it is not essentially prone to seasonal flooding. Other sites were within 50 m away from its associated river system and seasonal flooding of this rivers brings loads of sediments across a wide floodplain wherein this plantation were situated.

Other indicators influenced the SQI of other sites. In Cebolin planted to Manchuria and Tudela Black and, in Libas-gua having high SQI with 61%, 54%, and 68%, respectively, was due to low Sand contents which contributed to around 14-28% to the SQI. The site with the lowest SQI (Lower Carromata (41%)) was due primarily to its very high Exchangeable Ca Contents (7649.11 ppm) and very high sand content (86.29% textural class is – Loamy Sand, see Table 1) which contributes 14% and 10% to its SQI respectively. These SQI values indicate that in these areas, soils with very high Exchangeable Ca and Sand content could have a low-quality condition, and sites with optimal Exchangeable Ca contents and loamy to sandy loam texture could be classified as high quality soils.

Table 3. Corresponding weights for each indicator and the scoring principle necessary for computing SQI.

Indicator (MDS)	Scoring Principle	Weight
Exchangeable Ca	Optimum	0.63
% Sand	Less is better	0.26
Electrical Conductivity	Less is better	0.1
Available P	Optimum	0.1
Soil Respiration	Less is better	0.1

Table 4. The SQI of each site using linear scoring method.

Location	SQI (%)	Classification
Cebolin.M	61	High
Cebolin.T	54	High
Libas-gua	68	High
Lower Carromata	41	Low
Upper Carromata	93	Very High

Management of soil planted with soybean based on SQI in Caraga Region

Based on the SQI results shown in Table 4, Cebolin sites planted to Manchuria and Tudela black variety and soils in Libas-gua and Upper Carromata soybean farms revealed a high to very high quality soil. The main focus of management within these sites should be in the maintenance of its quality. Maintenance management suggests that a regular soil sampling and analysis of the five indicator parameters should be conducted. Changes in the SQI value from these soils based on the five parameters can serve as a forecasting system on the specific management or cultural practices employed in this field. On the other hand, soils in Lower Carromata planted with Manchuria variety showed a low soil quality as indicated by its unusually high exchangeable Ca and sand contents. Management for high exchangeable Ca content in the soil could be done by adding stable organic materials in the soil and improvements of drainage systems particularly in managing the seasonal flood that is known to occur in the area.

4 Conclusion and Recommendations

The physical, chemical and biological properties of these soils vary significantly thus, could make direct interpretation from individual properties difficult. The soil quality index (SQI) provides a simple yet uncompromised way for evaluating soil condition based on measured soil properties. The soil quality of the sites were generated following protocols from several studies. Out of the 16-property indicator, a total of five soil properties were extracted and use as the minimum data set (MDS) for the calculation of SQI in each site. The main indicator properties for determining the quality of the soils in the area were Exchangeable Ca and % Sand contents offering a 68% and 26% weights over other soil properties, respectively. High SQI classification was found on four out of five sites evaluated, these were the two sites in the Municipality of Trento (Cebolin.M (61%) & Cebolin.T (54%)) and two sites in the Municipality of San Miguel (Libas-gua (68%) & Upper Carromata (93%)). One site in San Miguel revealed a low SQI (Lower Carromata (41%)). These SQI values indicate that in these areas, soils with very high Exchangeable Ca and Sand content could have a low-quality condition, and sites with optimal Exchangeable Ca contents and loamy to sandy loam texture could be classified as high quality soils.

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution Statement

Sharyl Mae Daverao, Jason Gambuta, Avegael Sagaysay, Clyde Cabillo: Conduct of the study, soil sampling and parameter analysis. Reuben James Rollon, James Jade Lasquites: provided technical inputs in the writing of the article. Leo Jude Villasica: conceptualized the sampling design, did the statistical analysis, and spearheaded the editing of the paper. As a member of the JESEG Editorial Board, RJ Rollon and LJ Villasica did not interfere with the review process. All authors approved the final version of the article.

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