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COMPARING SOIL COLOUR USING COLOUR CHART AND COLOUR APP: A SEMI-QUANTITATIVE APPROACH WITH DATA TRANSFORMATION USING PEDOMETRIC METHODS

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ABSTRACT

This study aimed to explore an affordable and easily accessible alternative to the Munsell colour system, while also assessing the reliability of data output from the Munsell colour chart when used by two different individuals. The research involved the reevaluation of 28 stored soil samples using both the Munsell colour system and a soil colour app installed on an android phone. The resulting data was then analyzed and compared with the existing soil colour data. Three models emerged from this study: the existing soil colour data generated using the Munsell colour system (referred to as MCS1), the data produced by this study using the Munsell colour system (referred to as MCS2), and the data generated using the soil colour capture (referred to as SCC) app. All three sets of data were transformed from qualitative to semiquantitative and ultimately to quantitative data using pedometric techniques. These transformed data sets were subjected to both semiquantitative and statistical analyses. Comparison between MCS1 and MCS2 revealed that 46.43% of samples shared the same colour family, 25% had a similar colour family, and 28.57% displayed dissimilar colours. Similarly, when comparing MCS1 and SCC, 21.43% shared the same colour family, 42.86% had a similar colour family, and 35.71% exhibited dissimilar colours. Comparing MCS2 and SCC, 35.71% shared the same colour family, 39.29% had a similar colour family, and 25% showed dissimilar colours. Further analysis indicated a significant non-linear association between MCS1 and MCS2, suggesting that their mean values were not directly comparable. Similarly, MCS1 exhibited a significant negative correlation with SCC. The calculated p-values for these relationships were below 0.5, specifically 0.2908, 0.3848 and 0.4843 for MCS1, MCS2 and SCC, respectively. Therefore, the null hypotheses were rejected. With a significance level (p-value) greater than 0.05, the study concluded that the mean values derived from MCS1 versus MCS2, MCS1 versus SCC, and MCS2 versus SCC were not identical.

Key words: Munsell colour system, pedometrics, semiquantitative, soil colour capture app.

INTRODUCTION

Soil, a finite resource (Brady and Weil, 2013), is a crucial provider of nutrients for plant growth. Its colouration offers insights into its nutrient retention capabilities, stemming from both its parent material's mineral composition and the influence of various soil-forming factors like moisture and slope. Among the physical attributes of soil, colour stands out as the most conspicuous (Paglierani and Valan, 2018), surpassing texture, structure, and consistency. This distinct colour feature has proven invaluable for understanding the soil environment (Brady and Weil, 2016), making it a significant aspect of soil assessments.

The characterization of soil has been simplified using colour (Soil Survey Staff, 2014) as a pivotal characteristic for distinguishing horizons within a soil profile and classifying soil types in landscapes. In Nigeria and other regions, the Munsell Colour System (MCS), introduced by Albert Munsell in 1905, is commonly employed for on-site soil colour measurements in pedological studies. The United States Department of Agriculture (USDA) adopted this system as a reference (Soil Survey Staff, 1999). The MCS defines colours through three independent parameters: hue, value, and chroma, corresponding to colour tint (e.g., red, yellow, green), brightness, and difference from neutral gray (Munsell Colour Company, 2000). The Munsell notations are semiquantitative and necessitate further conversion for quantitative analysis.

To address this conversion, pedometrics, which applies mathematical and statistical methods to soil studies, is employed. This approach views soil issues

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through emerging quantitative techniques (McBratney and Lark, 2018). Nonetheless, challenges have arisen regarding the accuracy of Munsell chart-based soil colour identification. Gómez-Robledo *et al.* (2013) grouped these challenges into three factors: lighting conditions, sample properties, and observer sensitivity. In the Nigerian context, scarcity and affordability issues of Munsell colour charts have emerged due to unfavorable currency exchange rates, prompting exploration of alternatives.

This study involves measuring and assessing soil colour using the 'Soil Colour Capture' (SCC) Android application as an alternative to Munsell charts. This application employs mobile phone cameras to capture RGB signals, which are then transformed into Munsell colour notations using the phone's software. Gómez-Robledo *et al.* (2013) proposed that modern smart-phones can function as objective, rapid and cheap soil colour sensors under controlled lighting conditions, potentially surpassing the accuracy of the conventional visual Munsell chart-based determinations.

In recent years, advancements in soil colour measurement have led to the development of innovative techniques that enhance both accuracy and efficiency. This study presents a comparative analysis of three sets of soil colour data; MCS measurements by Shobayo *et al.* (2019), designated MCS1; the ones in the current study, MCS2; and the ones from the SCC application. Though initially qualitative, these models can be transitioned into quantitative formats. The study leverages both qualitative and quantitative analyses, utilizing two optical systems: CIELAB and RGB. The conversion of Munsell notations into CIELAB and RGB was achieved through pedometric techniques implemented within the *R* software (R Core Team, 2019). This approach effectively addresses challenges associated with visualizing soil colour data, paving the way for more precise and comprehensive soil colour assessments. This study evaluated the accuracy of observer sensitivity in assessing data linearity concerning appearance and to propose a more accessible, affordable, and dependable substitute for Munsell colour charts.

MATERIALS AND METHODS

Materials

The utilized items included soil samples, the Munsell soil colour chart, an Android phone (Infinix Smart 5 with dual 8-megapixel cameras, model: Infinix X657, running Android version 10), a soil description sheet, a cardboard sheet, a retort stand, and a petri dish. Additionally, the phone was equipped with the Soil Colour Capture (SCC) app.

Collection and Preparation of Soil Samples

The collection of soil samples followed the protocols established by the Soil Science Division Staff (2017). These protocols ensure consistency and reliability in soil sample collection, handling, and storage.

Use of Munsell Soil Colour Chart

The method inspired by Munsell's Soil Colour Chart was adopted for visually determining the soil colours. Each dried soil sample was rehydrated and evenly spread across a cardboard sheet. Colour chips closely resembling the soil's hue were positioned right behind apertures. By associating soil particles with these colour chips, the colour of the soil was identified according to Munsell's Chart, determining both the colour name and its corresponding Munsell notation, as outlined in Tables 1-3. The procedure of matching the soil samples with Munsell colour chips followed the methods described by Torrent and Barrón (1993), Rossel *et al.* (2006) and Rossel and Webster (2011). Although qualitative, this method provides a robust framework for initial soil colour classification.

Use of Soil Colour Capture (SCC) App

The SCC android application was used on an Infinix Smart 5 mobile phone equipped with dual 8-megapixel cameras for soil colour assessment. The SCC app offers a modern, cheap alternative to traditional methods, leveraging smartphone technology for rapid and objective soil colour measurements, as demonstrated by Gómez-Robledo *et al.* (2013) and Jiang *et al.* (2017). Following established protocols, soil samples collected by Shobayo *et al.* (2019) and those from our current study were prepared and placed in petri dishes on a white surface under clear, sunny weather conditions. Manual adjustments were made to camera settings, including focus mode and resolution, to ensure optimal image quality, as recommended by Stevens *et al.* (2013). Images were captured using the mobile phone positioned on a retort stand, allowing for consistent and balanced image acquisition. Subsequent data processing within the SCC app involved marking, calibration, and extraction of Munsell colour values, which were then documented in the Hue-Value-Chroma (HVC) system.

Soil Colour Transformation

The soil colour data obtained in the study by Shobayo *et al.* (2019) was denoted as MCS1. The data collected in the current study utilizing the Munsell colour chart was labeled as MCS2. Furthermore, data acquired via a specialized soil colour capture app was designated as SCC. To facilitate analysis, all three sets of data (MCS1, MCS2, and SCC) were subjected to pedometric transformations to HEXCODES, as shown in Figures 1-3. The basis for these transformations lies in their ability to provide precise and standardized colour measurements. The process of converting Munsell colour notations to HEXCODES involves using conversion algorithms that translate Munsell values into a digital format compatible with various colour spaces (Wyszecki and Stiles, 2000; Centore, 2016). The HEXCODES were converted to CIELAB (CIE, 1976; 2004) and sRGB (Stokes *et al.*, 1996) coordinates, which are essential for perceptually uniform colour representation and device-independent colour reproduction, respectively, for the purpose of statistical analysis.

Table 1: MCS1 converted to hexadecimal codes

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	HEXCODE
1	1	0	9	Ap	7.5YR	4	6	#865728FF
2	1	10	50	BA	5YR	5	6	#A66E46FF
3	1	51	84	B	2.5YR	4	4	#825745FF
4	1	85	200	Bt	2.5YR	4	6	#8E5237FF
5	2	0	29	Ap	7.5YR	4	6	#865728FF
6	2	30	65	B	7.5YR	5	6	#A3703FFF
7	2	66	110	Bt	2.5YR	4	4	#825745FF
8	2	111	195	BCt	2.5YR	4	6	#8E5237FF
9	3	0	22	Ap	10YR	4	6	#815A21FF
10	3	23	60	B	2.5Y	5	2	#867964FF
11	3	61	109	Btg	2.5Y	5	1	#827A6EFF
12	3	110	151	BCtg	2.5Y	6	1	#9C9486FF
13	4	0	26	Ap	7.5YR	4	4	#7E5A3BFF
14	4	27	74	Bt	7.5YR	5	8	#AB6D28FF
15	4	75	100	Bg	5YR	5	8	#B06A32FF
16	5	0	17	Ap	10YR	4	6	#815A21FF
17	5	18	40	Bg1	5Y	2.5	2	#383120FF
18	5	41	142	Bg2	5Y	2.5	2	#383120FF
19	6	0	29	Ap	10YR	4	4	#7A5C37FF
20	6	30	66	B	2.5Y	4	4	#755E33FF
21	6	67	98	Bg1	2.5Y	5	3	#8B7958FF
22	6	99	147	Bg2	10YR	4	4	#7A5C37FF
23	7	0	25	Ap	7.5YR	4	4	#7E5A3BFF
24	7	26	43	BC	2.5YR	3	4	#673E2FFF
25	8	0	13	Ap	10YR	3	3	#5A452CFF
26	8	14	71	Cv	2.5YR	4	4	#825745FF
27	9	0	25	A	10YR	4	3	#755D41FF
28	9	26	56	Bt	10YR	4	4	#7A5C37FF

Table 2: MCS2 converted to hexadecimal codes

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	HEXCODE
1	1	0	9	Ap	5YR	4	6	#8A542FFF
2	1	10	50	BA	7.5YR	4	6	#865728FF
3	1	51	84	B	2.5YR	5	6	#A96C4FFF
4	1	85	200	Bt	2.5YR	5	6	#A96C4FFF
5	2	0	29	Ap	7.5YR	4	6	#865728FF
6	2	30	65	B	7.5YR	4	6	#865728FF
7	2	66	110	Bt	10YR	5	4	#947650FF
8	2	111	195	BCt	10YR	5	6	#9D7338FF
9	3	0	22	Ap	7.5YR	4	3	#785C44FF
10	3	23	60	B	2.5Y	5	3	#8B7958FF
11	3	61	109	Btg	2.5Y	5	2	#867964FF
12	3	110	151	BCtg	10YR	5	3	#8F775BFF
13	4	0	26	Ap	10YR	4	6	#815A21FF
14	4	27	74	Bt	10YR	3	2	#554636FF
15	4	75	100	Bg	10YR	3	2	#554636FF
16	5	0	17	Ap	10YR	5	4	#947650FF
17	5	18	40	Bg1	7.5YR	4	6	#865728FF
18	5	41	142	Bg2	5YR	5	6	#A66E46FF
19	6	0	29	Ap	10YR	4	4	#7A5C37FF
20	6	30	66	B	10YR	4	3	#755D41FF
21	6	67	98	Bg1	10YR	3	3	#5A452CFF
22	6	99	147	Bg2	10YR	4	2	#6F5F4CFF
23	7	0	25	Ap	7.5YR	3	4	#624126FF
24	7	26	43	Ap	10YR	5	8	#A3711CFF
25	8	0	13	Ap	10YR	5	3	#8F775BFF
26	8	14	71	Cv	5YR	4	6	#8A542FFF
27	9	0	25	A	10YR	5	3	#8F775BFF
28	9	26	56	Bt	10YR	4	4	#7A5C37FF

Soil Colour Classification

Qualitative and semi-quantitative analysis was done on the colours of each soil sample. This involved converting the HSV values generated using pedometric methods to facilitate comparison across soil samples through the MCS1, MCS2, and SCC. Subsequently, a quantitative analysis was performed for statistical purposes. The primary goal was to visually assess the transformed data for similarities and differences.

Table 3: SCC converted to hexadecimal codes

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	HEXCODE
1	1	0	9	Ap	2.5YR	3	6	#723821FF
2	1	10	50	BA	2.5YR	3	6	#723821FF
3	1	51	84	B	7.5YR	5	6	#A3703FFF
4	1	85	200	Bt	5YR	5	6	#A66E46FF
5	2	0	29	Ap	7.5YR	6	4	#B38E6EFF
6	2	30	65	B	7.5YR	5	6	#A3703FFF
7	2	66	110	Bt	10YR	6	6	#B88E51FF
8	2	111	195	BCt	10YR	8	2	#BBD0B8FF
9	3	0	22	Ap	10YR	5	4	#947650FF
10	3	23	60	B	10YR	3	4	#5E4323FF
11	3	61	109	Btg	5Y	6	2	#9D957BFF
12	3	110	151	BCtg	10YR	3	4	#5E4323FF
13	4	0	26	Ap	10YR	4	3	#755D41FF
14	4	27	74	Bt	7.5YR	3	4	#624126FF
15	4	75	100	Bg	5YR	2	6	#532404FF
16	5	0	17	Ap	7.5YR	5	8	#AB6D28FF
17	5	18	40	Bg1	5YR	4	6	#8A542FFF
18	5	41	142	Bg2	10YR	8	2	#BBD0B8FF
19	6	0	29	Ap	2.5Y	6	2	#A0947CFF
20	6	30	66	B	5YR	3	4	#64402BFF
21	6	67	98	Bg1	5YR	4	3	#7A5A48FF
22	6	99	147	Bg2	7.5YR	5	6	#A3703FFF
23	7	0	25	Ap	5YR	5	6	#A66E46FF
24	7	26	43	Ap	10YR	4	4	#7A5C37FF
25	8	0	13	Ap	7.5YR	4	3	#785C44FF
26	8	14	71	Cv	5YR	3	2	#594439FF
27	9	0	25	A	10YR	5	3	#8F775BFF
28	9	26	56	Bt	10YR	7	3	#C4AC8CFF

For this study, the FAO soil description guidelines (FAO, 2006) served as a framework for colour contrast classification (pertaining to mottles). The data, generated semi-quantitatively, underwent conversion into hexadecimal codes as earlier mentioned (Tables 1-3, along with Figures 7-9), followed by further transformation into CIELAB and sRGB coordinates suitable for statistical analysis. In the context of this study, "Faint" indicated a subtle colour difference perceptible only on close inspection, implying closely related hues, chromas, and values. "Distinct" referred to a noticeable difference in hue, chroma, and value, while "Prominent" indicated a conspicuous difference, where one or more of these attributes stood several units apart. Thus, "Faint" was treated as the "same colour family," "Distinct" as "similar colour family," and "Prominent" as "dissimilar colours" for comparisons.

Pedometrical and Statistical Analysis

The data produced underwent analysis utilizing suitable packages in R, including "readr," "psych," "Hmisc," "corrplot," "RcolourBrewer," "aqp," "colourspace," and "sharpshootR" (R Core Team, 2019) – a statistical computing software. The analyses were correlations, multiple regression, and Kruskal-Wallis analysis.

RESULTS AND DISCUSSION

Figures 4-6 present visual comparisons categorized as faint, distinct, and prominent. Qualitative and semi-quantitative analyses of soil colours, along with the subsequent quantitative analysis, have been supported by various studies (Fan *et al*., 2017; Stiglitz *et al*., 2017; Herts *et al*., 2022). The use of the FAO Guidelines for soil description as a framework for colour contrast classification, with the transformation of data into colour

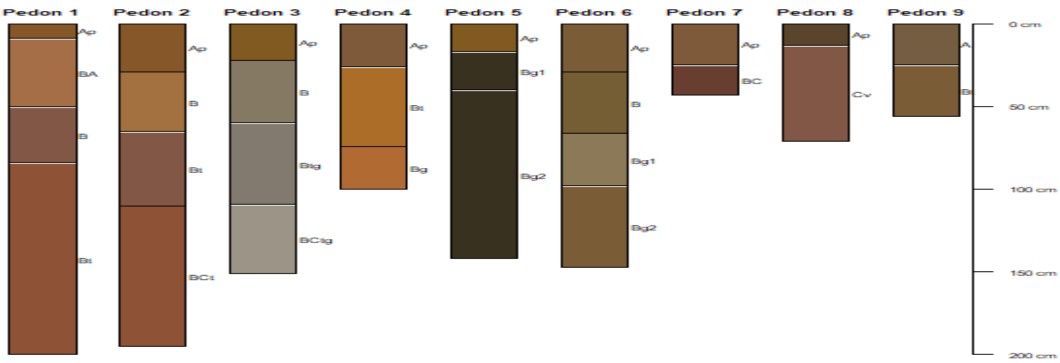

Figure 1: MCS1 measured soil samples colour distribution across pedal and genetic horizons

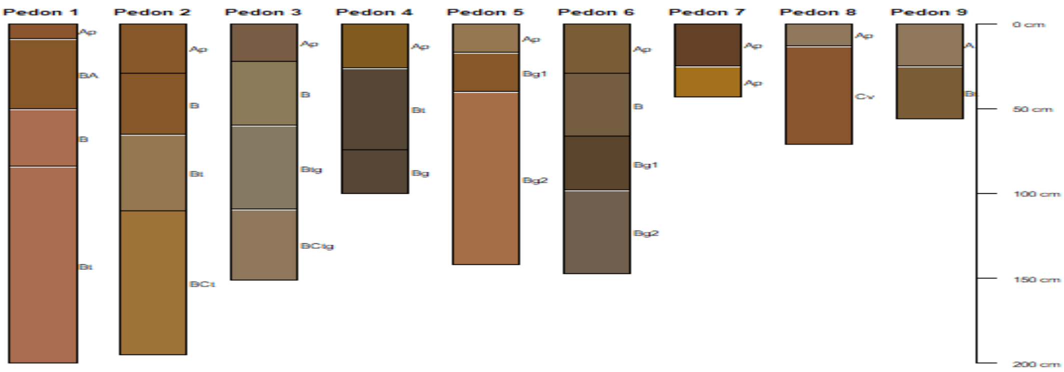

Figure 2: MCS2 measured soil samples colour distribution across pedal and genetic horizons

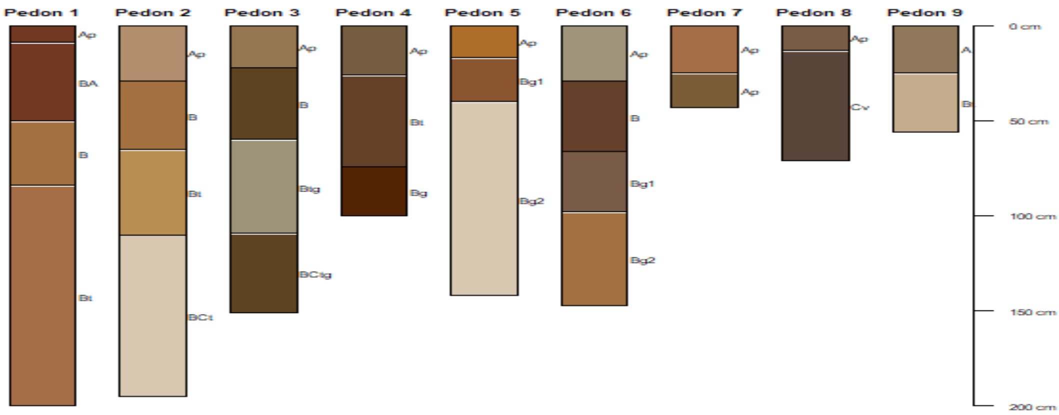

Figure 3: SCC measured soil samples colour distribution across pedal and genetic horizons

coordinates for statistical analysis, has also been documented by Yageta *et al*. (2019) who compared qualitative and quantitative soil fertility evaluation indicators, with colour differences categorized as "Faint," "Distinct," and "Prominent" for comparisons.

Comparing soil colours evaluated by MCS1 and MCS2 (Figure 4) showed that out of the 28 soil samples, 46.43% exhibited faint contrast (same colour family), 25% showed distinct contrast (similar colour family), and 28.57% displayed prominent contrast (dissimilar colours). Similarly, comparing MCS1 with SCC, 21.43% had faint contrast, 42.86% showed distinct contrast, and 35.71% exhibited prominent contrast. Further, MCS2 compared with SCC showed faint contrast at 35.71%, distinct contrast at 39.29%, and prominent contrast at 25%. The instances of dissimilar colours were attributed to the observer's sensitivity to those specific colours (Brown *et al*., 2004).

Transformed hue, value, and chroma (HVC) data from MCS1 and MCS2 were presented as semi-qualitative hexadecimal codes in Tables 1 and 2. Similarly, transformed HVC data from the Soil Colour Capture (SCC) app were shown in Table 3. Hexacode coordinates were transformed to aggregate soil colour information from genetic horizons, presented visually with associated occurrence weights in Figures 7, 8, and 9. Additionally, the figures displayed soil sample colour names generated using a cluster-detection algorithm (R Core Team, 2019).

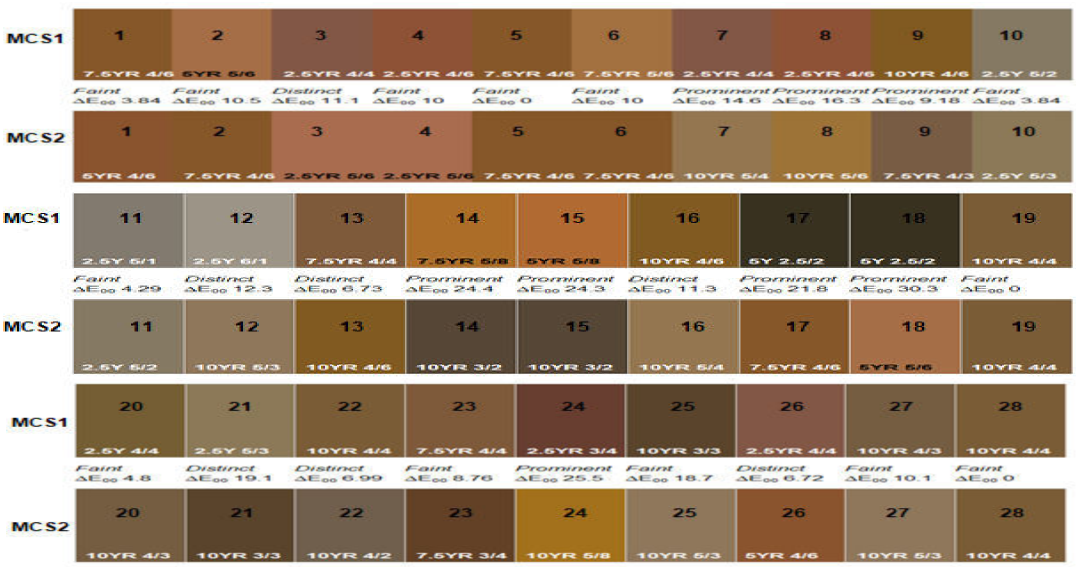

Figure 4: Metrics of contrasts between MCS1 and MCS2 soil colour measured 1,2, 3,… - Sample No.

Figure 5: Metrics of contrasts between MCS1 and SCC soil colour measured 1,2, 3,… - Sample No.

Figure 6: Metrics of contrasts between MCS2 and SCC soil colour measured 1,2, 3,… - Sample No.

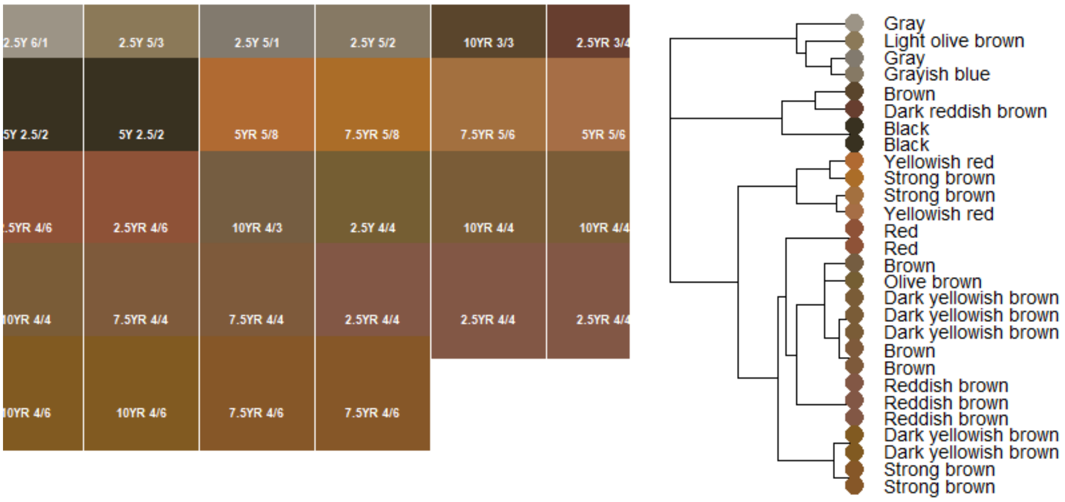

Figure 7: MCS1 Soil horizon colours and colour names

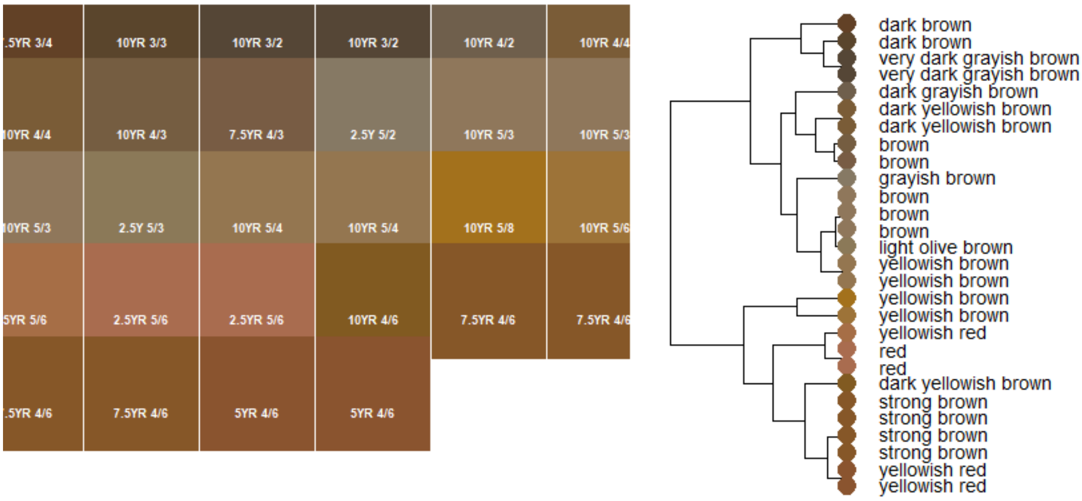

Figure 8: MCS2 Soil horizon colours and colour names

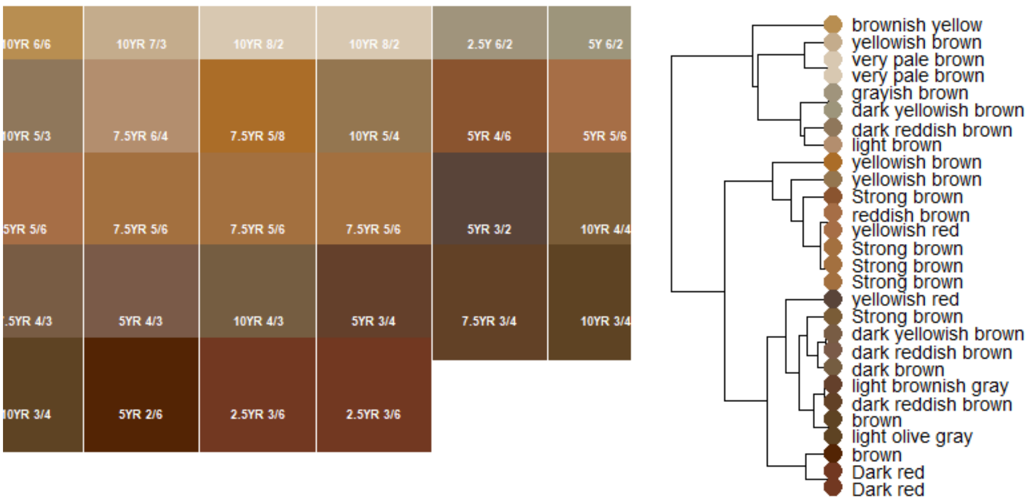

Figure 9: SCC Soil horizon colours and colour names

Munsell HVC data were further converted into CIELAB and sRGB coordinates for numerical statistical/predictive analysis (Tables 4-9). The study by Nodi *et al*. (2023) highlighted the importance of soil colour in detecting morphological properties during field research. Using the Munsell colour system necessitated converting Munsell notations into hexacode and subsequently CIELAB or RGB coordinates, especially when colour data required statistical analysis. While means of MCS1CIE, MCS2CIE, and MCS2RGB were normally distributed (Figures 10, 11 and 14), non-normal distributions (Figures 12, 13 and 15) precluded meeting ANOVA assumptions. The MCS1CIE showed a significant non-linear association with MCS2CIE and MCS2RGB, suggesting unreliability in mean value comparability. Likewise, MCS1RGB showed a significant negative correlation with MCS2CIE, SCCRGB and SCCCIE (Figures 16a & b), suggesting that as the value of MCS1RGB increases, the values of MCS2CIE, SCCRGB, and SCCCIE tend to decrease; implying the relationship was not random but rather indicated a meaningful pattern in the analyzed data. A noteworthy correlation existed between SCCRGB and SCCCIE, indicating interchangeable coordinates.

Table 4: MCS1 to converted CIELAB coordinates

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	L	A	B
1	Pedon 1	0	9	Ap	7.5YR	4	6	41.27724	14.9863995	34.346508
2	Pedon 1	10	50	BA	5YR	5	6	51.63431	18.0642549	31.110545
3	Pedon 1	51	84	B	2.5YR	4	4	41.24892	15.8756561	17.613264
4	Pedon 1	85	200	Bt	2.5YR	4	6	41.25969	22.387417	26.284949
5	Pedon 2	0	29	Ap	7.5YR	4	6	41.27724	14.9863995	34.346508
6	Pedon 2	30	65	B	7.5YR	5	6	51.64277	14.640636	34.876154
7	Pedon 2	66	110	Bt	2.5YR	4	4	41.24892	15.8756561	17.613264
8	Pedon 2	111	195	BCt	2.5YR	4	6	41.25969	22.387417	26.284949
9	Pedon 3	0	22	Ap	10YR	4	6	41.28482	10.3714568	37.715427
10	Pedon 3	23	60	B	2.5Y	5	2	51.61207	1.3243154	13.761792
11	Pedon 3	61	109	Btg	2.5Y	5	1	51.59656	0.8635463	7.437465
12	Pedon 3	110	151	BCtg	2.5Y	6	1	61.70371	0.1762589	8.402621
13	Pedon 4	0	26	Ap	7.5YR	4	4	41.26403	10.8688984	23.591401
14	Pedon 4	27	74	Bt	7.5YR	5	8	51.65521	18.5477425	46.905417
15	Pedon 4	75	100	Bg	5YR	5	8	51.64596	23.4733273	42.230939
16	Pedon 5	0	17	Ap	10YR	4	6	41.28482	10.3714568	37.715427
17	Pedon 5	18	40	Bg1	5Y	2.5	2	20.57131	0.1979106	12.028754
18	Pedon 5	41	142	Bg2	5Y	2.5	2	20.57131	0.1979106	12.028754
19	Pedon 6	0	29	Ap	10YR	4	4	41.27066	7.3777862	25.99946
20	Pedon 6	30	66	B	2.5Y	4	4	41.27617	3.5979795	27.76177
21	Pedon 6	67	98	Bg1	2.5Y	5	3	51.62644	2.0793417	20.51746
22	Pedon 6	99	147	Bg2	10YR	4	4	41.27066	7.3777862	25.99946
23	Pedon 7	0	25	Ap	7.5YR	4	4	41.26403	10.8688984	23.591401
24	Pedon 7	26	43	BC	2.5YR	3	4	30.78889	16.3251182	16.933367
25	Pedon 8	0	13	Ap	10YR	3	3	30.79905	5.6389267	18.067663
26	Pedon 8	14	71	Cv	2.5YR	4	4	41.24892	15.8756561	17.613264
27	Pedon 9	0	25	A	10YR	4	3	41.26092	5.629344	19.846688
28	Pedon 9	26	56	Bt	10YR	4	4	41.27066	7.3777862	25.99946

Table 5: MCS2 converted to CIELAB coordinates

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	L	A	B
1	Pedon 1	0	9	Ap	5YR	4	6	41.26934	18.736944	30.68642
2	Pedon 1	10	50	BA	7.5YR	4	6	41.27724	14.986399	34.34651
3	Pedon 1	51	84	B	2.5YR	5	6	51.62348	21.45413	26.33936
4	Pedon 1	85	200	Bt	2.5YR	5	6	51.62348	21.45413	26.33936
5	Pedon 2	0	29	Ap	7.5YR	4	6	41.27724	14.986399	34.34651
6	Pedon 2	30	65	B	7.5YR	4	6	41.27724	14.986399	34.34651
7	Pedon 2	66	110	Bt	10YR	5	4	51.63296	6.610847	25.48043
8	Pedon 2	111	195	BCt	10YR	5	6	51.65181	9.949994	38.81403
9	Pedon 3	0	22	Ap	7.5YR	4	3	41.25501	8.475735	17.896
10	Pedon 3	23	60	B	2.5Y	5	3	51.62644	2.079342	20.51746
11	Pedon 3	61	109	Btg	2.5Y	5	2	51.61207	1.324315	13.76179
12	Pedon 3	110	151	BCtg	10YR	5	3	51.62124	4.870262	18.95563
13	Pedon 4	0	26	Ap	10YR	4	6	41.28482	10.371457	37.71543
14	Pedon 4	27	74	Bt	10YR	3	2	30.78856	3.912342	12.21027
15	Pedon 4	75	100	Bg	10YR	3	2	30.78856	3.912342	12.21027
16	Pedon 5	0	17	Ap	10YR	5	4	51.63296	6.610847	25.48043
17	Pedon 5	18	40	Bg1	7.5YR	4	6	41.27724	14.986399	34.34651
18	Pedon 5	41	142	Bg2	5YR	5	6	51.63431	18.064255	31.11055
19	Pedon 6	0	29	Ap	10YR	4	4	41.27066	7.377786	25.99946
20	Pedon 6	30	66	B	10YR	4	3	41.26092	5.629344	19.84669
21	Pedon 6	67	98	Bg1	10YR	3	3	30.79905	5.638927	18.06766
22	Pedon 6	99	147	Bg2	10YR	4	2	41.24855	3.681301	13.29762
23	Pedon 7	0	25	Ap	7.5YR	3	4	30.80201	10.730243	21.9824
24	Pedon 7	26	43	Ap	10YR	5	8	51.66414	12.641607	51.30964
25	Pedon 8	0	13	Ap	10YR	5	3	51.62124	4.870262	18.95563
26	Pedon 8	14	71	Cv	5YR	4	6	41.26934	18.736944	30.68642
27	Pedon 9	0	25	A	10YR	5	3	51.62124	4.870262	18.95563
28	Pedon 9	26	56	Bt	10YR	4	4	41.27066	7.377786	25.99946

Table 6: SCC converted to CIELAB coordinates

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	L	A	B
1	Pedon 1	0	9	Ap	2.5YR	3	6	30.79796	23.3966623	26.02716
2	Pedon 1	10	50	BA	2.5YR	3	6	30.79796	23.3966623	26.02716
3	Pedon 1	51	84	B	7.5YR	5	6	51.64277	14.640636	34.87615
4	Pedon 1	85	200	Bt	5YR	5	6	51.63431	18.0642549	31.11055
5	Pedon 2	0	29	Ap	7.5YR	6	4	61.73075	9.3291381	22.49122
6	Pedon 2	30	65	B	7.5YR	5	6	51.64277	14.640636	34.87615
7	Pedon 2	66	110	Bt	10YR	6	6	61.75969	9.0681161	38.34647
8	Pedon 2	111	195	BCt	10YR	8	2	81.38258	2.071502	13.48786
9	Pedon 3	0	22	Ap	10YR	5	4	51.63296	6.6108472	25.48043
10	Pedon 3	23	60	B	10YR	3	4	30.80768	7.3571851	24.02723
11	Pedon 3	61	109	Btg	5Y	6	2	61.72144	-1.3594225	15.02659
12	Pedon 3	110	151	BCtg	10YR	3	4	30.80768	7.3571851	24.02723
13	Pedon 4	0	26	Ap	10YR	4	3	41.26092	5.629344	19.84669
14	Pedon 4	27	74	Bt	7.5YR	3	4	30.80201	10.7302429	21.9824
15	Pedon 4	75	100	Bg	5YR	2	6	20.58071	20.1546331	28.57951
16	Pedon 5	0	17	Ap	7.5YR	5	8	51.65521	18.5477425	46.90542
17	Pedon 5	18	40	Bg1	5YR	4	6	41.26934	18.7369437	30.68642
18	Pedon 5	41	142	Bg2	10YR	8	2	91.11847	-12.421049	10.5859
19	Pedon 6	0	29	Ap	2.5Y	6	2	61.71845	0.6812992	14.35288
20	Pedon 6	30	66	B	5YR	3	4	30.7958	13.5486885	19.54789
21	Pedon 6	67	98	Bg1	5YR	4	3	41.24916	10.4546104	15.77943
22	Pedon 6	99	147	Bg2	7.5YR	5	6	51.64277	14.640636	34.87615
23	Pedon 7	0	25	Ap	5YR	5	6	51.63431	18.0642549	31.11055
24	Pedon 7	26	43	Ap	10YR	4	4	41.27066	7.3777862	25.99946
25	Pedon 8	0	13	Ap	7.5YR	4	3	41.25501	8.4757345	17.896
26	Pedon 8	14	71	Cv	5YR	3	2	30.78129	7.4027943	10.08832
27	Pedon 9	0	25	A	10YR	5	3	51.62124	4.870262	18.95563
28	Pedon 9	26	56	Bt	10YR	7	3	71.64468	3.8896691	19.54421

Table 7: MCS1 converted to sRGB

Sample ID	Pedon No.	Top	Bottom	Name	Hue	Value	Chroma	r	g	b
1	Pedon 1	0	9	Ap	7.5YR	4	6	0.5252055	0.340437	0.1578492
2	Pedon 1	10	50	BA	5YR	5	6	0.6516906	0.4320947	0.2762389
3	Pedon 1	51	84	B	2.5YR	4	4	0.5110917	0.3404287	0.2713785
4	Pedon 1	85	200	Bt	2.5YR	4	6	0.5550868	0.3205433	0.2162466
5	Pedon 2	0	29	Ap	7.5YR	4	6	0.5252055	0.340437	0.1578492
6	Pedon 2	30	65	B	7.5YR	5	6	0.637312	0.4408493	0.24847
7	Pedon 2	66	110	Bt	2.5YR	4	4	0.5110917	0.3404287	0.2713785
8	Pedon 2	111	195	BCt	2.5YR	4	6	0.5550868	0.3205433	0.2162466
9	Pedon 3	0	22	Ap	10YR	4	6	0.504304	0.3518937	0.1301201
10	Pedon 3	23	60	B	2.5Y	5	2	0.5267029	0.476224	0.3908756
11	Pedon 3	61	109	Btg	2.5Y	5	1	0.5088136	0.478454	0.4328612
12	Pedon 3	110	151	BCtg	2.5Y	6	1	0.6100867	0.5818157	0.5265809
13	Pedon 4	0	26	Ap	7.5YR	4	4	0.4923909	0.352334	0.2313328
14	Pedon 4	27	74	Bt	7.5YR	5	8	0.6690249	0.4288437	0.155581
15	Pedon 4	75	100	Bg	5YR	5	8	0.6911048	0.4150053	0.1963905
16	Pedon 5	0	17	Ap	10YR	4	6	0.504304	0.3518937	0.1301201
17	Pedon 5	18	40	Bg1	5Y	2.5	2	0.2197187	0.1916434	0.1251596
18	Pedon 5	41	142	Bg2	5Y	2.5	2	0.2197187	0.1916434	0.1251596
19	Pedon 6	0	29	Ap	10YR	4	4	0.4765699	0.360387	0.2143803
20	Pedon 6	30	66	B	2.5Y	4	4	0.4580061	0.3687474	0.2013959
21	Pedon 6	67	98	Bg1	2.5Y	5	3	0.5448467	0.4733955	0.3455843
22	Pedon 6	99	147	Bg2	10YR	4	4	0.4765699	0.360387	0.2143803
23	Pedon 7	0	25	Ap	7.5YR	4	4	0.4923909	0.352334	0.2313328
24	Pedon 7	26	43	BC	2.5YR	3	4	0.4047002	0.2430202	0.1836799
25	Pedon 8	0	13	Ap	10YR	3	3	0.3520337	0.2690476	0.1744578
26	Pedon 8	14	71	Cv	2.5YR	4	4	0.5110917	0.3404287	0.2713785
27	Pedon 9	0	25	A	10YR	4	3	0.4584415	0.3652712	0.2549145
28	Pedon 9	26	56	Bt	10YR	4	4	0.4765699	0.360387	0.2143803

The study used multiple regression analysis to examine the three models. The highest R^2 and lowest p-value (Table 11) indicated MCS1's superior reliability, implying SCC's insignificance. Due to disparate distributions of mean values used for analysis (MCS1, MCS2, SCC being independent variables), the null hypothesis positing model and mean distribution reliability was tested via the Kruskal test function (R Core Team, 2019). For CIELAB coordinates, p-values were < 0.05 or nearly zero, leading to null hypothesis rejection (Table 12). Contrarily, sRGB coordinates' p-values were mostly > 0.05, affirming the null hypothesis. Given non-significant relationships between the models and their corresponding evaluation methods, further model fitness analysis was unnecessary.

Table 8: MCS2 converted sRGB

Sample ID	Pedon No.	Top	Bottom	Name	Munsell Colour Notation			sRGB Colour Notation		
					Hue	Value	Chroma	r	g	b
1	Pedon 1	0	9	Ap	5YR	4	6	0.5409717	0.330593	0.1852933
2	Pedon 1	10	50	BA	7.5YR	4	6	0.5252055	0.340437	0.1578492
3	Pedon 1	51	84	B	2.5YR	5	6	0.6642703	0.4232155	0.3100327
4	Pedon 1	85	200	Bt	2.5YR	5	6	0.6642703	0.4232155	0.3100327
5	Pedon 2	0	29	Ap	7.5YR	4	6	0.5252055	0.340437	0.1578492
6	Pedon 2	30	65	B	7.5YR	4	6	0.5252055	0.340437	0.1578492
7	Pedon 2	66	110	Bt	10YR	5	4	0.5801129	0.4622333	0.3125959
8	Pedon 2	111	195	BCt	10YR	5	6	0.6157417	0.4523969	0.2177761
9	Pedon 3	0	22	Ap	7.5YR	4	3	0.4713544	0.3589827	0.268153
10	Pedon 3	23	60	B	2.5Y	5	3	0.5448467	0.4733955	0.3455843
11	Pedon 3	61	109	Btg	2.5Y	5	2	0.5267029	0.476224	0.3908756
12	Pedon 3	110	151	BCtg	10YR	5	3	0.5589675	0.467335	0.3566388
13	Pedon 4	0	26	Ap	10YR	4	6	0.504304	0.3518937	0.1301201
14	Pedon 4	27	74	Bt	10YR	3	2	0.3339414	0.2736425	0.2104293
15	Pedon 4	75	100	Bg	10YR	3	2	0.3339414	0.2736425	0.2104293
16	Pedon 5	0	17	Ap	10YR	5	4	0.5801129	0.4622333	0.3125959
17	Pedon 5	18	40	Bg1	7.5YR	4	6	0.5252055	0.340437	0.1578492
18	Pedon 5	41	142	Bg2	5YR	5	6	0.6516906	0.4320947	0.2762389
19	Pedon 6	0	29	Ap	10YR	4	4	0.4765699	0.360387	0.2143803
20	Pedon 6	30	66	B	10YR	4	3	0.4584415	0.3652712	0.2549145
21	Pedon 6	67	98	Bg1	10YR	3	3	0.3520337	0.2690476	0.1744578
22	Pedon 6	99	147	Bg2	10YR	4	2	0.4360624	0.3706674	0.2969745
23	Pedon 7	0	25	Ap	7.5YR	3	4	0.3827022	0.2567391	0.1506936
24	Pedon 7	26	43	Ap	10YR	5	8	0.6409173	0.4443663	0.1093679
25	Pedon 8	0	13	Ap	10YR	5	3	0.5589675	0.467335	0.3566388
26	Pedon 8	14	71	Cv	5YR	4	6	0.5409717	0.330593	0.1852933
27	Pedon 9	0	25	A	10YR	5	3	0.5589675	0.467335	0.3566388
28	Pedon 9	26	56	Bt	10YR	4	4	0.4765699	0.360387	0.2143803

Table 9: SCC converted to sRGB

Sample ID	Pedon No.	Top	Bottom	Name	Munsell Colour Notation			sRGB Colour Notation		
					Hue	Value	Chroma	r	g	b
1	Pedon 1	0	9	Ap	2.5YR	3	6	0.4468915	0.2206162	0.12794174
2	Pedon 1	10	50	BA	2.5YR	3	6	0.4468915	0.2206162	0.12794174
3	Pedon 1	51	84	B	7.5YR	5	6	0.637312	0.4408493	0.24846998
4	Pedon 1	85	200	Bt	5YR	5	6	0.6516906	0.4320947	0.27623886
5	Pedon 2	0	29	Ap	7.5YR	6	4	0.7000982	0.5575056	0.43076725
6	Pedon 2	30	65	B	7.5YR	5	6	0.637312	0.4408493	0.24846998
7	Pedon 2	66	110	Bt	10YR	6	6	0.7224152	0.5557209	0.31700319
8	Pedon 2	111	195	BCt	10YR	8	2	0.8482915	0.7842988	0.69490747
9	Pedon 3	0	22	Ap	10YR	5	4	0.5801129	0.4622333	0.31259594
10	Pedon 3	23	60	B	10YR	3	4	0.3679063	0.2644507	0.13648352
11	Pedon 3	61	109	Btg	5Y	6	2	0.6163485	0.5838988	0.48074133
12	Pedon 3	110	151	BCtg	10YR	3	4	0.3679063	0.2644507	0.13648352
13	Pedon 4	0	26	Ap	10YR	4	3	0.4584415	0.3652712	0.25491453
14	Pedon 4	27	74	Bt	7.5YR	3	4	0.3827022	0.2567391	0.15069361
15	Pedon 4	75	100	Bg	5YR	2	6	0.3271944	0.1405905	0.01393841
16	Pedon 5	0	17	Ap	7.5YR	5	8	0.6690249	0.4288437	0.15558104
17	Pedon 5	18	40	Bg1	5YR	4	6	0.5409717	0.330593	0.18529327
18	Pedon 5	41	142	Bg2	10YR	8	2	0.836083	0.9255749	0.81926487
19	Pedon 6	0	29	Ap	2.5Y	6	2	0.6284468	0.5794825	0.48571138
20	Pedon 6	30	66	B	5YR	3	4	0.3940324	0.2499977	0.16682669
21	Pedon 6	67	98	Bg1	5YR	4	3	0.478992	0.3545817	0.28216703
22	Pedon 6	99	147	Bg2	7.5YR	5	6	0.637312	0.4408493	0.24846998
23	Pedon 7	0	25	Ap	5YR	5	6	0.6516906	0.4320947	0.27623886
24	Pedon 7	26	43	Ap	10YR	4	4	0.4765699	0.360387	0.21438027
25	Pedon 8	0	13	Ap	7.5YR	4	3	0.4713544	0.3589827	0.268153
26	Pedon 8	14	71	Cv	5YR	3	2	0.3493408	0.2663508	0.22389989
27	Pedon 9	0	25	A	10YR	5	3	0.5589675	0.467335	0.35663875
28	Pedon 9	26	56	Bt	10YR	7	3	0.767988	0.6742714	0.54990633

CONCLUSION

The study highlighted that the MCS1, MCS2 and SCC models were independent of one another, and their associations showed nonlinearity. Assessing the semi-quantitative data revealed a reasonable resemblance (amounting to 71.43%) between MCS1 and MCS2 based on soil colour - comprising 46.43% identical soil colours and 25% similar ones - thereby substantiating the reliability of the model employing the Munsell colour system. The likeness between MCS1 and SCC reached 64.29%, while MCS2 and SCC demonstrated 75% similarity, under- lining the dependability of the SCC's utility as well. Considering its cost-effectiveness and accessibility, SCC emerges as the preferable option. Nonetheless, an obstacle arises concerning soil colour nomenclature since the application lacks the capacity for this particular output, discouraging in-situ soil colour determination. It is essential to clarify that matters of availability and affordability are not universally problematic but rather context-dependent.

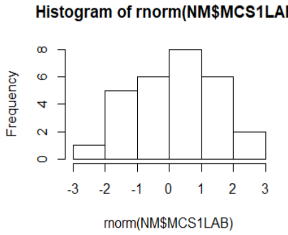

Figure 10: Mean distribution of transformed MCS1 data to CIELAB

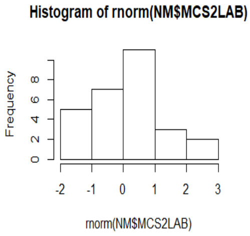

Figure 11: Mean distribution of transformed MCS2 data to CIELAB

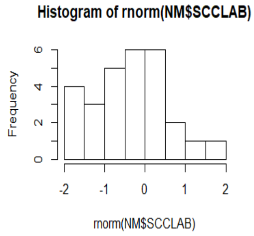

Figure 12: Mean distribution of transformed SCC data to CIELAB

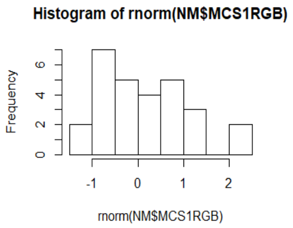

Figure 13: Mean distribution of transformed MCS1 data to sRGB

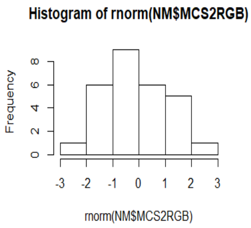

Figure 14: Mean distribution of transformed MCS2 data to sRGB

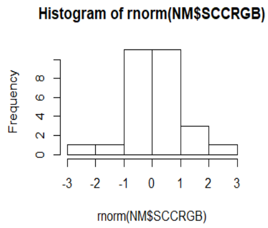

Figure 15: Mean distribution of transformed SCC data to sRGB

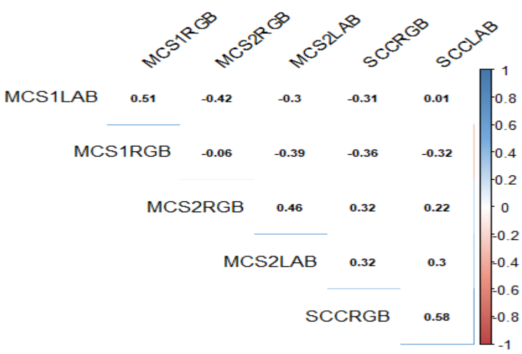

Figure 16a: Correlogram of the transformed data

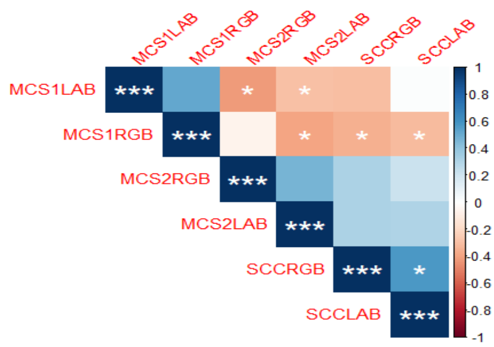

Figure 16b: Correlogram of the transformed data

Table 10: Means generated from MCS1CIE, MCS2CIE, SCCCIE, MCS1RGB, MCS2RGB and SCCRGB results

Mean MCS1 CIELAB	Mean MCS2 CIELAB	Mean SCC CIELAB	Mean MCS1 sRGB	Mean MCS2 sRGB	Mean SCC sRGB
30.2033825	30.23090133	26.7405941	0.3411639	0.352286	0.265149813
33.60303663	30.203383	26.7405941	0.4533414	0.3411639	0.265149813
24.91261337	33.13899	33.719852	0.374299633	0.4658395	0.442210427
29.977352	33.13899	33.6030383	0.3639589	0.4658395	0.453341387
30.2033825	30.203383	31.1837027	0.3411639	0.3411639	0.56279035
33.71985333	30.203383	33.719852	0.442210433	0.3411639	0.442210427
24.91261337	27.908079	36.39142537	0.374299633	0.451647367	0.531713097
29.977352	33.47194467	32.31398067	0.3639589	0.428638233	0.77583259
29.79056793	22.54224833	27.90807907	0.3287726	0.366163367	0.45164738
22.2327258	24.74108067	20.73069837	0.464600833	0.454608833	0.256280173
19.9658571	22.232725	25.12953583	0.473376267	0.464600833	0.560329543
23.42752997	25.149044	20.73069837	0.572827767	0.460980433	0.256280173
25.24144313	29.790569	22.24565133	0.3586859	0.3287726	0.35954241
39.03612317	15.63705733	21.17155097	0.417816533	0.272671067	0.263378303
39.1167421	15.63705733	23.10495103	0.434166867	0.272671067	0.160574437
29.79056793	27.908079	39.03612417	0.3287726	0.451647367	0.417816547
10.9326582	30.203383	30.23090123	0.178840567	0.3411639	0.35228599
10.9326582	33.60303833	29.761107	0.178840567	0.4533414	0.86030759
24.8826354	24.88263533	25.58420973	0.350445733	0.350445733	0.564546893
24.21197317	22.24565133	21.2974595	0.342716467	0.3595424	0.270285597
24.74108057	18.16854567	22.49440013	0.454608833	0.2651797	0.371913577
24.8826354	19.409157	33.719852	0.350445733	0.367901433	0.442210427
25.24144313	21.171551	33.6030383	0.3586859	0.2633783	0.453341387
21.34912507	38.53846233	24.8826354	0.277133433	0.398217167	0.350445723
18.16854657	25.149044	22.54224817	0.2651797	0.460980433	0.366163367
24.91261337	30.23090133	16.09080143	0.374299633	0.352286	0.27986383
22.24565067	25.149044	25.149044	0.3595424	0.460980433	0.460980417
24.8826354	24.88263533	31.69285303	0.350445733	0.350445733	0.664055243

Table 11: output of multiple regression analysis

	R^2	SE of R^2	p-value
MeanMCS2CIE	0.09	0.09	0.127
MeanSCCCIE	0	0	0.96
MeanMCS1RGB	0.26	0.13	0.0052
MeanMCS2RGB	0.18	0.12	0.0241
MeanSCCRGB	0.09	0.09	0.111

Table 12: Kruskall- Wallis rank sum test

CIELAB Coordinates	chi-squared	df	p-value
*MCS1CIE ~ MCS2CIE	19.683	17	0.2908
MCS2CIE ~ MCS1CIE	23.929	18	0.1574
*MCS1CIE ~ SCCCIE	22.257	21	0.3848
SCCCIE ~ MCS1CIE	16.439	18	0.5619
*MCS2CIE ~ SCCCIE	20.588	21	0.4843
SCCCIE ~ MCS2CIE	23.572	17	0.1315
sRGB Coordinates			
*MCS1RGB ~ MCS2RGB	14.348	17	0.6423
MCS2RGB ~ MCS1RGB	22.548	18	0.2086
*MCS1RGB ~ SCCRGB	22.109	21	0.3933
SCCRGB ~ MCS1RGB	18.71	18	0.4099
*MCS2RGB ~ SCCRGB	18.508	21	0.6167
SCCRGB ~ MCS2RGB	20.933	17	0.2293

Upon transforming soil colour data into statistically analyzable CIELAB and sRGB coordinates, no positive correlation was identified between the coordinates at the 5% significance level, with the exception of a correlation between SCCRGB and SCCCIE. This leads to the conclusion that the respective coordinates cannot be used interchangeably between CIELAB and sRGB. Regression analysis yielded MCS1 as the most accurate model. Additionally, employing the Kruskal test function, the study determined that only the means produced by MCS1RGB and MCS2RGB, as well as by MCS2RGB and SCCRGB, were found to be identical.

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