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Soil Organic Carbon in Typic Hapluderts on Different Slopes and Land Uses

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ABSTRACT

Organic carbon is a key component in the carbon cycle and plays a crucial role in determining soil quality. This research aimed to determine the soil organic carbon content on different slopes and land uses in Candirejo Village, Semin District, Gunungkidul Regency. Fieldwork was conducted using a survey method on Typic Hapluderts with varying slopes and land uses. Soil analyses included organic carbon, soil texture, soil bulk density, pH (H_2O), and soil color. The results indicated that soil organic carbon levels varied across different slopes and land uses. Average soil organic carbon content on flat slopes was 1.64% (low), on sloping slopes it was 1.21% (low), while the land uses content from highest to lowest was in forests 2.19% (medium), in shrublands 1.55% (low), in settlements 1.31%, in dry lands 1.20% (low), and in paddy soils 0.86% (very low). Slope did not significantly influence soil organic carbon levels. However, land use significantly influences soil organic carbon levels, leading to substantial differences in soil organic carbon content. Soil color coordinate L* (lightness) is linearly negatively correlated with soil Organic-C, with a value of r = 0.641. Soil organic carbon showed a strong, significant relationship with the soil color coordinate L* (lightness). Higher soil organic carbon content was associated with lower L* values, indicating darker soil color.

Keywords: Land use, organic carbon, slope, Typic Hapluderts

INTRODUCTION

Slope and land use are important factors that can affect soil properties, especially soil organic carbon levels. Differences in slope and land use can lead to different contributions of organic matter into the soil. According to Banjarnahor et al. (2018), rainwater-driven soil erosion on steep slopes can remove soil materials, such as organic carbon (OC), and transport them, thereby decreasing soil productivity. Each land use has its own vegetation diversity and density, as well as its own land management practices. Therefore, inappropriate land use can disrupt ecosystem balance.

Soil OC is an important component of the global carbon cycle, supporting the sustainability of terrestrial ecosystems (Farrasati et al., 2019). The value of soil OC in improving soil's physical, chemical, and biological properties is important. The higher the total OC content, the better the quality of mineral soil will be (Siregar, 2017). We must maintain soil quality well, because most of Earth's transformation processes occur there. According to Scharlemann et al. (2014), soil is the largest carbon store in terrestrial ecosystems, with carbon levels exceeding those in vegetation and the atmosphere.

The level of soil OC varies across regions due to differences in area characteristics. Candirejo Village, Semin District, Gunungkidul Regency, has regional characteristics, including soil types dominated by Typic Hapluderts, varying slopes, and diverse land uses. The slope includes flat and sloping areas, while land use includes shrublands, dry lands, settlements, paddy soils, and forests. In addition, many limestone mining activities in this village can cause environmental problems, such as declining soil quality. According to the Gunungkidul Regency Government (2007), Semin District has a critical land area of 773 ha, of which most is located in the Candirejo Village area.

Given the area's characteristics, the level of soil OC across various slopes and land uses in Candirejo Village is important to study to determine soil fertility indicators. It is because the amount of carbon can serve as a benchmark for soil management, which is important for sustainable land management and environmental conservation.

MATERIALS AND METHODS

The research area is located in Candirejo Village, Semin District, Gunungkidul Regency, Special Region of Yogyakarta (Figure 1). Based on WGS 1984 UTM Zone 49S, Candirejo Village is astronomically located at coordinates 471000 mE – 476000 mE and 9132000 mN – 9137000 mN. This study uses a survey method with purposive sampling to determine sample points, namely in Typic Hapluderts soil, based on differences in slope (flat and sloping) and land use (shrublands, dry lands, settlements, paddy soils, and forests). Soil sampling was carried out by creating a soil mini-pit measuring 30 cm × 30 cm × 30 cm to obtain data on soil morphological properties. The provisions for sampling on dry land (shrublands, dry lands, settlements, forests) are by taking two soil samples based on the difference in soil color in the top layer, while in wetland (paddy soils), by taking two soil samples in the plow layer at depths of 0-10 cm and 10-20 cm.

The variables analyzed were soil color using the Munsell method, organic-C using the Walkley and Black method, pH H_2O using the potentiometric method, soil bulk density using the ring method, and soil texture using the pipette method. The soil color characterization in the Munsell system can be quantitatively converted to the CIE-L*a*b* system (Vodyanitskii et al., 2016). In this system, the color of the soil can be expressed as three values, namely the L* (lightness) value which describes the content of dark pigment in the soil, the value of a* (redness) which describes the content of red pigment in the soil, and the value of b* (yellowness) which describes the content of yellow pigment in the soil. Data analysis was performed using a t-test, a one-way ANOVA, a Bonferroni post hoc test, and a normality test. The results of converting soil color from the Munsell system to the CIE-L*a*b* system can be regressed against soil organic-C to assess the closeness of the relationship, as reflected in the correlation coefficient (r).

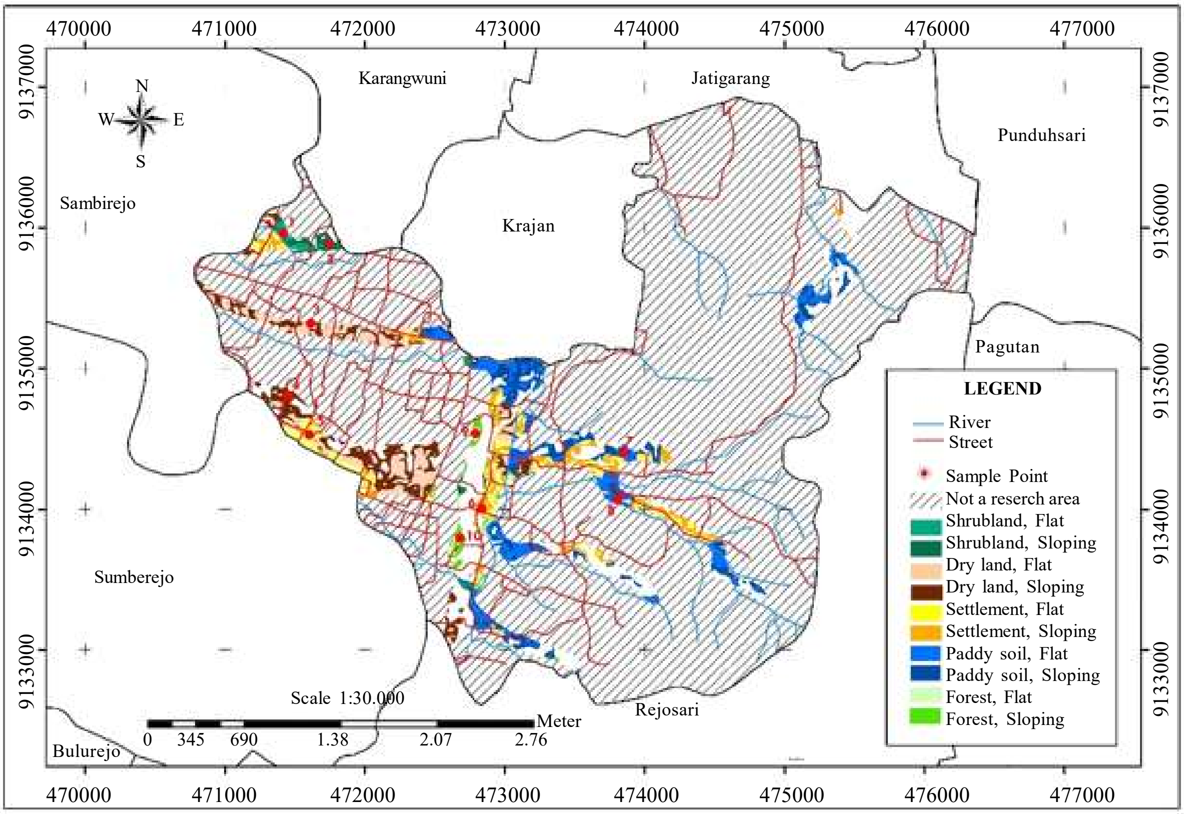

Figure 1. Map of the research location located on the soil of *Typic Hapluderts* in different areas slopes and land uses in Candirejo Village.

RESULTS AND DISCUSSION

Research Area

According to data from BMKG D.I. Yogyakarta, the research location had an annual rainfall intensity of 2110 mm year^{-1}. The research location had an average of 4.1 dry months (>60 mm month^{-1}) and 6.9 wet months (>100 mm month^{-1}). Based on the climate classification by Schmidt and Ferguson (1951), with an average Q value of 59.42%, the research area, Semin District, falls under climate type C (moderately wet). According to the 2010 Soil Type Map of Gunungkidul Regency, Candirejo Village was dominated by Typic Hapluderts soil type. Typic Hapluderts soil belongs to the ordo Vertisols, sub-ordo Uderts, and group Hapluderts. The research location had flat and sloping slopes. Vertisols were generally found in lowland and flat areas with conditions supporting water accumulation and stagnation (Jordanova, 2017). Land use in Candirejo Village consisted of forests (28.01 ha), dry lands (60.95 ha), paddy soils (48.27 ha), shrublands (17.03 ha), and settlements (50.12 ha).

Some Soil Physical Properties

The soil physical property analyses included soil color using the Munsell method, soil bulk density using the volumetric ring method, and soil texture using the pipette method, as presented in Tables 1 and 2.

Soil Color

Soil color can be used as a qualitative indicator of soil fertility levels and soil organic matter content, particularly carbon. Based on soil color analysis, the soil ranged from brown to black, with a Hue of 7.5YR-10YR, Value ≤ 5, and Chroma ≤ 3. High-quality soil was typically dark brown, which was generally related to a relatively high organic matter content (Fitriani et al., 2022). The conversion of soil color from the Munsell system to the CIE L*a*b* system was presented in Table 2.

Soil Bulk Density

The bulk density of soil is the mass of solids within the total volume of soil. The bulk density of soil at the research location ranged between 1.04

Table 1. Bulk density and textural classes of soils at different slopes and land use.

Slope	Land use	Layer (cm)	Bulk density (g.cm^{-3})	Texture (%)			Class
				Sand	Silt	Clay	
Flat	Shrubland	1 (0–10)	1.12[a]	14.34	20.25	65.41[abc]	Clay
		2 (10–30)	1.13[a]	16.47	13.50	70.03[abc]	Clay
	Dry land	1 (0–8)	1.40[a]	15.40	29.51	55.09[d]	Clay
		2 (8–30)	1.39[a]	15.12	28.07	56.81[d]	Clay
	Settlement	1 (0–9)	1.25[a]	22.13	42.00	35.87[a]	Clay Loam
		2 (9–30)	1.43[a]	17.57	43.55	38.88[a]	Silty Clay Loam
	Paddy soil	1 (0–10)	1.25[a]	15.33	28.74	55.93[b]	Clay
		2 (10–20)	1.26[a]	16.78	31.94	51.28[b]	Clay
	Forest	1 (0–18)	1.04[a]	5.60	23.94	70.46[c]	Clay
		2 (18–30)	1.13[a]	6.48	54.54	38.98[c]	Silty Clay Loam
Sloping	Shrubland	1 (0–9)	1.24[a]	8.12	9.11	82.78[abc]	Clay
		2 (9–30)	1.28[a]	6.29	22.45	71.25[abc]	Clay
	Dry land	1 (0–11)	1.26[a]	12.02	18.13	69.84[d]	Clay
		2 (11–30)	1.23[a]	9.10	18.08	72.81[d]	Clay
	Settlement	1 (0–10)	1.44[a]	8.53	40.87	50.60[a]	Silty Clay Loam
		2 (10–30)	1.22[a]	7.41	23.15	69.45[a]	Clay
	Paddy soil	1 (0–10)	1.21[a]	18.42	32.74	48.84[b]	Clay
		2 (10–20)	1.34[a]	21.34	30.11	48.55[b]	Clay
	Forest	1 (0–8)	1.14[a]	26.95	24.32	48.73[cd]	Clay
		2 (8–30)	1.37[a]	29.13	24.44	46.43[cd]	Clay

Table 2. Conversion of soil color from the Munsell system to the CIE L*a*b* system.

Slope	Land use	Layer (cm)	Soil color Munsell system	CIE L*a*b* color system conversion		
				L*	a*	b*
Flat	Shrubland	1 (0–10)	10YR 2/1 (*black*)	20.5	2.0	5.4
		2 (10–30)	7.5YR 2.5/1 (*black*)	25.6	2.9	4.9
	Dry land	1 (0–8)	7.5YR 3/1 (*very dark gray*)	30.8	2.9	5.5
		2 (8–30)	10YR 3/1 (*very dark gray*)	30.8	1.9	6.0
	Settlement	1 (0–9)	10YR 3/1 (*very dark gray*)	30.8	1.9	6.0
		2 (9–30)	10YR 3/2 (*very dark grayish brown*)	30.8	3.5	12.2
	Paddy soil	1 (0–10)	10YR 4/2 (*dark grayish brown*)	41.2	3.2	13.3
		2 (10–20)	10YR 3/2 (*very dark grayish brown*)	30.8	3.5	12.2
	Forest	1 (0–18)	10YR 2/1 (*black*)	20.5	2.0	5.4
		2 (18–30)	10YR 2/2 (*very dark brown*)	20.5	3.6	11.1
Sloping	Shrubland	1 (0–9)	10YR 2/2 (*very dark brown*)	20.5	3.6	11.1
		2 (9–30)	7.5YR 3/1 (*very dark gray*)	30.8	2.9	5.5
	Dry land	1 (0–11)	10YR 3/1 (*very dark gray*)	30.8	1.9	6.0
		2 (11–30)	10YR 2/1 (*black*)	20.5	2.0	5.4
	Settlement	1 (0–10)	7.5YR 2.5/2 (*very dark brown*)	25.6	5.3	10.0
		2 (10–30)	7.5YR 3/2 (*dark brown*)	30.8	5.5	11.2
	Paddy soil	1 (0–10)	7.5YR 5/3 (*brown*)	51.6	6.9	16.8
		2 (10–20)	7.5YR 4/3 (*brown*)	41.2	7.8	17.5
	Forest	1 (0–8)	10YR 2/2 (*very dark brown*)	20.5	3.6	11.1
		2 (8–30)	10YR 4/3 (*brown*)	41.2	5.0	19.4

and 1.44 g cm^{-3} (Figure 2). When dry, Vertisol had a bulk density of 1.60–1.81 g cm^{-3} (Sunarminto et al., 2008). The average bulk density values across different slopes, land uses, and soil layers showed no significant differences or were similar. It was because the research site had the same mineral soil type, Typic Hapluderts. The amount of accumulated organic matter in the soil influenced the bulk density. Adding organic matter to the soil increased the number of soil pores and formed a crumbly soil structure, thereby decreasing soil bulk density (Saputra et al., 2018).

Soil Texture

Soil texture was the relative proportion of sand, silt, and clay fractions in a soil. The soil texture classes at the research location were clay, clay loam, and silty clay loam. The soil texture was dominated by clay, with clay fractions > 35% (Figure 3). The average percentages of clay fractions in soil across different slopes and layers showed no significant differences or were similar. However, the average percentages of clay fractions across different land uses showed significant differences. It was due to the considerable differences in clay fractions caused bythe varying characteristics of each land use.

Some Soil Chemical Properties

The soil chemical property analysis included soil pH (H_2O) measured potentiometrically and soil OC determined by the Walkley and Black method, as presented in Table 3.

Soil pH H_2O

The degree of acidity (pH) was the activity of hydrogen ions contained in the soil solution. The soil pH at the research site ranged from 5.70 to 6.60, indicating slightly acidic conditions (Figure 4). According to Debele (1985), of the total distribution of Vertisols worldwide, 61% had a pH of 5.5-6.7, 21% had a pH of 6.7-7.3, and the remaining 9% had a pH greater than 8. The slightly acidic pH of the soil H_2O at the research site may have resulted from significant leaching due to the relatively high rainfall of 2110 mm yr^{-1}. The average pH of soil H_2O across different slopes was not significant, whereas it was significant across different land uses and layers. Soil conditions, land management, and

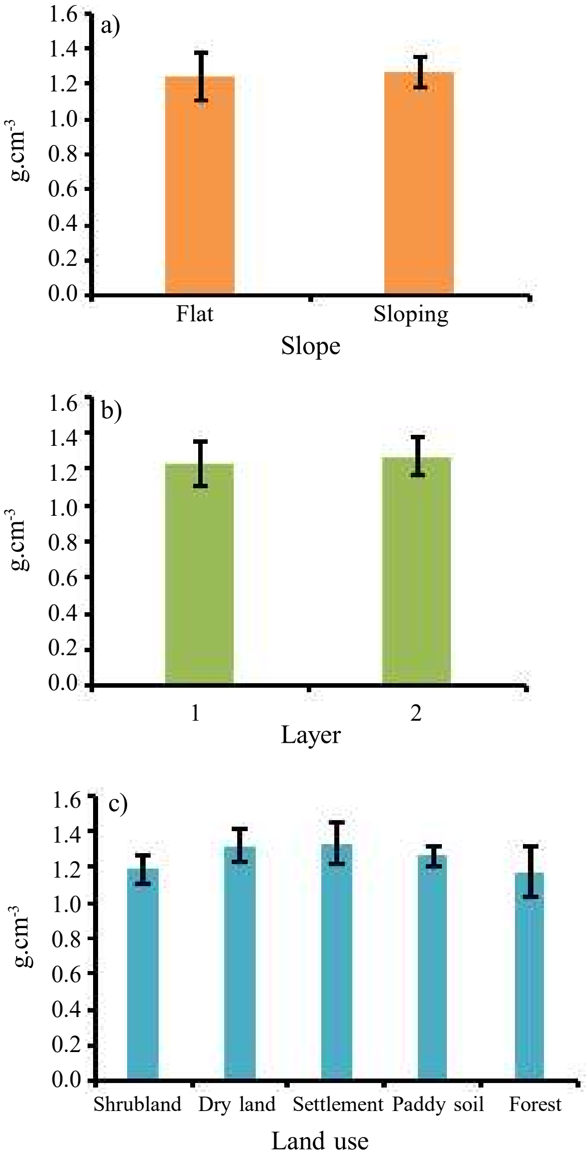

Figure 2. Average soil bulk density and standard deviation on different slopes (a), soil layers (b), and land uses (c).

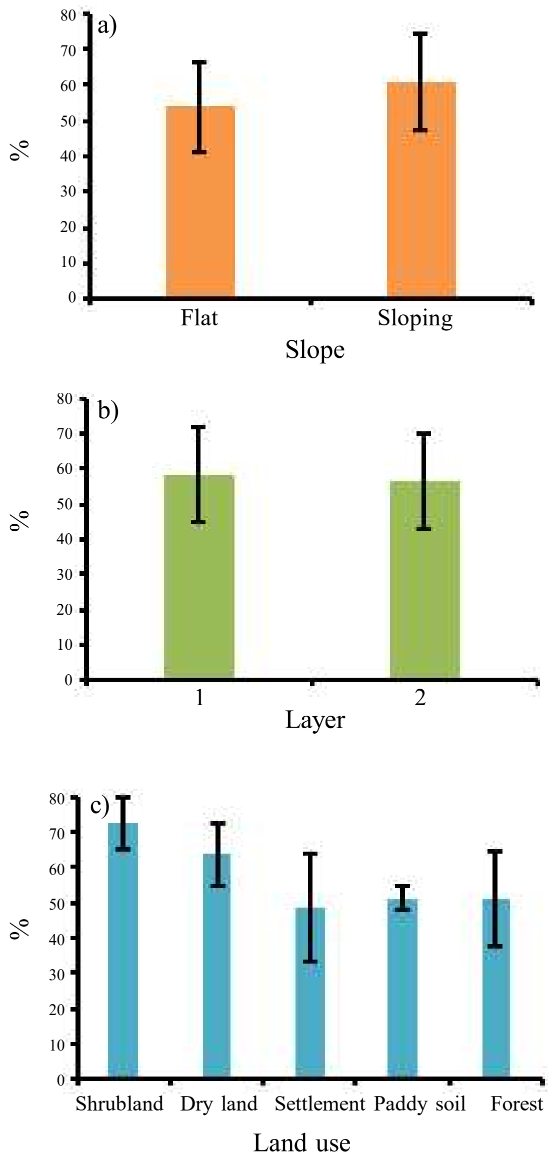

Figure 3. Average soil clay fractions and standard deviation on different slopes (a), soil layers (b), and land uses (c).

organic matter accumulation influenced soil water pH. Land conditions that were frequently wet would make the soil more acidic because the more water present, the more H^+ ions would be released. Intensive soil cultivation and the application of organic and inorganic fertilizers would increase soil acidity due to physiological reactions triggered by these fertilizers. Organic acids from the decomposition of organic matter can bind H^+ ions, thereby increasing soil pH (Siregar et al., 2017).

Soil Organic-C

Organic carbon was an important component of organic matter that could serve as an indicator of soil fertility because it acted as a reservoir of nutrients derived from the decomposition of organic matter, thereby influencing nutrient cycling and the availability of essential nutrients. The soil OC at the research site ranged from 0.76% to 3.05%, with values from very low to high (Figure 5). The average soil OC values across different slopes and layers showed no significant differences or were similar. Soil OC values were influenced by slope conditions. Steep slopes caused high kinetic energy in surface runoff, resulting in low soil OC due to soil transport to flatter areas (Septianugraha et al., 2015). Generally, soil OC content was higher at the surface and decreased gradually with soil depth (Siringoringo, 2014). The average soil OC values on different land uses showed significant results. Sequentially, the land uses with the highest to lowest average soil OC values were forests 2.19% (medium), shrublands

Table 3. pH (H_2O) and Organic-C of soils at different slopes and land use.

Slope	Land use	Layer (cm)	pH H_2O	Organic-C (%)	Status
Flat	Shrubland	1 (0–10)	6.44^{a}	2.06^{a}	Medium
		2 (10–30)	6.05^{a}	1.78^{a}	Low
	Dry land	1 (0–8)	6.15^{b}	1.36^{b}	Low
		2 (8–30)	6.22^{b}	1.41^{b}	Low
	Settlement	1 (0–9)	6.47	1.50^{c}	Low
		2 (9–30)	5.84	1.10^{c}	Low
	Paddy soil	1 (0–10)	5.75^{abc}	0.80^{abcd}	Very low
		2 (10–20)	5.70^{abc}	0.76^{abcd}	Very low
	Forest	1 (0–18)	6.60^{c}	3.05^{d}	High
		2 (18–30)	6.00^{c}	2.58^{d}	Medium
Sloping	Shrubland	1 (0–9)	6.37^{a}	1.26^{a}	Low
		2 (9–30)	6.30^{a}	1.10^{a}	Low
	Dry land	1 (0–11)	6.38^{b}	0.99^{b}	Very low
		2 (11–30)	5.88^{b}	1.07^{b}	Low
	Settlement	1 (0–10)	6.39	1.58^{c}	Low
		2 (10–30)	5.93	1.08^{c}	Low
	Paddy soil	1 (0–10)	5.83^{abc}	0.89^{abcd}	Very low
		2 (10–20)	5.81^{abc}	1.01^{abcd}	Low
	Forest	1 (0–8)	6.27^{c}	2.04^{d}	Medium
		2 (8–30)	6.13^{c}	1.11^{d}	Low

1.55% (low), settlements 1.31% (low), dry lands 1.20% (low), and paddy soils 0.86% (very low). Soil OC values across different land uses were influenced by vegetation presence and land management. Forest land had the highest values due to being dominated by teak trees around ±20 years old with abundant litter, and only minimal soil cultivation was performed at planting. Plants with higher root biomass could contribute more to soil OC formation (Yang et al., 2023). Soil management could reduce soil organic matter by exposing it to air, thereby increasing microbial decomposition. Soil processing and management practices could lead to a decrease in soil organic matter or soil OC due to organic fractions being unprotected from decomposers (Salimon et al., 2009). Poor soil aeration would affect the decomposition and mineralization processes of organic matter, thereby impacting soil OC levels (Bakri et al., 2022).

Calculation of Stored Organic Carbon in Soil

Each land use had different values of stored OC in the soil. The characteristic conditions of each land use greatly influenced it. The values of stored OC in the soil were obtained by converting soil carbon content values to units of weight (ton) and area (ha). The analysis of stored OC in soil across different slopes and land uses is presented in Table 4.

The amount of stored OC in the soil was influenced by soil bulk density and soil OC content. Soil bulk density in the topsoil layer tended to be low due to the influence of root systems and the accumulation of organic material from vegetation. The presence of vegetation in a land-use area significantly increased soil OC: the more vegetation or the higher the vegetation density, the greater the soil OC.

The stored OC content in soils for different slopes shows that flat slopes had a higher value of 282.33 tons ha^{-1}, while sloping slopes had a value of 207.82 tons ha^{-1}. In order, the stored OC content in soils for different land uses from highest to lowest were forests 144.14 tons ha^{-1}, shrublands 106.93 tons ha^{-1}, settlements 99.01 tons ha^{-1}, dry lands 97.08 tons ha^{-1}, and paddy soils 43.88 tons ha^{-1}. Based on the measured OC stored in soil, it was possible to estimate soil OC stocks in Typic Hapluderts on different slopes and land uses, as presented in Table 5. The analysis results showed a total soil OC stock of Typic Hapluderts across different slopes and land uses, with a value of 9,423.12 tons in Candirejo Village.

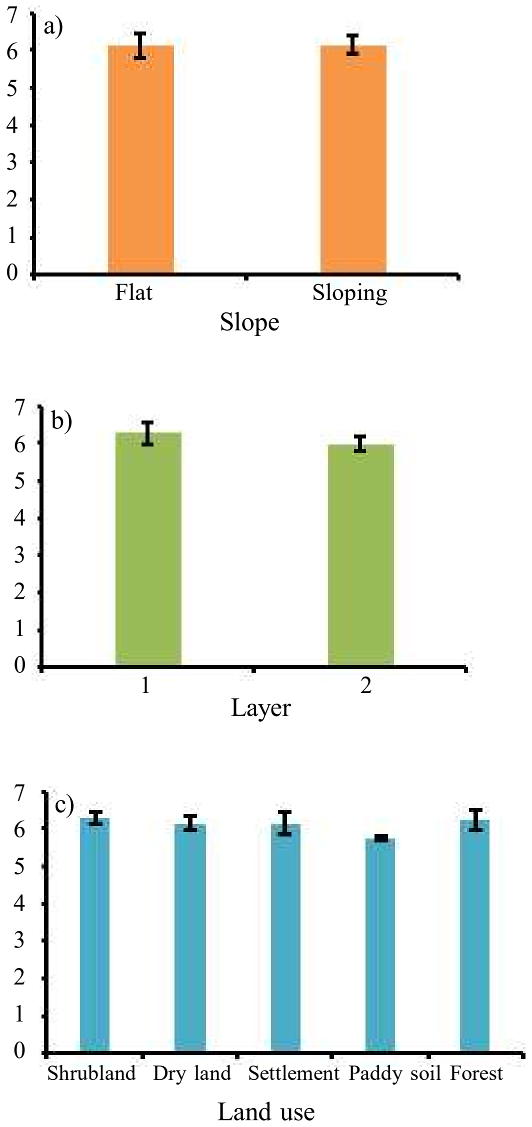

Figure 4. Average soil pH (H_2O) and standard deviation on different slopes (a), layers (b), and land uses (c).

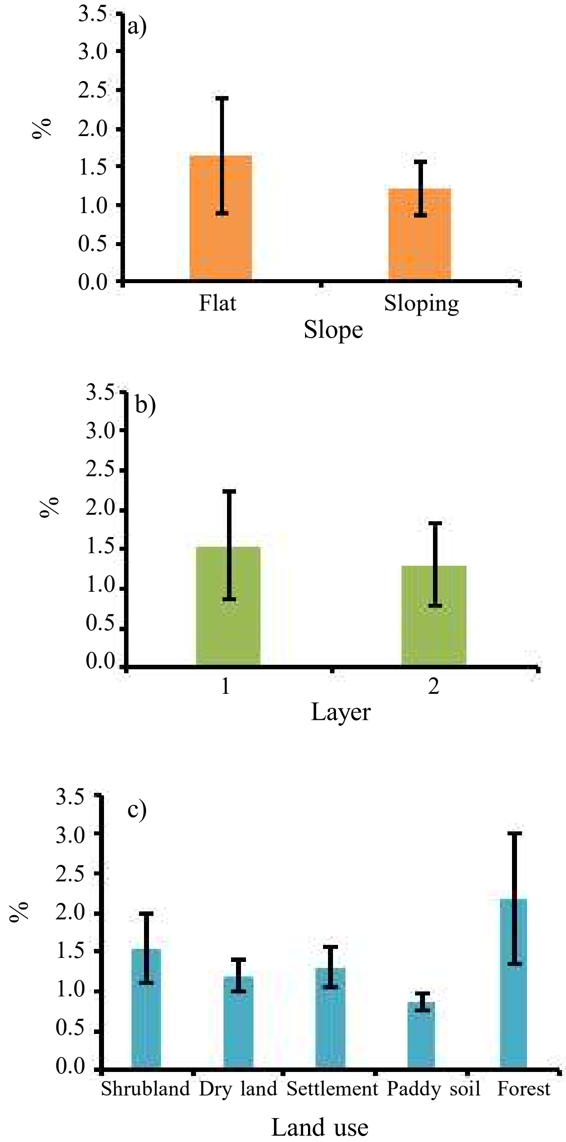

Figure 5. Average soil organic carbon and standard deviation on different slopes (a), layers (b), and land uses (c).

Relationship Between Soil Color and Soil Organic Carbon

Based on the conversion of soil color from the Munsell system to the CIE L*a*b* system, we determined the relationship between soil color and soil OC. The soil OC content had the greatest influence on the soil color coordinate L* (lightness) compared to the soil color coordinates a* (redness) and b* (yellowness). The results of a simple linear regression analysis showed a strong, significant relationship between the soil color coordinate L* (lightness) and soil OC. The higher the x value (soil OC), the lower the y value (coordinate L* or lightness), resulting in a darker color, and vice versa (Figure 6). According to Fitriani et al. (2022), soil organic matter darkens soil color by lowering its value and chroma, so soils with high organic matter content tend to be darker.

Relationship Between Soil Bulk Density, Clay Fraction, and Soil Organic Matter

The relationships between soil bulk density parameters and the clay fraction (%) and soil organic matter (%) could be determined using multiple linear regression. The results showed that soil bulk density was strongly related to the clay fraction and soil organic matter, with about 40.12% of the clay fraction and organic matter contributing to it. The multiple linear regression equation between soil bulk density and the clay fraction and organic matter was $Y = 1.5728 - 0.0028X1 - 0.0638X2$, indicating that

Table 4. Stored organic carbon in soils for different slopes and land use.

Slope	Land use	Layer (cm)	Bulk density (g cm^{-3})	Organic- C (%)	Soil carbon (g cm^{-2})	Stored organic carbon (ton ha^{-1})	Total stored organic carbon (ton ha^{-1})
Flat	Shrubland	1 (0–10)	1.12	2.06	0.23	23.07	63.30
		2 (10–30)	1.13	1.78	0.40	40.23	
	Dry land	1 (0–8)	1.40	1.36	0.15	15.23	58.35
		2 (8–30)	1.39	1.41	0.43	43.12	
	Settlement	1 (0–9)	1.25	1.50	0.16	16.88	49.91
		2 (9–30)	1.43	1.10	0.33	33.03	
	Paddy soil	1 (0–10)	1.25	0.80	0.10	10.00	19.58
		2 (10–20)	1.26	0.76	0.09	9.58	
	Forest	1 (0–18)	1.04	3.05	0.57	57.10	92.08
		2 (18–30)	1.13	2.58	0.34	34.98	
Sloping	Shrubland	1 (0–9)	1.24	1.26	0.14	14.06	43.63
		2 (9–30)	1.28	1.10	0.29	29.57	
	Dry land	1 (0–11)	1.26	0.99	0.13	13.72	38.73
		2 (11–30)	1.23	1.07	0.25	25.01	
	Settlement	1 (0–10)	1.44	1.58	0.22	22.75	49.10
		2 (10–30)	1.22	1.08	0.26	26.35	
	Paddy soil	1 (0–10)	1.21	0.89	0.10	10.77	24.30
		2 (10–20)	1.34	1.01	0.13	13.53	
	Forest	1 (0–8)	1.14	2.04	0.18	18.60	52.06
		2 (8–30)	1.37	1.11	0.33	33.46	

Table 5. Soil organic carbon stocks Typic Hapluderts in different slopes and land use Candirejo Village.

Slope	Land use	Stored organic carbon (ton ha^{-1})	Area (ha)	Carbon stocks (ton)
Flat	Shrubland	63.30	8.55	541.22
	Dry land	58.35	37.73	2,201.54
	Settlement	49.91	22.03	1,099.47
	Paddy soil	19.58	25.13	491.94
	Forest	92.08	10.49	965.93
Total (∑ =)		282.33	103.93	5,300.10
Sloping	Shrubland	43.63	8.48	369.98
	Dry land	38.73	23.22	899.25
	Settlement	49.10	28.09	1,379.33
	Paddy soil	24.30	23.14	562.37
	Forest	52.06	17.52	912.09
Total (∑ =)		207.82	100.45	4,123.02
Total amount (∑ =)		491.04	204.38	9,423.12

as the values of the clay fraction and soil organic matter increased, the soil bulk density values decreased. Soil bulk density had a low and insignificant relationship with the clay fraction, whereas it had a moderate and significant relationship with soil organic matter (Figure 7). Soil organic matter content had a greater influence on soil bulk density than the clay fraction. An increase

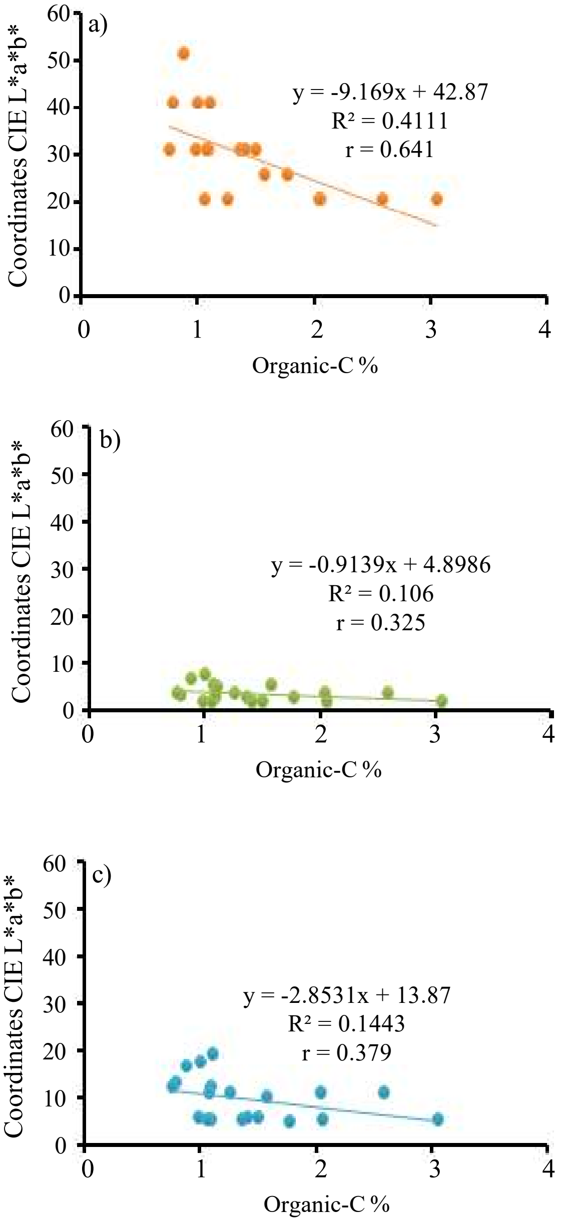

Figure 6. Relationship between soil color coordinates L*(a), coordinates a*(b), and coordinates b*(c) with soil organic carbon.

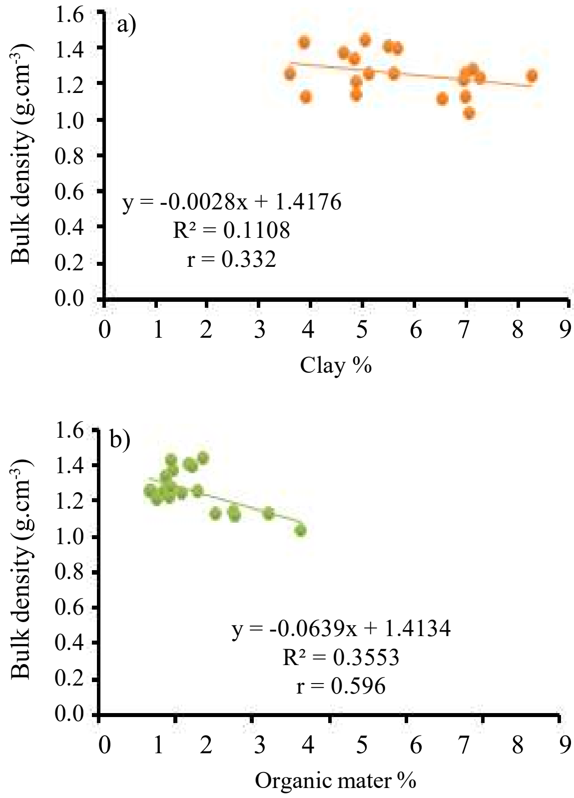

Figure 7. Relationship between soil bulk density and clay fraction (a), and soil bulk density with soil organic matter (b)

in soil organic matter content was consistently followed by a decrease in soil bulk density, contributing significantly to the decrease. Additionally, the research area had the same soil type, Typic Hapluderts, so the clay fraction values were similar.

CONCLUSIONS

The soil organic carbon content on flat slopes was 1.64% (low), while on sloping slopes it was 1.21% (low). In order, the land uses with soil organic carbon content from highest to lowest were forests 2.19% (moderate), shrublands 1.55% (low), settlements 1.31% (low), dry lands 1.20% (low), and paddy soils 0.86% (very low). Different slopes had no significant effect on soil organic carbon content, whereas different land uses did.

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