



Predicting Fertility and Properties of Sugarcane Soil Series via Soil Color

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Abstract: Soil color, shaped by pedo-chemical reactions, is one of the most immediately perceptible soil properties, which often reflects the underlying parent material that influences specific soil characteristics. Thus, making it an essential soil physicochemical, biological, and fertility indicator for farmers. This study examined the relationship between soil color (value and chroma) and physicochemical and fertility parameters including Percent Organic Carbon (% OC); pH (H₂O and CaCl₂); Total Nitrogen (N); Available Phosphorus (P); exchangeables Potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg), and Aluminum (Al); Exchangeable Iron (Fe), Cation Exchange Capacity (CEC), and Particle Size Distribution (% clay, silt, and sand) in soil samples collected from depths of 0–30 cm (topsoil) and 30–60 cm (subsoil) across different soil series (Guimbalaon, Isabel, Luisiana, San Manuel, and Silay) under sugarcane cultivation. The study showed significant results, indicating strong correlations between soil color and physico-chemical and fertility parameters at both depths. In the topsoil, % OC, and exchangeables Mg and K showed significant correlations with soil color value, while in the subsoil, significant correlations were found for pH (CaCl₂), exchangeables Mg and K, and extractable Fe. Similarly, soil color chroma was significantly correlated in the topsoil with % OC, exchangeables Mg and Na, % clay, % sand, and pH (H₂O); in the subsoil, significant correlations were observed for % OC, exchangeables Mg, Na, and Ca, total N, CEC, % clay, and % sand. These findings underscore the potential of soil color as a valuable indicator of soil physicochemical and fertility properties in sugarcane-cultivated soils.

Keywords: Soil color; fertility; physicochemical; sugarcane; correlation

1. Introduction

Soil Color is one of the most apparent and significant soil characteristics, serving as an indicator of certain physical and chemical properties and providing valuable clues about processes that are or have been operating in the soil [1]. It is consistently used as a definitive criterion in the identification, classification, and separation of soil [2,3], and is a key property in soil interpretation [4]. Because color is easily perceived in the field and is related to other soil properties, it has often been used as a rapid assessment indicator of drainage class, soil classification, and soil organic carbon, which affects the use of variable-rate fertilizer and pesticide applications [5,6]. In addition, the quantity of organic matter and the condition of iron influence soil color. Research indicates a strong correlation between soil color and properties like soil

organic carbon (SOC) content, iron content, soil water content, and texture [7]. Soils with dark surface horizons typically have a high organic matter content, making them fertile and conducive to plant growth. Furthermore, dark brown and black soils are believed to be rich in nitrogen, well-aerated and drained, and less prone to erosion. The studies by Konen et al. [6] and Schulze et al. [8] confirm a consistent relationship between SOC content and soil color. Likewise, in the study by Chen et al. [9], soil samples collected from areas within a field with varying soil brightness levels, determined from a color slide, predicted soil organic carbon with 98% accuracy. In 2003, Tanzanian farmers in the Maswa and Same districts, participating in the Soil-Water Management Research Group (SWMRG) project, relied on readily available local cues, such as soil color, worm presence, cracks, salt content, sand and gravel content, and drying behavior, to differentiate between fertile and infertile soils. Interestingly, these soil indicators used in Tanzania closely mirrored those employed by farmers in Benin, West Africa [10]. Thus, Soil Color is an important criterion for farmers, as it often reflects the soil's hidden parent material, which determines specific soil characteristics [11]. Recent bibliometric analyses also highlight that soil and plant health are central themes in sustainable agricultural systems research [12]. Recent work has further emphasized that soil fertility is a dynamic property closely tied to land-use practices and ecosystem diversification [13]. Soil-management interventions, such as the incorporation of crop residues and superabsorbent polymers, have likewise been shown to modify soil physical properties and influence crop growth and yield [14]. Hence, this study examined the potential of soil color for assessing physicochemical and fertility properties of soils.

2. Materials and Methods

2.1 Collection and Preparation of Soil Samples

The study collected soil samples from five (5) identified sugarcane-cultivated soil series, namely: Guimbalaon, Isabela, Luisiana, San Manuel, and Silay. In each soil series, five (5) sugarcane-cultivated farms were selected. In each farm, twenty (20) geo-coordinated sampling points were randomly selected. A soil sample from 0-30 cm (topsoil) and 30-60 cm (subsoil) depths was collected at each sampling point using an auger, then air-dried, composited, homogenized, sieved, and prepared for soil laboratory analysis.

2.2 Laboratory Analyses

Prepared soil samples were analyzed at the Central Analytical Services Laboratory, Visayas State University, Visca, Baybay City, Leyte, Philippines. Moisture content of the soil samples was measured as a quality-control parameter to ensure consistent air-drying before analysis; it was not included as a primary color-correlation variable, as its relationship to color is confounded by temporal variability and beyond the scope of this study. The following soil analyses were:

- Soil pH - measured potentiometrically in water using a solution ratio of 1:2.5 [15]. pH in CaCl_2 was additionally determined potentiometrically using 0.01 M CaCl_2 solution at a 1:2.5 soil: solution ratio.
- Total Nitrogen (N) - determined using the Kjeldahl Method according to Bremner and Mulvaney [16]. To prepare for analysis, a one-gram soil sample was sifted through a 0.425 mm sieve (corresponding to a #40 mesh screen) and transferred to a 30 mL digestion flask. One gram of selenium reagent mixture and 6 mL of concentrated sulfuric acid (H_2SO_4) were added. The mixture was digested for 1.5 hours before being distilled using a Buchi distillation apparatus, during which 50 mL of 40% NaOH was added. The resulting distillates were then titrated with a standardized 0.05 N H_2SO_4 solution.
- Percent Organic Carbon (C) - determined by the Walkley-Black method [17], which involved organic carbon oxidation with 1 M $\text{K}_2\text{Cr}_2\text{O}_7$ in the presence of concentrated H_2SO_4 . Titration was done with 0.5 M standard FeSO_4 .
- Available Phosphorus (P) - extracted using 0.03 M NH_4F in 0.1 M HCl (Bray and Kurtz No. 2) and quantified using a spectrophotometer following the method of Murphy and Riley [18] for color development.
- To determine the levels of exchangeable bases [Potassium (K), Calcium (Ca), Magnesium (Mg), and Sodium (Na)] in a soil sample, a procedure involving extraction with 1 N NH_4OAc adjusted to pH 7.0 was employed. Specifically, 2.5 grams of soil, having passed through a 2mm mesh sieve, was combined with 25 ml of the extracting solution in a 50 ml Erlenmeyer flask. This mixture was then

agitated for five minutes using a mechanical shaker. Subsequently, the solution was filtered through Whatman filter paper #42 to obtain the filtrate. Quantification of exchangeable bases was performed by atomic absorption spectrophotometry (AAS).

- Percent Soil Fraction (sand, silt, and clay) distribution - Percent sand, silt, and clay of the soil samples were determined using the pipette method, following the particle size distribution analysis of ISRIC [15]. Organic matter in the soil samples was destroyed using 30% hydrogen peroxide. Dispersion was done using a blender with the addition of 10 mL of Calgon solution (sodium hexametaphosphate). Percent sand was determined by physical separation using a 63 μm sieve. Percent silt and clay were determined by pipetting at specific time intervals.
- Cation Exchange Capacity (CEC) - determined using the ammonium acetate method at pH 7.0. Soil samples were saturated with ammonium acetate solution, shaken, and filtered. This was rinsed with isopropyl alcohol, and the filtrate was discarded. The same soil was added to 10% NaCl and digested in a distilling apparatus after the addition of 25 mL 4 N NaOH. Distillates were then titrated finally with standardized 0.05 N H_2SO_4 .
- Exchangeable Aluminum (Al) – determined using the Ammonium Acetate, 1M pH 7.0 Method. Soil samples were saturated with ammonium acetate solution, shaken, filtered, and analyzed by atomic absorption spectroscopy.
- Exchangeable Iron (Fe) – determined using the Ammonium Acetate, 1M pH 7.0 Method. Soil samples were saturated with ammonium acetate solution, shaken, filtered, and analyzed by atomic absorption spectroscopy.

2.3 Soil Color Determination

The color of the collected fresh sample soils was determined using the Munsell Soil Color Chart (1994 revised edition). The chart contains three (3) soil color parameters: Hue, Value, and Chroma. To identify the soil color, it was matched to the color chips found on the chart.

2.4 Data Analysis

Data collected were analyzed for Pearson's Correlation and Regression Analysis using the Statistical Procedures for Agricultural Research (STAR) 2.0.1 software [19]. Soil Color Measurement Protocol. Soil color was determined in the laboratory on air-dried samples using the standard Munsell Soil Color Chart (Munsell Color, 2000 edition). Readings were performed under natural diffuse daylight by a single trained observer to eliminate inter-observer variability. Each sample was read in both the dry and moist state (moistened with distilled water). Munsell hue, value, and chroma were recorded for all samples; however, this study focused on value and chroma for continuous statistical analysis. Hue was recorded but excluded from quantitative analysis because all five soil series fell within closely adjacent hue groups (7.5YR to 10YR), limiting its discriminatory power for regression in this dataset. This exclusion is acknowledged as a scope limitation, and future work should include hue analysis using a wider range of soil series or digital colorimetry methods [20].

3. Results and Discussion

3.1 Correlation and Regression of Soil Color Value to Soil Physicochemical and Fertility Parameters

Soil color is typically the most obvious characteristic observed. A soil's coloration is determined by pedochemical processes such as oxidation, hydration, and the spread of iron oxides, which can produce shades of red, yellow, or orange. Dark soils can suggest inadequate drainage, affecting which crops can be grown. Color also serves as a reliable indicator of organic matter content and decomposition, the presence of minerals such as titanium and manganese, moisture content, and soil texture. The Munsell Color Chart, which uses hue, value, and chroma to define color, is a standard tool for evaluating soil color in the field. Hue signifies the primary spectral color, value represents lightness, and chroma denotes purity. For farmers, soil color is important because it often reveals the parent material, which determines specific soil characteristics [11]. Soil color can provide insights into general soil properties and chemical processes occurring below the surface. Soil reaction and acidity, which are likewise reflected indirectly in soil color, can be ameliorated through amendments such as bioelectric power-plant ash, with measurable improvements in crop performance on

acidic soils [21]. Table 1a showed a significantly negative correlation between soil color value and percent organic carbon and exchangeable magnesium at $\alpha < 0.05$ or 5% with an $r^2 = 0.7726$ and an $r^2 = 0.8945$, respectively (Table 1b) in the Guimbalaon series at a depth of 0 – 30 cm, while no correlation was found in all parameters at 30 – 60 cm depth. This further showed an inverse relationship between soil color value and percent organic matter and exchangeable magnesium, indicating that an increase in one parameter is associated with a corresponding decrease in the other. Franzmeier [22], as cited by Konen et al. [6], presented several equations correlating organic matter concentrations with Munsell value and chroma, all with $r^2 = 0.48$. Fernandez and Schulze [23] noted that visual matching of soil colors is inadequate for developing relationships between soil color and organic matter content. Kelly and Judd [24] reported that individuals can interpolate accurately and consistently between color chips. Still, soil color perception is subjective, and variability among soil scientists exists, as demonstrated by Post et al. [25], as cited by Konen et al. [6].

Table 1a. Correlated matrix for soil color value and soil fertility parameters of Guimbalaon Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Organic Carbon	-0.8790	High negative	0.0496
Soil color value vs. pH (H ₂ O)	-0.4558	Low negative	0.4405
Soil color value vs. pH (CaCl ₂)	-0.3215	Low negative	0.5978
Soil color value vs. Total N	-0.7383	Medium negative	0.1543
Soil color value vs. Available P	-0.8212	High negative	0.0882
Soil color value vs. Exchangeable K	0.5662	Medium positive	0.3197
Soil color value vs. Exchangeable Na	0.2893	Low positive	0.6369
Soil color value vs. Exchangeable Ca	-0.3225	Low negative	0.5966
Soil color value vs. Exchangeable Mg	-0.9458	High negative	0.0150
Soil color value vs. CEC	-0.2874	Low negative	0.6392
Soil color value vs. Exchangeable Al	0.3683	Low positive	0.5419
Soil color value vs. Exchangeable Fe	-0.7142	Medium negative	0.1753
Soil color value vs. % Clay	0.5920	Medium positive	0.2929
Soil color value vs. % Silt	-0.1653	Low negative	0.7905
Soil color value vs. % Sand	-0.3652	Low negative	0.5456

Table 1b. Regression matrix for soil color value and soil fertility parameters of Guimbalaon Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Percent Organic Carbon	Organic Carbon = 4.33 + (-1.16*soil color value)	0.7726	0.0496
Exchangeable Magnesium	Exchangeable Mg = 1782.32 + (-508.68*soil color value)	0.8945	0.0150

Table 2a showed a significantly positive correlation between soil color value and exchangeable potassium at $\alpha < 0.05$ (5%), with an $r^2 = 0.8006$ (Table 2b), obtained from the Isabela series at the 0–30 cm depth. This direct relationship means that an increase in one parameter corresponds to a similar increase in the other. According to Jones and Wild [26], as cited by Kone et al. [27], soil color notation on the Munsell chart may provide an opportunity to scale the K-supplying capacity of soil, including exchangeable and reserve K, by considering soil clay content and the exchangeable potassium percentage. No significant correlation was observed among all parameters in the subsoil (30–60cm depth) layer of the Isabela series. Tables 3a – 3b presented the correlation and regression matrix of soil color value and soil fertility parameters of the Lusiana series at 30 – 60 cm depths. A significantly positive correlation was observed in the subsoil between soil color value and exchangeable magnesium at $\alpha < 0.05$ (5%; Table 3a), with an $r^2 = 0.8332$ (Table 3b). However, there was no correlation between soil color value and the soil fertility parameters in the topsoil (0–30cm depth).

Table 2a. Correlated matrix for soil color value and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Organic Carbon	-0.1366	Low negative	0.8266
Soil color value vs. pH (H ₂ O)	0.2229	Low positive	0.7185
Soil color value vs. pH (CaCl ₂)	-0.1010	Low negative	0.8716
Soil color value vs. Total N	-0.0480	Low negative	0.9389
Soil color value vs. Available P	0.3243	Low positive	0.5945
Soil color value vs. Exchangeable K	0.8948	High positive	0.0403
Soil color value vs. Exchangeable Na	-0.5171	Medium negative	0.3723
Soil color value vs. Exchangeable Ca	-0.0458	Low negative	0.9418
Soil color value vs. Exchangeable Mg	-0.3953	Low negative	0.5101
Soil color value vs. CEC	-0.3687	Low negative	0.5414
Soil color value vs. Exchangeable Al	0.8760	High positive	0.0514
Soil color value vs. Exchangeable Fe	0.0357	Low positive	0.9546
Soil color value vs. % Clay	-0.1681	Low negative	0.7869
Soil color value vs. % Silt	0.1863	Low positive	0.7641
Soil color value vs. % Sand	0.0924	Low positive	0.8826

Table 2b. Regression matrix for soil color value and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Potassium	Exchangeable K = -13056.76 + (4395.38*soil color value)	0.8006	0.0403

Table 3a. Correlated matrix for soil color value and soil fertility parameters of the Louisiana Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Organic Carbon	-0.5218	Medium negative	0.3672
Soil color value vs. pH (H ₂ O)	-0.1506	Low negative	0.8090
Soil color value vs. pH (CaCl ₂)	-0.3378	Low negative	0.5782
Soil color value vs. Total N	-0.6075	Medium negative	0.2771
Soil color value vs. Available P	-0.6414	Medium negative	0.2435
Soil color value vs. Exchangeable K	0.0050	Low positive	0.9936
Soil color value vs. Exchangeable Na	0.2574	Low positive	0.6759
Soil color value vs. Exchangeable Ca	0.5274	Medium positive	0.3610
Soil color value vs. Exchangeable Mg	0.9128	High positive	0.0305
Soil color value vs. CEC	0.7714	Medium positive	0.1266
Soil color value vs. Exchangeable Al	0.5732	Medium positive	0.3124
Soil color value vs. Exchangeable Fe	-0.4418	Low negative	0.4564
Soil color value vs. % Clay	-0.5638	Medium negative	0.3222
Soil color value vs. % Silt	0.0272	Low positive	0.9654
Soil color value vs. % Sand	0.5247	Medium positive	0.3640

Table 3b. Regression matrix for soil color value and soil fertility parameters of the Louisiana Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Magnesium	Exchangeable Mg = -1053.36 + (216.56*soil color value)	0.8332	0.0305

Tables 4a – 4b presented the correlation and regression matrix of soil color value and soil fertility parameters of the San Manuel series at 30 – 60 cm depth. A significantly negative correlation was observed in the subsoil between soil color value and pH (CaCl₂) and exchangeable potassium, and a positive correlation between soil color value and exchangeable iron at $\alpha < 0.05$ or 5% (Table 4a) with an $r^2 = 0.8655$, $r^2 = 0.8636$, and $r^2 = 0.8248$, respectively (Table 4b). Humus and iron compounds significantly affect color. The color of iron-containing soil minerals that undergo oxidation-reduction reactions can provide useful information on soil hydrologic conditions [7]. However, there is no correlation between soil color values and soil fertility parameters in the topsoil (0-30 cm depth).

Table 4a. Correlated matrix for soil color value and soil fertility parameters of San Manuel Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Organic Carbon	-0.4539	Low negative	0.4426
Soil color value vs. pH (H ₂ O)	-0.7861	Medium negative	0.1148
Soil color value vs. pH (CaCl ₂)	-0.9303	High negative	0.0219
Soil color value vs. Total N	0.0928	Low positive	0.8820
Soil color value vs. Available P	-0.5615	Medium negative	0.3246
Soil color value vs. Exchangeable K	-0.9293	High negative	0.0223
Soil color value vs. Exchangeable Na	-0.5330	Medium negative	0.3551
Soil color value vs. Exchangeable Ca	-0.8431	High negative	0.0728
Soil color value vs. Exchangeable Mg	-0.2713	Low negative	0.6588
Soil color value vs. CEC	-0.4320	Low negative	0.4676
Soil color value vs. Exchangeable Al	-0.0967	Low positive	0.8771
Soil color value vs. Exchangeable Fe	0.9082	High positive	0.0329
Soil color value vs. % Clay	-0.4444	Low negative	0.4534
Soil color value vs. % Silt	0.6306	Medium positive	0.2540
Soil color value vs. % Sand	0.1166	Low positive	0.8519

Table 4b. Regression matrix for soil color value and soil fertility parameters of San Manuel Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
pH CaCl ₂	pH CaCl ₂ = 8.90 + (-0.96*soil color value)	0.8655	0.0219
Exchangeable Potassium	Exchangeable K = 218.43 + (-52.17*soil color value)	0.8636	0.0223
Exchangeable Iron	Exchangeable Fe = -225.78 + (91.53*soil color value)	0.8248	0.0329

Tables 5a – 5b presented the correlation and regression matrix of soil color value and soil fertility parameters of the Silay series at 30 – 60 cm depth. There is no correlation of soil color value to the soil fertility parameters at the topsoil, while a significantly negative correlation was observed in the subsoil between soil color value and exchangeable iron at $\alpha < 0.05$ or 5% (Table 5a) with an $r^2 = 0.8030$ (Table 5b).

Table 5a. Correlated matrix for soil color value and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Organic Carbon	-0.3541	Low negative	0.5587
Soil color value vs. pH (H ₂ O)	0.7129	Medium positive	0.1765
Soil color value vs. pH (CaCl ₂)	0.4959	Low positive	0.3955
Soil color value vs. Total N	-0.5040	Medium negative	0.3866
Soil color value vs. Available P	-0.2421	Low negative	0.6948
Soil color value vs. Exchangeable K	0.0550	Low positive	0.9301

Table 5a. Correlated matrix for soil color value and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth. (continue)

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color value vs. Exchangeable Na	-0.0664	Low negative	0.9155
Soil color value vs. Exchangeable Ca	0.8621	High positive	0.0602
Soil color value vs. Exchangeable Mg	0.8308	High positive	0.0814
Soil color value vs. CEC	0.6396	Medium positive	0.2452
Soil color value vs. Exchangeable Al	0.4044	Low positive	0.4995
Soil color value vs. Exchangeable Fe	-0.8961	High negative	0.0396
Soil color value vs. % Clay	0.6186	Medium positive	0.2660
Soil color value vs. % Silt	0.0459	Low positive	0.9416
Soil color value vs. % Sand	-0.5259	Medium negative	0.3627

Table 5b. Regression matrix for soil color value and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Fe	Exchangeable Fe = 155.61 + (-30.00*soil color value)	0.8030	0.0396

3.2 Correlation and Regression of Soil Color Chroma to Soil Physicochemical and Fertility Parameters

The importance of soil color analysis stems from the fact that soil properties such as organic matter, iron mineralogy, and moisture content are strongly correlated with soil color [25,28]. Beyond fertility, these same soil attributes also govern biogeochemical processes such as methane oxidation, which varies markedly across soil environments and has implications for greenhouse gas mitigation [29]. Soil color is composed of three parameters, namely hue (a specific color), value (lightness and darkness), and chroma (color intensity). Tables 6a – 6b presented the correlation and regression matrix of soil color chroma and soil fertility parameters of the Guimbalaon series at 0 – 30 cm (topsoil) and 30 – 60 cm (subsoil) depths. In the topsoil, a notable negative correlation was observed between soil color chroma and both the percentage of organic carbon and the percentage of exchangeable magnesium. This relationship was statistically significant at the 0.05 level (5%), as indicated in Table 6a. The coefficients of determination (r^2) for these correlations were 0.8311 and 0.9015, respectively (Table 6b). Ibarra-F et al. [30] also explored soil color parameters in Mexico using a chroma meter, finding correlations between soil organic carbon (SOC) and hue, value, chroma, and reflectance. Their research, which supported these findings, yielded r^2 values from 0.01 to 0.53. Conversely, no correlation was found between soil color chroma and any of the soil fertility parameters at 30–60 cm depth.

Table 6a. Correlated matrix for soil color chroma and soil fertility parameters of Guimbalaon Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	-0.9117	High negative	0.0311
Soil color chroma vs. pH (H ₂ O)	-0.5479	Medium negative	0.3391
Soil color chroma vs. pH (CaCl ₂)	-0.4045	Low negative	0.4994
Soil color chroma vs. Total N	-0.7635	Medium negative	0.1331
Soil color chroma vs. Available P	-0.7981	Medium negative	0.1056
Soil color chroma vs. Exchangeable K	0.6222	Medium positive	0.2623
Soil color chroma vs. Exchangeable Na	0.4206	Low positive	0.4807
Soil color chroma vs. Exchangeable Ca	-0.3643	Low negative	0.5466
Soil color chroma vs. Exchangeable Mg	-0.9495	High negative	0.0135
Soil color chroma vs. CEC	-0.3311	Low negative	0.5862
Soil color chroma vs. Exchangeable Al	0.5516	Medium positive	0.3351

Table 6a. Correlated matrix for soil color chroma and soil fertility parameters of Guimbalaon Soil Series collected at 0 – 30 cm depth. (continue)

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Exchangeable Fe	-0.6073	Medium negative	0.2774
Soil color chroma vs. % Clay	0.6353	Medium positive	0.2494
Soil color chroma vs. % Silt	-0.1096	Low negative	0.8608
Soil color chroma vs. % Sand	-0.4164	Low negative	0.4855

Table 6b. Regression matrix for soil color chroma and soil fertility parameters of Guimbalaon Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Percent Organic Carbon	Percent Organic C = 1.66 + (-0.29*soil color chroma)	0.8311	0.0311
Exchangeable Magnesium	Exchangeable Mg = 597.58 + (-122.17*soil color chroma)	0.9015	0.0135

Tables 7a – 7d present the correlation and regression matrix of soil color chroma and soil fertility parameters of the Isabela series at 0 – 30 cm (topsoil) and 30 – 60 cm (subsoil) depths. Results revealed a significantly positive correlation in the topsoil between soil color chroma and percent sand at $\alpha < 0.05$ (5%) (Table 7a) with an $r^2 = 0.8088$ (Table 7b). Generally, light or pale soil colors suggest coarse texture, significant leaching, and warm temperatures. Sandy soils, in particular, can suffer from poor structure and high salinity, but their physical and mechanical properties can be improved using amendments such as rice husk ash and gypsum [31]. However, Schulze et al. [8] discovered that soil texture was not strongly correlated with Munsell color values within a particular area. Meanwhile, in the subsoil layer (30–60 cm depth) of the studied soil series, a clear inverse correlation emerged between soil color chroma and key soil properties: organic carbon percentage, total nitrogen, cation exchange capacity, and clay content. Conversely, soil color chroma exhibited a significant positive correlation with sand percentage, with a significance level of $\alpha < 0.05$ (5%) (Table 7c). These results are consistent with those of Sanchez-Maranon et al. [32], who also noted a strong negative relationship between chroma and organic carbon, a finding supported by other research [33,34]. They also reported a strong positive relationship between chroma and sand content ($r^2 = 0.52$, $P < 0.01$). Further supporting this, Konen et al. [6] analyzed 130 Ap horizons and found relationships among soil color, SOC content, and particle size. That study, along with the work of Schulze et al. [8], despite differences in soil types and locations, confirms the consistent link between SOC content and soil color. Table 7d provides the regression matrix for these correlations.

Table 7a. Correlated matrix for soil color chroma and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	-0.5974	Medium negative	0.2874
Soil color chroma vs. pH (H ₂ O)	-0.4626	Low negative	0.4327
Soil color chroma vs. pH (CaCl ₂)	-0.6318	Medium negative	0.2529
Soil color chroma vs. Total N	-0.4602	Low negative	0.4354
Soil color chroma vs. Available P	-0.7628	Medium negative	0.1336
Soil color chroma vs. Exchangeable K	-0.0589	Low negative	0.9250
Soil color chroma vs. Exchangeable Na	0.2074	Low positive	0.7379
Soil color chroma vs. Exchangeable Ca	-0.4455	Low negative	0.4521
Soil color chroma vs. Exchangeable Mg	-0.2204	Low negative	0.7217
Soil color chroma vs. CEC	-0.6725	Medium negative	0.2136
Soil color chroma vs. Exchangeable Al	-0.3644	Low negative	0.5465
Soil color chroma vs. Exchangeable Fe	0.4799	Low positive	0.4133

Table 7a. Correlated matrix for soil color chroma and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth. (continue)

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. % Clay	-0.8602	High negative	0.0614
Soil color chroma vs. % Silt	-0.7684	Medium negative	0.1291
Soil color chroma vs. % Sand	0.8993	High positive	0.0378

Table 7b. Regression matrix for soil color chroma and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Percent Sand	Percent Sand = -29.44 + (74.34*soil color chroma)	0.8088	0.0378

Table 7c. Correlated matrix for soil color chroma and soil fertility parameters of Isabela Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	-0.9273	High negative	0.0233
Soil color chroma vs. pH (H ₂ O)	-0.3307	Low negative	0.5867
Soil color chroma vs. pH (CaCl ₂)	-0.6065	Medium negative	0.2781
Soil color chroma vs. Total N	-0.9069	High negative	0.0336
Soil color chroma vs. Available P	0.3653	Low positive	0.5454
Soil color chroma vs. Exchangeable K	0.6534	Medium positive	0.2318
Soil color chroma vs. Exchangeable Na	-0.3714	Low negative	0.5383
Soil color chroma vs. Exchangeable Ca	0.3946	Low positive	0.5110
Soil color chroma vs. Exchangeable Mg	-0.4896	Low negative	0.4025
Soil color chroma vs. CEC	-0.9657	High negative	0.0076
Soil color chroma vs. Exchangeable Al	0.3246	Low positive	0.5941
Soil color chroma vs. Exchangeable Fe	0.2346	Low positive	0.7040
Soil color chroma vs. % Clay	-0.9830	High negative	0.0027
Soil color chroma vs. % Silt	-0.7151	Medium negative	0.1745
Soil color chroma vs. % Sand	0.9513	High positive	0.0128

Table 7d. Regression matrix for soil color chroma and soil fertility parameters of Isabela Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Percent Organic Carbon	Percent Organic C = 1.74 + (-0.70*soil color chroma)	0.8599	0.0233
Total Nitrogen	Total N = 0.1731 + (-0.0625*soil color chroma)	0.8226	0.0336
Cation Exchange Capacity	CEC = 43.40 + (-21.14*soil color chroma)	0.9327	0.0076
Percent Clay	Percent Clay = 92.45 + (-46.60*soil color chroma)	0.9663	0.0027
Percent Sand	Percent Sand = -27.27 + (61.84*soil color chroma)	0.9050	0.0128

Tables 8a – 8b presented the correlation and regression matrix of soil color chroma and soil fertility parameters of the Louisiana series at 30 – 60 cm depths. A significantly negative correlation was found in the subsoil between soil color chroma and exchangeable magnesium at $\alpha < 0.05$ (5%; Table 8a), with $r^2 = 0.8087$ (Table 8b). However, there is no correlation between soil color chroma and soil fertility parameters at 0–30 cm depth.

Table 8a. Correlated matrix for soil color chroma and soil fertility parameters of the Louisiana Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	0.5164	Medium positive	0.3731
Soil color chroma vs. pH (H ₂ O)	-0.1967	Low negative	0.7512
Soil color chroma vs. pH (CaCl ₂)	0.0101	Low negative	0.9871
Soil color chroma vs. Total N	0.7227	Medium positive	0.1678
Soil color chroma vs. Available P	0.2274	Low positive	0.7130
Soil color chroma vs. Exchangeable K	0.0265	Low positive	0.9662
Soil color chroma vs. Exchangeable Na	-0.6286	Medium negative	0.2560
Soil color chroma vs. Exchangeable Ca	-0.7992	Medium negative	0.1047
Soil color chroma vs. Exchangeable Mg	-0.8993	High negative	0.0378
Soil color chroma vs. CEC	-0.8752	High negative	0.0519
Soil color chroma vs. Exchangeable Al	-0.6096	Medium negative	0.2751
Soil color chroma vs. Exchangeable Fe	0.2499	Low positive	0.6852
Soil color chroma vs. % Clay	0.6181	Medium positive	0.2665
Soil color chroma vs. % Silt	-0.4645	Low negative	0.4305
Soil color chroma vs. % Sand	-0.5084	Medium negative	0.3818

Table 8b. Regression matrix for soil color chroma and soil fertility parameters of the Louisiana Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Magnesium	Exchangeable Mg = 701.53 + (-128.81*soil color chroma)	0.8087	0.0378

Results shown on Table 9a revealed that there is an inverse relationship between soil color chroma obtained at a 0 – 30 cm depth of the San Manuel series to the exchangeable sodium and magnesium and percent clay at $\alpha < 0.05$ or 5% with an $r^2 = 0.8537, 0.9734$, and 0.8204 , respectively (Table 9b). This further means that a corresponding decrease in the other accompanies an increase in one parameter. Table 9c showed that there is an inverse relationship between soil color chroma and percent organic carbon, exchangeable sodium, cation exchange capacity, and percent clay at $\alpha < 0.05$ or 5% in the subsoil of San Manuel series with an r^2 of $0.9326, 0.9605, 0.9811$, and 0.9437 , respectively (Table 9d). In the study by Konen et al. [6], significant relationships were observed between organic C concentration and the percentage of reflectance, Munsell value and chroma, the percentage of sand, the percentage of clay, and the geometric mean particle diameter. Beyond compositional analysis, statistical process-control approaches such as SPC and Cpk have also been applied to characterize the variability of clay-soil properties, including Atterberg limits [35]. More broadly, soil and site characteristics are increasingly recognized as ecological factors governing species persistence and informing conservation strategies [36].

Table 9a. Correlated matrix for soil color chroma and soil fertility parameters of San Manuel Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	-0.5802	Medium negative	0.3051
Soil color chroma vs. pH (H ₂ O)	-0.6918	Medium negative	0.1957
Soil color chroma vs. pH (CaCl ₂)	-0.5890	Medium negative	0.2960
Soil color chroma vs. Total N	-0.6586	Medium negative	0.2268
Soil color chroma vs. Available P	-0.3455	Low negative	0.5691
Soil color chroma vs. Exchangeable K	-0.3733	Low negative	0.5360
Soil color chroma vs. Exchangeable Na	-0.9240	High negative	0.0249
Soil color chroma vs. Exchangeable Ca	-0.8011	High negative	0.1032

Table 9a. Correlated matrix for soil color chroma and soil fertility parameters of San Manuel Soil Series collected at 0 – 30 cm depth. (continue)

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Exchangeable Mg	-0.9866	High negative	0.0019
Soil color chroma vs. CEC	-0.7285	Medium negative	0.1627
Soil color chroma vs. Exchangeable Al	0.3387	Low positive	0.5771
Soil color chroma vs. Exchangeable Fe	0.4072	Low positive	0.4963
Soil color chroma vs. % Clay	-0.9058	High negative	0.0342
Soil color chroma vs. % Silt	0.2602	Low positive	0.6725
Soil color chroma vs. % Sand	0.7292	Medium positive	0.1621

Table 9b. Regression matrix for soil color chroma and soil fertility parameters of San Manuel Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Sodium	Exchangeable Na = 104.22 + (-27.19 *soil color chroma)	0.8537	0.0249
Exchangeable Magnesium	Exchangeable Mg = 946.41 + (-104.87 *soil color chroma)	0.9734	0.0019
Percent Clay	Percent Clay = 65.13 + (-10.01 *soil color chroma)	0.8204	0.0342

Table 9c. Correlated matrix for soil color chroma and soil fertility parameters of San Manuel Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	-0.9657	High negative	0.0076
Soil color chroma vs. pH (H ₂ O)	-0.2014	Low negative	0.7454
Soil color chroma vs. pH (CaCl ₂)	-0.1377	Low negative	0.8252
Soil color chroma vs. Total N	-0.7640	Medium negative	0.1326
Soil color chroma vs. Available P	0.4285	Low positive	0.4716
Soil color chroma vs. Exchangeable K	-0.3636	Low negative	0.5475
Soil color chroma vs. Exchangeable Na	-0.9801	High negative	0.0034
Soil color chroma vs. Exchangeable Ca	-0.7073	Medium negative	0.1816
Soil color chroma vs. Exchangeable Mg	-0.8542	High negative	0.0653
Soil color chroma vs. CEC	-0.9905	High negative	0.0011
Soil color chroma vs. Exchangeable Al	-0.1943	Low negative	0.7542
Soil color chroma vs. Exchangeable Fe	-0.0511	Low negative	0.9350
Soil color chroma vs. % Clay	-0.9714	High negative	0.0058
Soil color chroma vs. % Silt	0.6564	Medium positive	0.2289
Soil color chroma vs. % Sand	0.8690	High positive	0.0558

Table 9d. Regression matrix for soil color chroma and soil fertility parameters of San Manuel Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Percent Organic Carbon	Percent Organic C = 1.44 + (-0.28 *soil color chroma)	0.9326	0.0076
Exchangeable Sodium	Exchangeable Na = 88.32 + (-19.84 *soil color chroma)	0.9605	0.0034
Cation Exchange Capacity	CEC = 25.31 + (-3.27 *soil color chroma)	0.9811	0.0011
Percent Clay	Percent Clay = 70.97 + (-14.05 *soil color chroma)	0.9437	0.0058

Table 10a showed that there is an inverse relationship between soil color chroma and exchangeable magnesium, and between soil color chroma and percent clay at $\alpha < 0.05$, or 5% of the Silay series at 0–30 cm depth, with $r^2 = 0.8055$ and 0.7989 , respectively (Table 10b). However, a direct relationship was observed between soil color chroma and pH (H₂O) $\alpha < 0.05$ or 5% with an $r^2 = 0.7729$ in the topsoil of the same series.

The agronomic implications of pH-related variation are well documented for other crops; for instance, alkaline conditions affect early root development and varietal yield in corn [37], and influence the response of hybrid corn to ammonium-based fertilizers under drought [38]. Table 10c showed that there is a significantly negative correlation between soil color chroma and exchangeable calcium and magnesium, and cation exchange capacity at $\alpha < 0.05$ (5%) with $r^2 = 0.9443$, 0.8937 , and 0.7815 , respectively (Table 10d), collected at 30-60 cm depth of the Silay soil series.

Table 10a. Correlated matrix for soil color chroma and soil fertility parameters of Silay Soil Series collected at 0 – 30 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	0.6890	Medium positive	0.1982
Soil color chroma vs. pH (H ₂ O)	0.8791	High positive	0.0495
Soil color chroma vs. pH (CaCl ₂)	0.7889	Medium positive	0.1127
Soil color chroma vs. Total N	0.7855	Medium positive	0.1153
Soil color chroma vs. Available P	-0.6417	Medium negative	0.2431
Soil color chroma vs. Exchangeable K	0.2832	Low positive	0.6443
Soil color chroma vs. Exchangeable Na	-0.5864	Medium negative	0.2987
Soil color chroma vs. Exchangeable Ca	-0.4386	Low negative	0.4601
Soil color chroma vs. Exchangeable Mg	-0.8975	High negative	0.0388
Soil color chroma vs. CEC	-0.2368	Low negative	0.7014
Soil color chroma vs. Exchangeable Al	-0.2248	Low negative	0.7162
Soil color chroma vs. Exchangeable Fe	-0.2203	Low negative	0.7218
Soil color chroma vs. % Clay	-0.8938	High negative	0.0409
Soil color chroma vs. % Silt	-0.2786	Low negative	0.6499
Soil color chroma vs. % Sand	0.8349	High positive	0.0785

Table 10b. Regression matrix for soil color chroma and soil fertility parameters of Silay Soil Series collected at 0 – 30 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
pH (H ₂ O)	pH (H ₂ O) = 4.47 + (0.65*soil color chroma)	0.7729	0.0495
Exchangeable Magnesium	Exchangeable Mg = 679.07 + (-201.19 *soil color chroma)	0.8055	0.0388
Percent Clay	Percent Clay = 50.19 + (-14.75 *soil color chroma)	0.7989	0.0409

Table 10c. Correlated matrix for soil color chroma and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth.

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. Organic Carbon	0.5602	Medium positive	0.3260
Soil color chroma vs. pH (H ₂ O)	-0.4544	Low negative	0.4420
Soil color chroma vs. pH (CaCl ₂)	-0.2246	Low negative	0.7164
Soil color chroma vs. Total N	0.6673	Medium positive	0.2185
Soil color chroma vs. Available P	-0.1820	Low negative	0.7696
Soil color chroma vs. Exchangeable K	0.2630	Low positive	0.6691
Soil color chroma vs. Exchangeable Na	-0.3962	Low negative	0.5091
Soil color chroma vs. Exchangeable Ca	-0.9718	High negative	0.0057
Soil color chroma vs. Exchangeable Mg	-0.9454	High negative	0.0152
Soil color chroma vs. CEC	-0.8840	High negative	0.0466
Soil color chroma vs. Exchangeable Al	-0.1532	Low negative	0.8057
Soil color chroma vs. Exchangeable Fe	0.7584	Medium positive	0.1373
Soil color chroma vs. % Clay	-0.8468	High negative	0.0703

Table 10c. Correlated matrix for soil color chroma and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth. (continue)

Correlated Variables	Pearson Correlation Coefficient	Interpretation	P-value
Soil color chroma vs. % Silt	-0.4649	Low negative	0.4301
Soil color chroma vs. % Sand	0.8470	High positive	0.0701

Table 10d. Regression matrix for soil color chroma and soil fertility parameters of Silay Soil Series collected at 30 – 60 cm depth.

Soil Fertility Parameters	Regression Equation	R ²	Pr (>F)
Exchangeable Calcium	Exchangeable Ca = 3523.09 + (-710.38 *soil color chroma)	0.9443	0.0057
Exchangeable Magnesium	Exchangeable Mg = 752.86 + (-140.16 *soil color chroma)	0.8937	0.0152
Cation Exchange Capacity	CEC = 11.36 + (-1.34 *soil color chroma)	0.7815	0.0466

4. Conclusions

This study demonstrates that soil color is a practical and informative indicator of soil physicochemical and fertility properties in sugarcane-cultivated soils. In the topsoil (0–30 cm depth), soil color value was significantly correlated with organic carbon, exchangeable magnesium, and exchangeable potassium, whereas in the subsoil (30–60 cm depth), it was significantly correlated with pH (CaCl₂) and exchangeable magnesium, potassium, and iron. Chroma, on the other hand, showed broader associations correlating with organic carbon, exchangeable magnesium and sodium, particle-size fractions (clay and sand), and pH (H₂O) in the topsoil, and with organic carbon, exchangeable magnesium, sodium, and calcium, total nitrogen, cation exchange capacity, and percentages of sand and clay in the subsoil layer. These findings indicate that Munsell color readings can complement conventional laboratory analyses by offering a rapid, low-cost field screening tool for fertility status, particularly where laboratory access is limited. Pending validation across larger, independent datasets, color-based assessment offers a scalable approach to support site-specific nutrient management in tropical sugarcane systems.

5. Limitations

Several limitations of this study must be acknowledged. First, all correlation and regression analyses are based on $n = 5$ data points (one composite sample per soil series and depth), severely limiting statistical power. At this sample size, achieving $p < 0.05$ requires $|r| > 0.878$, so only the strongest associations are detected. Second, no correction for multiple comparisons was applied across the approximately 300 correlation tests performed; some reported significant correlations may represent Type I errors and should be treated as hypothesis-generating rather than confirmatory. Third, compositing 20 soil borings per farm into a single analytical sample eliminates within-series variability. Fourth, the regression equations presented have not been independently validated; leave-one-out cross-validation or testing on an independent dataset is required before these equations can be applied predictively. Fifth, hue was excluded from the analysis because all five series fell within the 7.5YR-10YR hue range, limiting its discriminatory power in this dataset. Future studies should increase sample size per series, include hue analysis, and validate regression equations before field-scale predictive use, ideally complemented by digital colorimetry approaches such as near-infrared spectroscopy [20].

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