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Characteristics and utilization of black soils in Indonesia

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ABSTRACT

Black soils store a high amount of soil organic carbon (SOC) and play a crucial role in climate change, food security, and land degradation neutrality. However, data and information regarding black soils in tropical regions, including Indonesia, are limited. This study aimed to characterize and identify the utilization of black soils in Indonesia based on legacy soil survey data. We collated 142 soil pedon samples of Mollisols from articles, technical reports, and existing datasets. The site information (site position, elevation, land use type, parent material) and selected physicochemical properties were stored in a spreadsheet, from which exploratory data analysis was conducted. The result showed that the median SOC content was 1.53%, ranging from 0.6 to 8.2 %; cation exchange capacity was 30 cmol kg^{-1}, ranging from 9 to 95 cmol kg^{-1}; base saturation was 87%, ranging from 11 to 100 %; and bulk density was 1.21 g cm^{-3}, ranging from 1.13 to 1.36 g cm^{-3}. Other soil characteristics (particle size distribution, exchangeable bases, pH, pore, and water retention) varied with horizon type and land use/land cover. The black soils have been used for paddy fields, dryland farming, and gardens with low management intensity. Main cultivated crops include rice (*Oryza sativa*), corn (*Zea mays*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and nutmeg (*Myristica fragrans*), clove (*Syzygium aromaticum*), coconut (*Cocos nucifera*), and cocoa (*Theobroma cocoa)*. Threats to black soil functions include soil erosion, carbon loss, and nutrient imbalance. Soil and water conservation measures, integrated soil nutrient management, and agroforestry are among the best land management practices for black soils.

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1. INTRODUCTION

High concentrations of greenhouse gasses (CO_2, CH_4, N_2O, water favor, ozone, perfluorocarbons) in the atmosphere trigger climate change (IPCC, 2021) and subsequently impact agriculture and other aspects of life (Mikhaylov et al., 2020). Reducing greenhouse gasses (GHG) emissions and sequestering CO_2 are strategies to mitigate climate change impact. Vegetations, including crops, can sequester CO_2 from the atmosphere and store carbon in their biomass during photosynthesis; better crop growth, higher biomass, and higher CO_2 can be absorbed (Wang et al., 2021). Burning crop residues will release carbon into the atmosphere, whereas incorporating them into the soil will increase soil organic carbon (SOC) content. Thus, zero burning and soil organic matter management are among the approach to increase soil carbon stock and decrease CO_2 emission.

Data on soil carbon stock are crucial to assess carbon sequestration and storage. Soils store carbon in the long term. This soil function is essential in the terrestrial ecosystem because soil accumulates more carbon than carbon in biomass or the atmosphere. Stored carbon in the soils also prevents GHG emissions (Bossio et al., 2020). Good land management could ascertain that SOC does not emit into the atmosphere. Meanwhile, good crop management could ensure plants sequester CO_2 to biomass by photosynthesis. Good plant residue management could ensure the crop residue is back on land and become soil organic material.

The SOC content has no net change when the carbon input and loss are balanced. If the carbon input from photosynthesis is higher than carbon loss, the SOC content will increase (Ontl & Schulte, 2012). Soil carbon comprises 9% of the mitigation potential of forest, 72% for wetland and 47% for agriculture and grasslands. Thus, soil carbon is important to land-based efforts to prevent carbon emissions, remove atmospheric carbon dioxide and deliver ecosystem services in addition to climate mitigation (Bossio et al., 2020).

Black soils are soft, with a deep humus layer and rich organic matter content on the top layer (Han & Li, 2018; Song et al., 2022). The International Network of Black Soils (INBS) defines black soils as soils that have (i) black or very dark surface horizons, typically with a chroma of ≤ 3 moist, a value of ≤ 3 moist and ≤ 5 dry (by Munsell colors); (ii) high organic carbon content as per following: ≥ 1.2% for cold and temperate and ≥ 0.6% for tropical regions and (iii) thickness of very dark to black surface horizons not less than 25 cm (FAO, 2019, 2022). In the USDA Soil Taxonomy (Soil Survey Staff, 2022), the black soil is mostly Mollisols and excludes dark Vertisols and Andisols (Sorokin et al., 2021). In addition to high soil carbon stock, black soils are productive for food production; therefore, their occurrences are crucial in climate change, food security, and land degradation. The best sustainable land management should be applied to prevent carbon loss from this soil.

The black soils are found predominantly in cold and temperate regions, such as the United States, Canada, Russia, Ukraine, northeast China, Argentina, and Uruguay (Liu et al., 2012). In tropical regions, information on the occurrence of black soils is limited. In Brazil, black soils are found in the Araripe basin (Northeast Brazil), developed from limestone and covered by savanna-steppe to woodland savanna (Pinheiro Junior et al., 2022). In Indonesia, the black soils (Mollisols) were found in East Nusa Tenggara Province and developed from sedimentary and volcanic materials with udic and ustic humidity regimes. Recently, Sulaeman et al. (2021) identified the spatial distribution of black soil in Indonesia based on available soil maps and concluded that these soils cover about 6.3 Mha found mainly in Sulawesi, Nusa Tenggara, Maluku Islands, Papua, Aceh, and Eastern Java.

Currently, information regarding black soil properties and utilization is limited in Indonesia. Hence, this study aimed to characterize and identify the utilization of these black soils based on legacy soil survey data. Understanding characteristics and utilization are prerequisites for the sustainable use of these black soils.

2. MATERIAL AND METHODS

2.1. Data collation

As the first step, this nationwide study developed a black soil dataset. Soil profiles of Mollisols were collated from articles, technical reports, and existing datasets. A spreadsheet was designed with the field as follows: id, initial of soil observation, latitude, longitude, altitude, slope, land use type, parent material, soil name according to Soil Taxonomy subgroup, administrative name (village, district, regency, province), soil horizon designation, upper boundary, lower boundary, Munsell Color (hue, value, chroma), particle size distribution (sand, silt, clay), pH, soil organic carbon (SOC), total Nitrogen (TN), C/N ratio, total P_2O_5, total K_2O, Olsen P_2O_5, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Na, the sum of bases, cation exchange capacity (CEC), base saturation (BS), bulk density (BD), total pore, rapid drainage pore, slow drainage pore, water retention, and available water. The next step was extracting and re-arranging data from datasets from previous study of Sulaeman et al. (2012) by selecting the data profiles of Mollisols only.

From 2015-2018, the first author conducted soil surveys in Aceh, East Java, North Sulawesi, Gorontalo, Central Sulawesi, West Sulawesi, South Sulawesi, South-eastern Sulawesi, North Maluku, Maluku, and East Nusa Tenggara. The surveys were not to map black soils but to characterize profiles of Mollisols in land resource mapping and evaluation. These soil survey data were also included in the dataset. Additional published data in articles, technical reports, and student theses enriched the dataset.

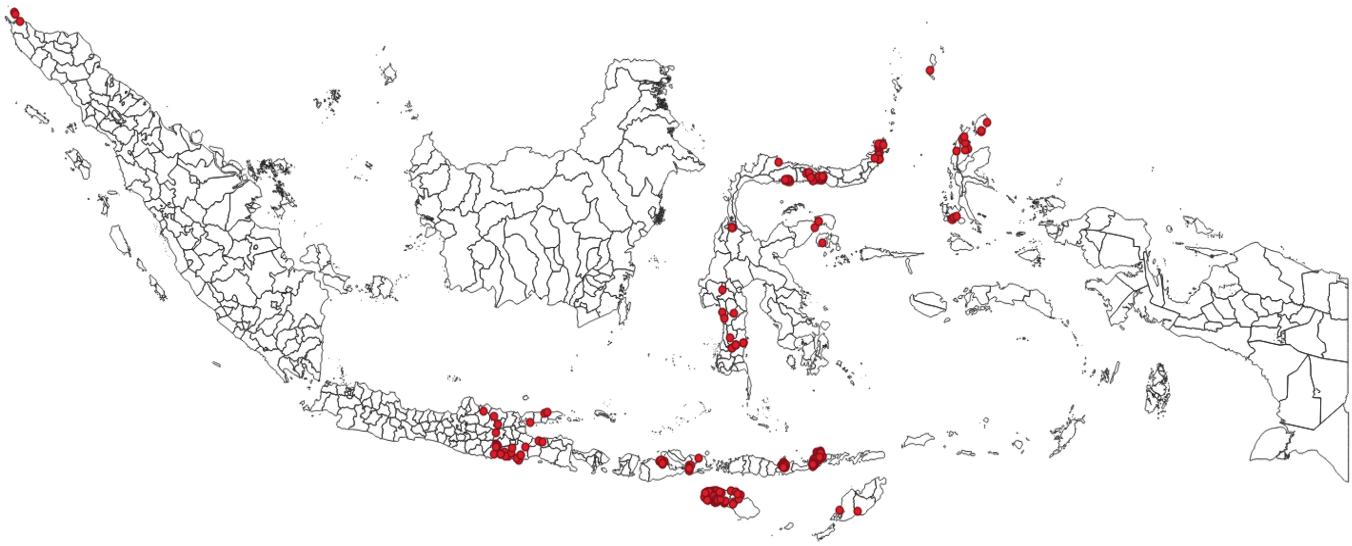

Figure 1. Distribution of 291 black soil profiles from 1994 to 2017. As many as 54 profiles in the dataset have no coordinate location. From 345 soil profiles, only 142 profiles were sampled for soil laboratory analysis.

The established dataset was verified for its color, thickness, and solum depth. Only the profiles that fulfill the black soil criteria were selected. One profile of Mollisols can be sampled from 1 to 3 samples for soil laboratory analysis to determine chosen soil chemical and physical properties. Then, soil properties were entered manually. Currently, 345 profiles have been collected from 1994 to 2017, from which 54 profiles have no coordinate locations (Fig. 1). As many as 182 profiles are from 1994 to 1998, 58 profiles from 2002 to 2008, 15 profiles from 2010-2017, and 15 profiles no year information. From 345 soil profiles, only 142 profiles were sampled for soil laboratory analysis.

2.2. Data analysis and visualization

These resulted data were subject to data analysis. Exploratory data analyses and statistical descriptions were conducted using R (R Development Core Team, 2021). Brief statistics were determined to calculate minimum, median, mean, and maximum values. In brief statistics, the data distribution is hard to understand. Grouping data by horizon type or land use/land cover was conducted to gain insight into the data pattern. The median value was used rather than the mean value to measure the central tendency of data. It was used because many soil characteristics data were not normally distributed.

Boxplot or box and whisker plot was created to describe data distribution, including outliers. Box was ranged from quartile 25% and quartile 75%, divided by a bold line as the median. Dash line referred to whisker, calculated by 1.5 of interquartile ranges.

3. RESULTS

3.1. Brief statistics

Brief statistic of selected soil properties covering minimum, maximum, median, and mean value is presented in Table 1. This study collates 142 soil pedon samples, from which not all soil properties were analyzed in a soil laboratory. Particle size distribution, SOC, TN, pH, available P_2O_5, exchangeable bases, CEC, and BS, were soil properties commonly determined. In contrast, BD, soil pores, water retention, total P_2O_5, and total K_2O were sometimes analyzed. Most soil samples had a medium texture, concentrating on clay loam, clay, loam, sandy loam, and sandy clay loam (Fig. 2). Also, soil samples were mainly from the forest, mixed gardens, and paddy fields. Soils were developed from alluvial-colluvial, andesitic volcanic material, limestone, and tuff. Other soils originated from calcareous sedimentary rocks.

Table 1. Brief statistics of selected black soil properties

Soil property	Unit	N	Minimum	Median	Mean	Maximum
1. Sand fraction	%	142	1	34	35	83
2. Silt fraction	%	142	5	33	31	62
3. Clay fraction	%	142	5	34	33	77
4. pH water	-	137	4.0	6.8	6.8	8.6
5. pH KCl	-	79	3.8	5.4	5.7	7.6
6. Soil organic carbon	%	142	0.59	1.53	1.96	8.20
7. Total nitrogen	%	142	0.04	0.12	0.16	0.48
8. C/N ratio	-	142	8	12	13	23
9. Total P_2O_5	mg $100g^{-1}$	53	11	91	105	461
10. Total K_2O	mg $100g^{-1}$	53	11	37	83	251
11. Olsen P_2O_5	ppm	131	5	34	40	189
12. Exchangeable Ca	cmol kg^{-1}	137	1.32	16.35	19.21	50.72
13. Exchangeable Mg	cmol kg^{-1}	137	0.39	4.11	5.31	21.62
14. Exchangeable K	cmol kg^{-1}	137	0.07	1.15	1.21	3.06
15. Exchangeable Na	cmol kg^{-1}	137	0.05	1.26	1.55	12.29
16. Cation exchange capacity	cmol kg^{-1}	142	8.96	29.80	31.92	95.42
17. Base saturation	%	142	11	87	84	100
18. Bulk density	g cm^{-3}	26	1.13	1.21	1.24	1.36
19. Total pore	cm^3 cm^{-3}	26	0.43	0.49	0.48	0.53
20. Rapid drainage pore	cm^3 cm^{-3}	26	0.08	0.14	0.14	0.25
21. Slow drainage pore	cm^3 cm^{-3}	26	0.04	0.06	0.06	0.08
22. Water retention at pF 1	cm^3 cm^{-3}	26	0.39	0.46	0.44	0.50
23. Water retention at pF 2	cm^3 cm^{-3}	26	0.24	0.34	0.34	0.41
24. Water retention at pF 2.5	cm^3 cm^{-3}	26	0.16	0.27	0.28	0.37
25. Water retention at pF 4.2	cm^3 cm^{-3}	26	0.02	0.09	0.11	0.23
26. Available water	cm^3 cm^{-3}	26	0.14	0.17	0.16	0.19

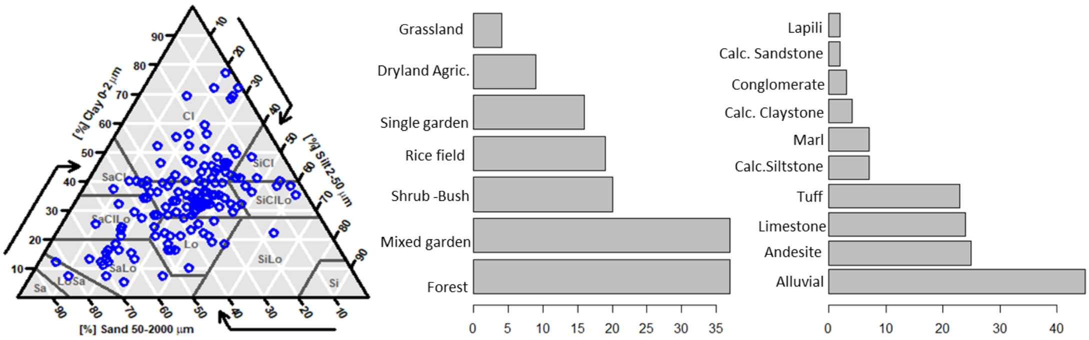

Figure 2. Sample distribution based on texture class and sample number based on land use/land cover and parent material

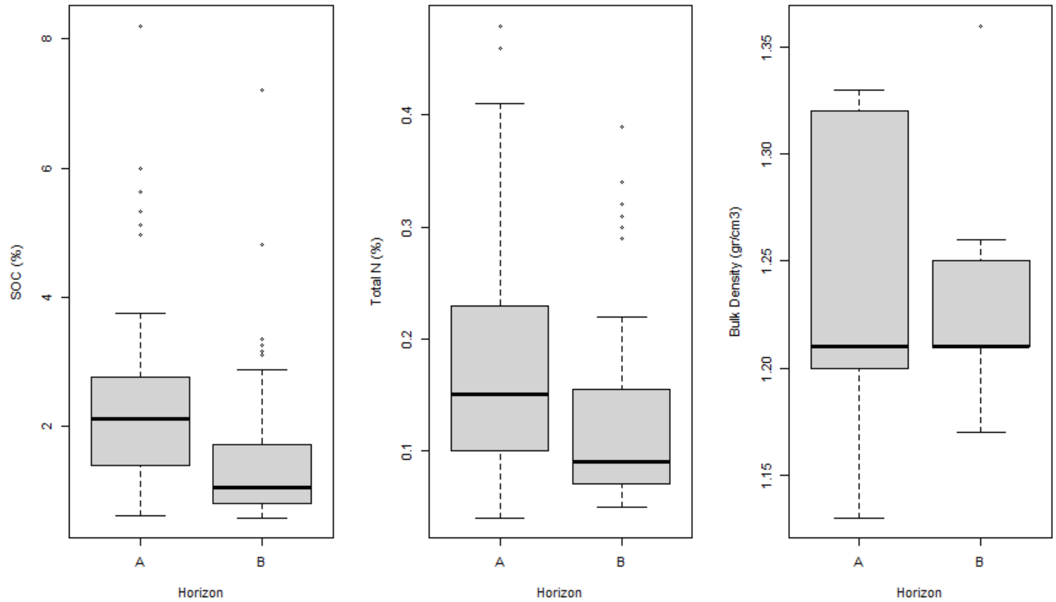

Figure 3. Soil organic carbon (SOC), total nitrogen (TN), and bulk density (BD) of black soils from Indonesia differentiated by soil horizon type

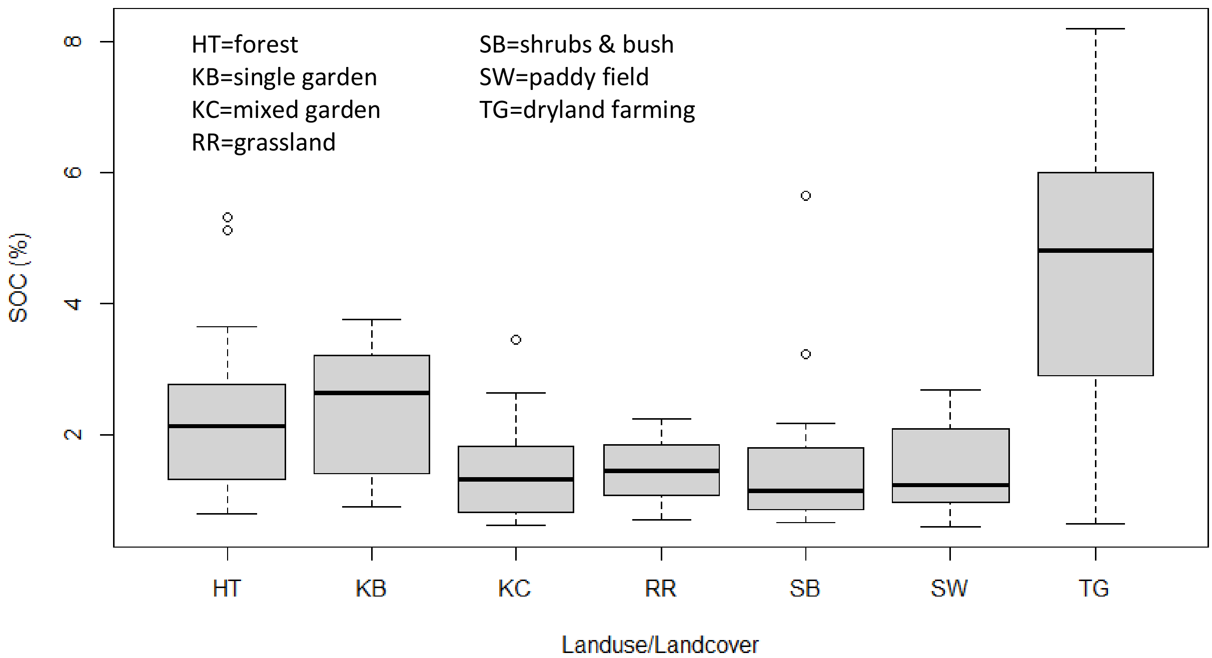

Figure 4. Soil organic carbon (SOC) of black soils from Indonesia differentiated by landcover

3.2. SOC, TN, C/N ratio, and BD

The SOC content is of great concern to black soils. Even though the soil is classified as Mollisols, if the SOC content is less than 0.6% in tropical regions, the soil is not categorized as black soil. In Indonesia, the SOC content of black soils ranged from 0.6% to 8.2%, with a median of 1.5%. In some locations, SOC content was about 8 %, found from a site at 1,500 m above sea level. Perhaps, the cold temperature in that site slows the decomposition of organic matter, leading to a high accumulation of organic matter and high SOC.

The median SOC content was higher in the A horizon than in the B horizon (Fig. 3). Also, the median SOC content varies with land use/land cover type. The forests and the single garden showed higher SOC than other land uses, except for dryland farming in high altitudes. Again, this dryland was from a site at 1,500 m above sea level, where cold temperatures retarded organic matter decomposition.

The TN content ranged from 0.04 to 0.48%, with a median of 0.12% (Table 1), suggesting that black soils have low TN (<0.51%). The TN content varied with depth, where the A horizon showed a higher TN content than the B horizon (Fig. 3). This is reasonable because the TN depends upon soil organic matter, which tends to be higher on the soil surface. The C/N ratio ranged from 8 to 23, with a median of 12 (Table 1). This number indicates that black soils have a medium C/N ratio.

The BD of black soils ranged from 1.13 g cm^{-3} to 1.36 g cm^{-3}, with a median of 1.21 g cm^{-3}. The median values are similar between the A horizon and B horizon; however, the A horizon shows more data variation than the B horizon. Soil organic matter content is possibly responsible for this BD variation because the SOC content in the A horizon also varies. This pattern suggests that more samples are required to understand the soil BD.

3.3. Total P_2O_5, Available P_2O_5, Total K_2O, and Available K

The phosphorus and potassium content in the soil is essential, especially for determining if soils need P or K fertilizer application. N, P, and K are the macronutrient, and sufficient amounts should be available for crop growth. Soil phosphorus is commonly measured as total P_2O_5 and available P_2O_5, whereas soil potassium is usually characterized as total K_2O and available K in exchangeable K.

The total P_2O_5 of black soils ranged from 11 to 461 mg $100g^{-1}$ (Table 1), yet the median value of the A horizon is lower than that of the B horizon (Fig. 5). Moreover, the available P_2O_5 ranged from 5 to 189 ppm (Table 1). Still, the median value is higher in the A horizon than in the B horizon (Fig. 5). The available P_2O_5 indicates phosphorus that plants can use.

The total K_2O of black soils ranged from 11 to 251 mg $100g^{-1}$. Yet, the median value of the A horizon is lower than the B horizon (Fig. 5). Meanwhile, the exchangeable K ranged from 0.07 to 3.06 cmol kg^{-1}. Still, the median is higher in the A horizon than in the B horizon. Exchangeable K indicates potassium that plants can use in dryland soils.

3.4. Exchangeable bases and CEC

Besides the SOC, the soil CEC and BS are basic information in black soils. The CEC of black soils from Indonesia ranged from 8.96 to 95.42 cmol kg^{-1}, with a median of 29.86 cmol kg^{-1} (Table 1). Hence, most black soils are categorized as high CEC (>25 cmol kg^{-1}). The dataset had an outlier of CEC or maximum value (Fig. 6). This CEC is developed from andesitic volcanic material located 1,500 meters above sea level—cold temperatures in high altitude slow organic material decomposition. In addition, the short-order minerals that dominate soils from volcanic materials make a strong bind between organic compounds with soil particles.

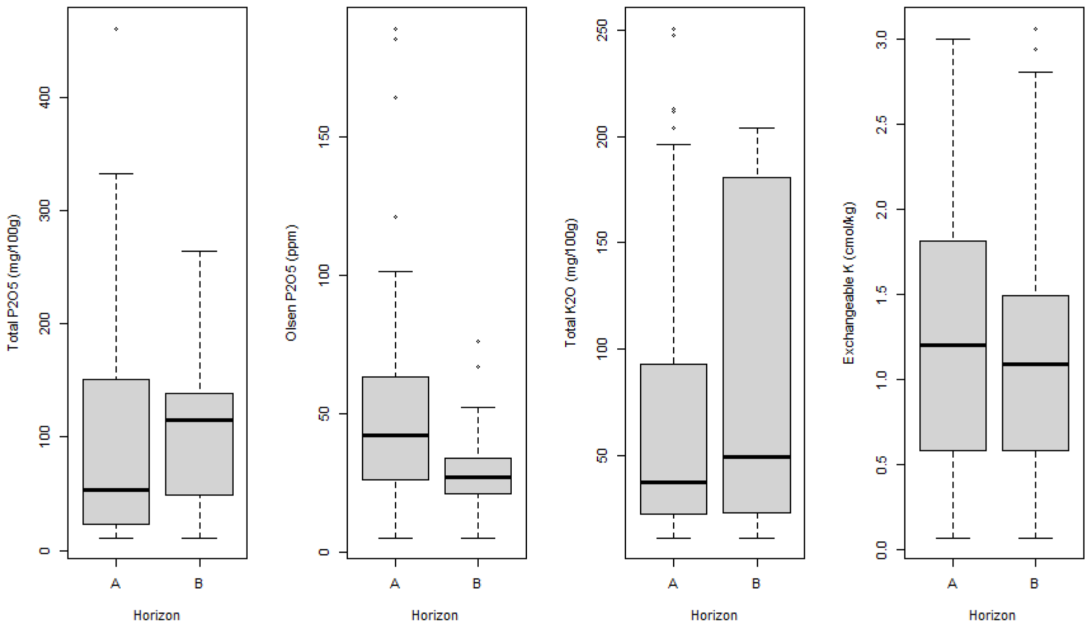

Figure 5. Phosphorus (total and available) and potassium (total and available) content of black soils from Indonesia grouped based on soil horizon type

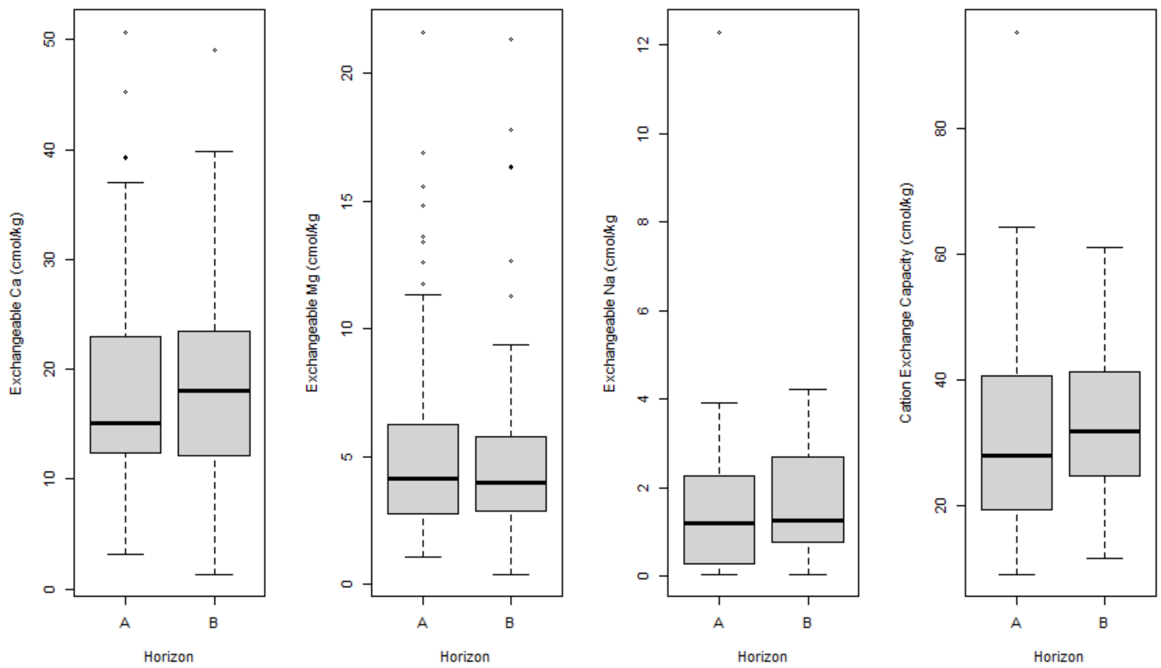

Figure 6. Exchangeable bases (Ca, Mg, Na) and cation exchange capacity of black soils from Indonesia based on horizon type

This high CEC is beneficial for black soils and reflects high soil fertility because they have a large capacity to retain nutrients, which is responsible for good plant growth. In return, plants give their soil residue to soils, increasing soil carbon stock and improving soil properties.

Exchangeable Ca ranged from 1.32 to 50.72 cmol kg^{-1}, with a median of 16.35 cmol kg^{-1} (Table 1). This data suggest that black soils have high exchangeable Ca (>10 cmol kg^{-1}). The median at the B horizon (about 18) was higher than at the A horizon (about 15 cmol kg^{-1}) (Fig. 6). Black soils mainly originated from Ca-rich parent materials (limestones, marls, calcareous sedimentary rocks, intermediate volcanic materials) in low rainfall regions (< 1000 mm/year). Accordingly, Ca leaching is low, leading to Ca accumulation in the soils.

Exchangeable Mg ranged from 0.39 to 21.62 cmol kg^{-1}, with a median of 4.11 cmol kg^{-1} (Table 1). The A horizon and B horizon have a similar median of 4 cmol kg^{-1} (Fig. 6). Black soils show high exchangeable Mg (> 2 cmol kg^{-1}). Low rainfall led to limited Mg leaching and Mg-rich parent materials were responsible for the accumulation of Mg.

Exchangeable Na ranged from 0.05 to 12.29 cmol kg^{-1}, with a median of 1.26 cmol kg^{-1} (Table 1). The median of A horizon dan B horizon was relatively the same, about 1 cmol kg^{-1} (Fig. 6). Black soils show very high exchangeable Na (> 1 cmol kg^{-1}). They developed in semi-arid regions with low rainfall (annual rainfall of 1000 mm or less). As a result, Na leaching is limited, leading to Na accumulation in the soil.

3.5. Soil acidity and base saturation

The soil base saturation is relatively high, ranging from 80% to 100%. The median is higher in the A horizon than in the B horizon (Fig. 7). Also, the A horizon shows more BS variation than the B horizon. The BS is the percentage of exchangeable bases (Ca, Mg, K, Na) to cation exchange capacity. Here, the proportion of each cation is vital for assessing nutrient availability. In black soils, exchangeable Ca is much higher than other cations, leading to a nutrient imbalance. The exchangeable Ca, Mg, and K are the macronutrient essential for crop growth and production.

The pH$_w$ (pH extracted by water) of black soils ranged from 4 to 8.6, with a median value lower on the A horizon than on the B horizon (Fig. 7). Nevertheless, the pH$_w$ varied more in the B horizon than the A horizon. The pH$_k$ (extracted by KCl) is lower than the pH$_w$ and varied more than pH$_w$ in the A and B horizons. The median is similar between the A and B horizons. Both figures suggest that black soils have basic reactions, as shown by pH 6 to 8. In this condition, Ca^{2+} is abundant in the soil solution and becomes a problem in nutrient availability in anions form. The Ca^{2+} may react to phosphate, causing P to be unavailable for plants.

3.6. Soil pores and water retention

Figure 8 shows a boxplot of soil pores and water retention. Soil pore was identified as total pore and drainage pore. The total pore of black soils ranged from 0.43 to 0.53 cm^3 cm^{-3}. It means that 1 cm^3 of soil contains 0.53 cm^3 of pore. Soil pore is essential for gas and water circulation: soil aeration and drainage control plant growth and root health. During heavy rainfall, all pores are occupied by water.

Drainage pore refers to the volume of water that can be drained from a unit volume of soil when the soil moisture pressure is decreased from atmospheric pressure to some specific negative pressure. For 1 cm^3 of soil, water that can be drained ranged from 0.08 to 0.25 cm^3 for rapid drainage and ranged from 0.04 to 0.08 cm^3 for slow drainage (Table 1). Rapid drainage pores show higher variation than slow drainage pores (Fig. 8). Thus, in black soils volume of water that can be drained ranges from 4 to 25 cm^3 from 100 cm^3 of soils.

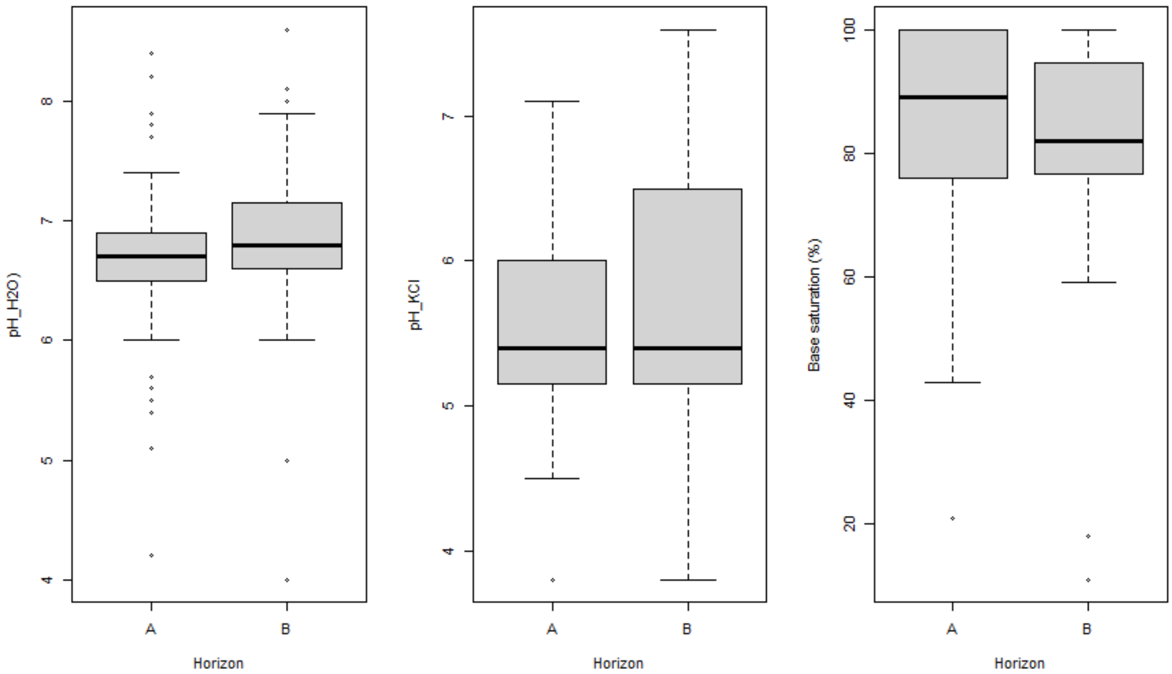

Figure 7. Soil acidity and base saturation of black soil from Indonesia based on horizon type

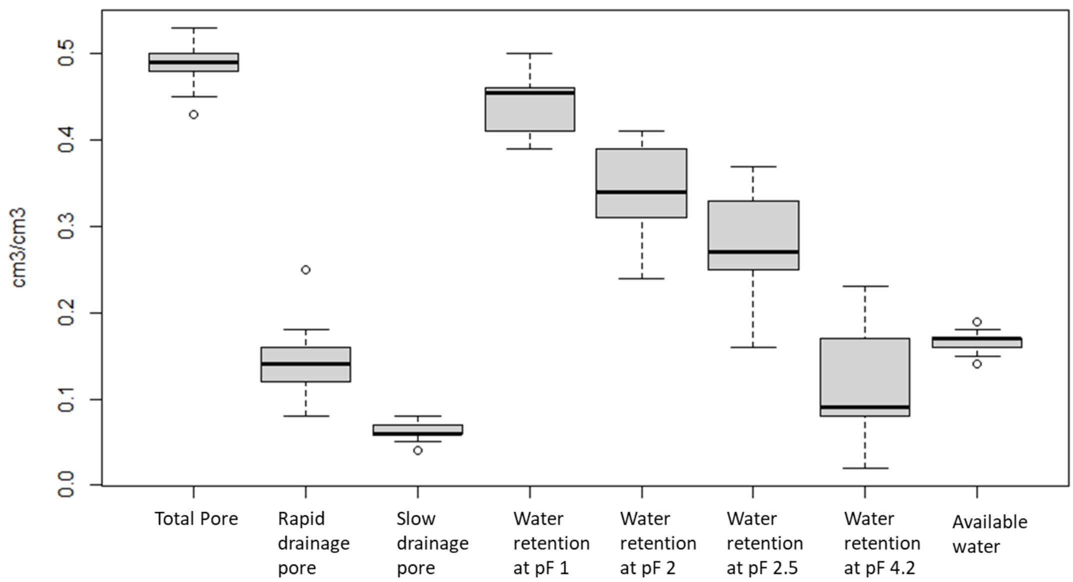

Figure 8. Soil pore, water retention, and available water black soils from Indonesia

Water retention refers to the volume of water that the unit volume of soils can hold. This soil water is crucial for the life of plants and organisms and contributes to soil health and land productivity. With increasing tension, water that can be retained decreases (Fig. 8). Available water is the deduction of water held at pF 2.5 to pF 4.2 (Fig. 8). It is apparent that variation in water volume is higher at high tension than at lower tension.

3.7. Soil utilization

Table 2 shows that black soils in Indonesia have been used for cropland, including paddy fields, dryland farming, and gardens. In nature, black soils were found in various land covers, namely forests, shrubs and bushes, and savannah. Converting virgin black soils for cropland will change carbon input to the soils, and soil tillage will disturb soil structure and possibly emit carbon into the atmosphere.

During the soil survey, we found that most farmers use these black soils less intensively for crop cultivation. Farmers constructed terraces for most ricefield and dryland in sloping areas to conserve soil and water. However, farmers burn crop residues and weeds during land preparation, releasing carbon into the atmosphere. Implementing best management practices can increase crop production and sustainable use of this soil.

Table 2 also shows the main cultivated crops in the black soils, including food crops, industrial crops, and tree crops. Farmers grow rice (*Oryza sativa*) and corn (*Zea mays*) in paddy fields. The cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and corn (*Zea mays*) are cultivated in dryland. In the gardens, farmers grow nutmeg (*Myristica fragrans*), clove (*Syzygium aromaticum*), coconut (*Cocos nucifera*), cocoa (*Theobroma cocoa*), teak (*Tectona grandis*), albizia (*Albizia Chinensis*), and damar (*Agathis dammara*) either as single crop or multiple crops. Farmers in mixed gardens grow food crops between woody crops, such as planting sweet potatoes and cassava under cocoa and coconuts trees.

In the cropland area, the frequently used soils covered Hapludolls, Haprendolls, and Argiudolls in the humid moisture regime area and Haplustolls and Argiustolls in the ustic moisture regime area (Table 2). Each soil group has unique characteristics, including *fluventic, vertic, fluvaquentic, oxyaquic, lithic, typic, udic, pachic, andic,* and *vitrandic*. Soil Survey Staff (2022) defines these specific characteristics. Thus, although farmers use and manage the same black soils, they are challenged by site-specific soil characteristics and behavior. Choosing the best crop and land management technology should consider these unique soil characteristics.

4. DISCUSSION

Our study has collated soil legacy soil data and then selected soil profile observation to fulfill the criteria of black soils. From one soil profile, one to tree sample from the soil layer was identified and considered an independent sample. We did not take the average sample values for a given soil profile observation. Depending upon the study's objective, not all soil chemical and physical characteristics were determined in the laboratory. However, our data provides better insight into the tropical black soils of Indonesia. We suggest researchers collect more data to better understand black soil by exploring recent publications or conducting detailed research on black soil characteristics and management.

Table 2. Landuse, crop, and type of black soils

Landuse	Crop type	Parent materials	Number of profiles*	Soil Taxonomy
Paddy field	Rice (*Oryza sativa* L), mungbean (*Vigna radiata*), soybean (*Glycine max* L.)	Alluvium, colluvium limestone, reef limestone, mudstone, claystone, basalt, intermediate lava, pumice, andesite, lahar, sand sediment, clay sediment	36	Hapludolls (Fluventic, Vertic) Haplustolls (Fluvaquentic, Oxyaquic, Vertic, Fluventic)
Dryland Farming	upland rice (*Oryza sativa* L), corn (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), mungbean (*Vigna radiata*), soybean (*Glycine max* L.)	Limestone, reef limestone, calcareous claystone, marl, schist, intermediate tuff, intermediate lava, mafic lava, andesite breccia, lapilli, pumice, aluvium, koluvium	40	Hapludolls (Lithic, Typic) Argiudolls (Typic, Udic) Haplustolls (Lithic, Pachic, Typic) Argiustolls (Lithic, Pachic, Typic)
Single Garden	Coconut (*Cocos nucifera* L), cocoa (*Theobroma cacao* L), palm oil (*Elaeis guineensis* Jacq.), coffee (*Coffea* sp.), banana (*Musa acuminata* L), clove (*Syzygium aromaticum* L.), sugar palm (*Arenga pinnata* (Wurmb) Merr.), palmyra (*Borassus flabillifer* L), candlenut (*Aleurites moluccanus*), tamarind (*Tamarindus indica* L.), eucalyptus (*Eucalyptus urophylla* S. T. Blake), teak (*Tectona grandis* L.), Albizia (*Albizia chinensis*),	Limestone, marl, slate, calcareous claystone, pumice tuff, intermediate tuff, mafic lava, intermediate lava, basalt, andesite, clay and sand sediment, alluvium-colluvium	39	Haprendolls (Lithic, Typic) Hapludolls (Lithic, Typic, Fluventic, Pachic) Argiudolls (Typic) Haplustolls (Fluventic, Pachic, Typic)
Mixed Garden	Coconut (*Cocos nucifera* L), clove (*Syzygium aromaticum* L.), nutmeg (*Myristica fragrans* Hout), water apple (*Syzygium aqueum*), jackfruit (*Artocarpus heterophyllus*), corn (*Zea mays* L.), banana (*Musa acuminata* L), cassava (*Manihot esculenta* Crantz), orange (*Citrus sinensis*), teak (*Tectona grandis* L.), Albizia (*Albizia chinensis*)	Reef limestone, tufaceous limestone, limestone calcareous sandstone, basalt, andesite, lapilli, pumice, lahar, intermediate tuff, andesite lava, marl, intermediate lava, mafic lava, alluvium, colluvium, clay and sand sediment	78	Haprendolls (Lithic) Hapludolls (Lithic, Typic, Vitrandic, Fluventic, Pachic) Argiudolls (Typic, Lithic, Andic, Vertic) Haplustolls (Lithic, Entic, Fluventic, Pachic, Typic)

Notes: *) the rest soil profiles (152 profiles) were in forest, shrub, bush, savannah/ grassland

Understanding the characteristics of black soil, such as the SOC dynamic, is required to select the best sustainable soil management. Black soils have become global consent communities because they store high carbon stock. Accordingly, the INBS was established to stock and tested these best practices in other regions. This initiative is beneficial because the researcher can avoid the duplication of research topics. Finally, the available budget can be allocated to other critical aspects of black soil management.

Several observations in this dataset identified that black soil had been used for agriculture, namely rainfed ricefield, dryland farming, and gardens (single crop or mixed crops). Terracing is implemented either for ricefield in sloping land or some dryland location. In field surveying, we observed that black soils are not used optimally, meaning the best land and crop management technologies can improve soils and increase crop production. This farming system has a significant influence on carbon dynamics in the soil.

In natural conditions, the back soils were covered by monsoon rain forests, karst forests, or savannah forests. In these natural conditions, all were in balance for an extended period, hundred to thousand years or more. The change in land cover or land use, the land was disturbed, and the change tends to decrease soil carbon stock. Nevertheless, good soil and crop management practices may increase soil carbon stock. Hao et al. (2022) show soil carbon stock in agriculture; straw return could continuously increase soil organic carbon in inter-annual rotation of soybean and maize cropping system in Mollisols. Thus, soil carbon stock Java increased due to improved soil and crop management.

The long-term occurrence of black soil can be a big issue. The functons of Indonesian soils, including black soils, are threatened by erosion, organic carbon loss, and nutrient imbalance (Montanarella et al., 2016). High annual rainfall (more than 2000 mm) and short but high-intensity rainfall in drier regions trigger soil erosion. The soil erosion removes fertile topsoil and leaves relatively low fertile soil (Chalise et al., 2019). Moreover, farmers still practice burning weed and crop residues in several locations because burning is a cheaper technique for land clearing during land preparation. Land burning will emit carbon into the atmosphere, kill microbes, and dry the soil. Best land management practices should be promoted including soil and water conservation measures and integrated soil nutrient management.

Using black soil for gardens, where perennial crops are planted in monoculture or mixed, is the best option and should be promoted. Perennial crops have deep roots; hence root exudates and residue can be stored deeper. At the same time, deep roots can use nutrients in deep layers to grow. Roots can also be waterways to infiltrate water into a deeper layer and prevent water accumulation on the surface during the rainy season. Perennial crops have a more dense canopy and many leaves for photosynthesis. A dense canopy can prevent solar radiation directly to the ground and can avert raindrops from coming directly to the ground. The perennial crop has large crop residue that can increase carbon stock in the soil.

Mixed gardens or single gardens are other forms of agroforestry. Many research and reviews demonstrate the benefit of agroforestry for soil, cattle, and carbon sequestration (Franzel et al. (2014); Sileshi et al. (2014); Bell et al. (2020); Bateni et al. (2021)). These agroforestry practices should be strengthened and promoted in black soil land management.

5. CONCLUSION

Most Indonesian black soils contain 1.53 % SOC, 30 cmol kg^{-1} CEC, 87% base saturation, 1.21 g cm^{-3} BD, and various figures of TN, C/N ratio, soil phosphorus, exchangeable cations, soil reaction, soil pores, water retention, and available water. In Indonesia, black soils are used for paddy fields, dry land farming, and gardens; hence, sustainable soil management is needed by considering the main soil threats, including loss of soil carbon, nutrient imbalance, and soil erosion.

The sustainable use of soil and management become priorities in utilizing black soil. Adopting agroforestry in black soil utilization should be promoted to maintain and sustain soils while benefitting these soils' environmental service. With increasing soil datasets, one can recommend the best land management practices efficiently so that black soils can contribute more toward climate change mitigation and adaptation, food security, and land degradation neutrality can be increased.

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Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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