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Influence of land cover types on soil quality and carbon storage in Moramo Education Estate, Southeast Sulawesi, Indonesia

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Abstract. *Alam S, Ginting S, Hemon MT, Leomo S, Kilowasid LMH, Karim J, Nugroho Y, Matatula J, Wirabuana PYAP. 2022. Influence of land cover types on soil quality and carbon storage in Moramo Education Estate, Southeast Sulawesi, Indonesia. Biodiversitas 23*: 4371-4376. This study investigated the influence of different land cover types on soil quality and carbon storage in Moramo Education Estate (MEE). Information is required as fundamental consideration to determine the best landscape management strategies for supporting soil conservation and climate change mitigation. Data were collected from three types of land cover generally found in this area, including forests, shrubs, and savannas. Three permanent sampling plots were randomly placed in every land cover as replicates with a size of 20 m × 20 m. Six parameters were used to describe the soil quality, i.e., soil acidity, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity. The above and belowground carbon storage from every plot was quantified. The soil quality and carbon storage among land cover types were compared using analysis of variance and Tukey's honestly significant difference. Pearson's correlation analysis was also applied to evaluate the relationship between soil quality and carbon storage. The results show that soil quality significantly differed in the exchangeable potassium and cation exchange capacity. A similar trend was also demonstrated in aboveground carbon storage. The highest average carbon storage was recorded in forests (150.50 ± 27.79 t ha^{-1}), followed by shrubs (52.50 ± 15.02 t ha^{-1}) and savannas (45.97 ± 4.42 t ha^{-1}). The total carbon storage at different land covers was significantly correlated to soil acidity, available phosphorus, and cation exchange capacity. Carbon storage improved with the increased available phosphorus and cation exchange capacity. In contrast, carbon storage was negatively correlated with soil acidity. Overall, the land cover types significantly influenced soil quality and carbon storage in MEE.

Keywords: Carbon stock, climate change mitigation, landscape management, permanent sampling plot, soil conservation

INTRODUCTION

Soil conservation and climate change mitigation have become strategic issues in agriculture development (Amelung et al. 2020), particularly in tropical countries. The management of the agriculture sector is currently targeted to stabilize the food supply and contribute to maintaining soil quality and reducing carbon emissions in the atmosphere (Castellini et al. 2021; Lynch et al. 2021). To anticipate these challenges, the optimum scenario of agriculture development is necessary to accommodate the objective of environmental preservation and farm cultivation. This scheme is only possible to implement when land managers know the influence of land cover on soil quality and carbon storage. The statement is also supported by previous studies that recorded the soil quality and carbon storage principally varying in every land cover due to the interaction between soil and the vegetation above it (Sugihara et al. 2014; Chandra et al. 2016; Puspanti et al. 2021; Sadono et al. 2021). For example, higher plant biomass is commonly found in good soil than in poor soil because nutrients are more available in good soil to support plant growth (Bhandari and Zhang 2019). Meanwhile, higher biomass accumulation will generate more litterfall that becomes the input of organic matter into the soil (Uriarte et al. 2015; Giweta 2020). When the organic matter decomposes, nutrients will be released into the soil, improving fertility (Purwanto and Alam 2020; Villa et al. 2021). Therefore, information about soil quality and carbon storage is highly required by land managers as consideration materials to determine land conversion strategies in agriculture development.

Moramo Education Estate (MEE) is a special-purpose area managed by Universitas Halu Oleo in Southeast Sulawesi. It is a natural ecosystem with three land cover types: forest, shrub, and savanna. According to a government policy, MEE will become the priority location for integrated agriculture development. This area is designed as a research center and site experiment to facilitate the innovation of good agriculture practices, such as nutrient management, pest and disease control, and crop yield estimation. However, this scheme will negatively impact MEE's contribution to ecological functions because there will be an intensive land conversion from natural ecosystems to agricultural land. It will also reduce carbon absorption and cause an imbalanced nutrient cycle. Therefore, a preliminary study on the soil quality variation and carbon storage distribution at different land covers in MEE is required to determine an optimum scenario for land transition. This information will help managers formulate priority land covers that can be converted into agricultural land. The effort is expected to minimize the negative impacts of land-use change on MEE ecosystems.

This study aimed to evaluate the effect of land covers on soil quality and carbon storage in MEE. The primary focus of this research was to compare the soil fertility and carbon stock among land cover types and examine the connectivity between soil characteristics and carbon storage accumulation from different land covers. Results will provide adequate information as a basic consideration to select the priority land cover type for agriculture development without sacrificing the ecological function of MEE.

MATERIALS AND METHODS

Study area

This study was conducted in MEE located in South Konawe District, Southeast Sulawesi, Indonesia. The geographic position of this site is E4°6'30"-4°7'30" and S122°35'0"-122°35'30" (Figure 1). Its altitude ranges from 25 to 137 m above sea level. Topography is predominantly a hilly area with an 8%-15% slope level. The average daily temperature is 27.6 °C, with a minimum temperature of 23.1 °C and a maximum temperature of 32.2 °C. Annual rainfall reaches 3,179.70 mm $year^{-1}$ with an average air humidity of 81%. The dry period is relatively longer than two months and commonly occurs from September to October. The land cover of MEE is dominated by forests (70%), followed by savannas (20%) and shrubs (10%).

Data collection

The field survey was conducted using a stratified sampling method. The different land covers were assumed as the primary factor that caused the variations in soil quality and carbon storage. Three permanent sampling plots were randomly placed in every land cover with a size of 20 m × 20 m (Grussu et al. 2016). The coordinate of each plot was also recorded using a global positioning system. This method aimed to support the long-term monitoring of soil quality and carbon storage dynamics at the study site. Then, the data collection process in every plot was divided into two steps, i.e., soil sampling and vegetation measurement.

Soil sampling was conducted from three different positions in every plot using ring samples, 7 cm in diameter and 10 cm in height. The soil sample was collected at a depth of 0-10, 11-20, and 21-30 cm (Sadono et al. 2021a). Afterward, the samples were brought to the laboratory to determine their bulk density, soil acidity, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity. The bulk density was analyzed using the core method, and soil acidity was determined using a pH meter. The determination of soil organic carbon was conducted using the Walkley-Black method, and the total nitrogen was quantified using the Kjeldahl method. The ammonium acetate NH_4OAc 1M, pH 7,0 extraction method was applied to quantify the exchangeable potassium and the available phosphorus was quantified using the Bray method. Finally, cation exchange capacity was determined using the ammonium acetate method. The soil analysis protocol was undertaken following the guidance of soil analysis published by Estefan et al. (2013).

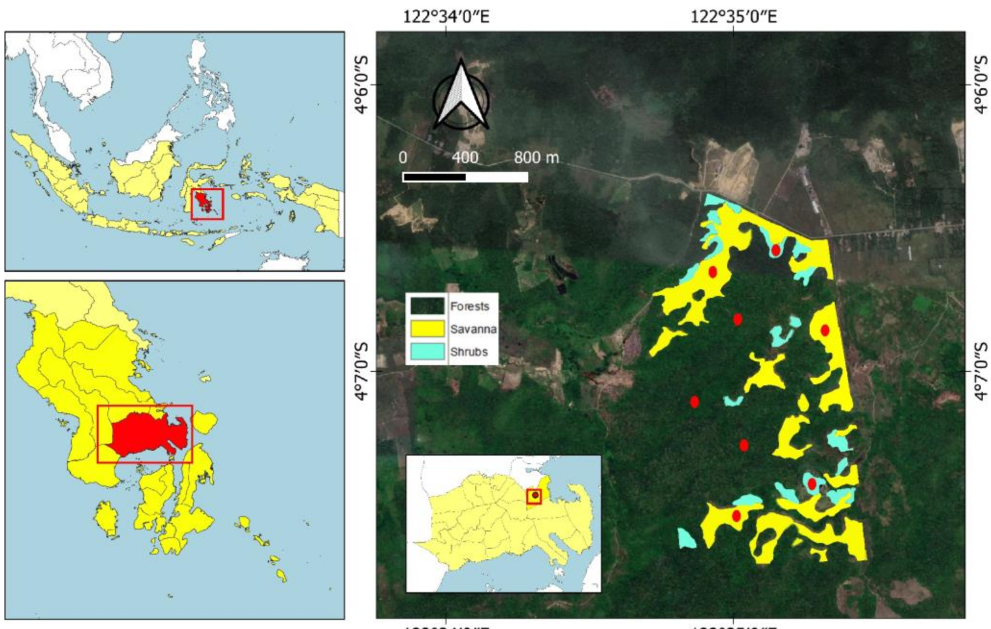

Figure 1. Study site of Moramo Education Estate in South Konawe, Southeast Sulawesi, Indonesia. Red circles indicate sampling plots for data collection

Table 1. Summary statistics of the soil quality and carbon storage at different land cover types

Land Use	Unit	pH	SOC (%)	TN (%)	Av-P (ppm)	Exc-K (meq 100 g^{-1})	CEC (meq 100 g^{-1})	AGC (t ha^{-1})	BGC (t ha^{-1})	TCS (t ha^{-1})
Savanna	Mean	4.54	1.44	0.14	4.38	0.16	10.3	6.07	39.90	45.97
	SD	0.29	0.52	0.03	1.05	0.06	1.22	1.45	2.97	4.42
	SE	0.12	0.21	0.01	0.43	0.03	0.50	0.84	1.71	2.55
	Min	4.16	0.88	0.10	3.39	0.09	8.62	4.40	36.70	41.10
	Max	4.92	2.06	0.19	6.03	0.27	11.7	7.00	42.50	49.50
Forest	Mean	4.25	1.64	0.15	5.11	0.30	13.2	114.00	36.50	150.50
	SD	0.47	0.75	0.05	2.62	0.06	2.01	18.00	9.79	27.79
	SE	0.19	0.31	0.02	1.07	0.02	0.82	10.39	5.65	16.04
	Min	4.30	0.98	0.12	2.37	0.24	10.8	96.60	29.60	126.20
	Max	4.50	3.06	0.24	9.07	0.37	16.4	132.00	47.70	179.70
Shrub	Mean	4.65	1.59	0.13	3.28	0.26	11.3	14.10	38.40	52.50
	SD	0.19	0.53	0.03	1.79	0.09	1.64	9.33	5.69	15.02
	SE	0.08	0.22	0.01	0.73	0.04	0.67	5.39	3.29	8.67
	Min	4.28	0.93	0.10	1.26	0.14	9.94	7.50	32.10	39.60
	Max	4.81	2.29	0.17	6.40	0.39	14.2	24.80	43.10	67.90

Note: pH (soil acidity), SOC (soil organic carbon), TN (total nitrogen), Av-P (available phosphorus), Exc-K (Exchangeable potassium), CEC (cation exchange capacity), AGC (aboveground carbon storage), BGC (belowground carbon storage), TCS (total carbon storage), SD (standard deviation), SE (standard error), Min (minimum), Max (maximum)

The vegetation measurement was performed using a nested method wherein every sampling plot was divided into several subplots to support the plant inventory based on their life stages: 1 m × 1 m (understorey), 2 m × 2 m (seedlings), 5 m × 5 m (saplings), 10 m × 10 m (poles), and 20 m × 20 m (trees) (Rambey et al. 2021). Several parameters were measured from the vegetation survey, including species, plant density, and diameter at breast height. However, the diameter measurement was only implemented for the poles and trees.

The carbon storage of vegetation in below and aboveground conditions was quantified using a conversion factor from biomass because approximately 50% of biomass was composed of carbon elements (Latifah and Sulistiyono 2013; Taillardat et al. 2018; Wirabuana et al. 2020a). First, aboveground biomass in poles and trees was quantified using an allometric equation developed by Chave et al. (2005). Meanwhile, the root biomass of poles and trees was calculated using a conversion factor, wherein a ratio between the root biomass and total aboveground biomass of 1:5 was recorded (Wirabuana et al. 2020b). Next, the biomass accumulation in understorey, seedlings, and saplings was measured using a destructive method. The harvesting process was performed in every subplot. First, the fresh weight of each sample was measured using a hanging balance. Then, approximately 500 g subsample was brought to the laboratory for drying using an oven at 70 ℃ for 48 h (Sadono et al. 2021b). Then, biomass was computed by multiplying the ratio of dry-fresh weight from the subsample with the total fresh weight. A similar method was also applied to quantify biomass in litter and necromass. In parallel, the soil biomass was counted based on the ring samples' relationship between its bulk density and estimated soil volumes. Then, the result was multiplied by the soil organic carbon content to obtain the carbon stock in the soil. The measurement of the soil carbon stock was performed in accordance with the guidance published by Hairiah et al. (2011). The total carbon storage in every land cover type was counted by summing the carbon accumulation in soil, litter, necromass, and vegetation.

Data analysis

Statistical analysis was conducted using R software version 4.1.1 with a significant level of 5%. The Agricolae package was selected to support the data analysis. A descriptive test was applied to quantify the data attributes, including minimum, maximum, mean, standard deviation, and standard error. The normality of data was examined using the Shapiro-Wilk test, and the homogeneity of variance was evaluated using Bartlet's test. Comparison means of the soil quality and carbon storage among the three land covers were tested using the one-way analysis of variance and Tukey's honestly significant difference. Pearson's correlation analysis was also used to determine the critical soil parameters correlated to carbon storage.

RESULTS AND DISCUSSION

Soil quality distribution

Soil quality among land cover types was not significantly different in most parameters, except Exc-K (Figure 2). The highest average Exc-K was discovered in forests (0.30 ± 0.06 meq 100 g^{-1}), followed by shrubs (0.26 ± 0.09 meq 100 g^{-1}) and savannas (0.16 ± 0.06 meq 100 g^{-1}). As one of the soil macronutrients, the available potassium in the study location is very low because the soil develops from sandstone parent material with an acidic soil pH so that K leaching in the soil profile is intensive. Thus, the source of K only relies on donations from organic matter. On the other hand, the high contribution of organic matter to forest soils also helps a lot to maintain increasing levels of available K in the soil. This fact is confirmed by the higher exchangeable K in forests than in other land cover types.

The high availability of nutrients in forests can be caused by the dense vegetation that supplies many organic matters into the soil through litterfall. More litterfall accumulation aboveground can maintain land humidity, which supports microorganism life (Krishna and Mohan 2017; Sales et al. 2020). Furthermore, many pieces of literature confirm that the abundance of soil bacteria significantly accelerates the decomposition process (Jacoby et al. 2017; Grzyb et al. 2020; Miljaković et al. 2020). As a result, many nutrients will be released from litterfall into the soil layers (Tang et al. 2013; Uriarte et al. 2015; Pérez et al. 2021). Therefore, vegetation plays an important role in improving soil quality through the nutrient cycle. Vegetation becomes one of the fundamental factors affecting the weathering process during soil genesis (Catoni et al. 2016; Finlay et al. 2020). The results also imply that the declining vegetation density from forests to savanna gradually decreases soil quality.

Carbon storage variation

The total carbon storage from the three land cover types was significantly different, wherein forests had the highest carbon storage than other land covers by approximately 150.50 ± 27.79 t ha^{-1} (Figure 3). It was almost four times higher than the carbon stock in shrubs and savannas. The most extensive accumulation of carbon stock in forests occurred due to the vast contribution of vegetation aboveground. The relative contribution of the aboveground to the total carbon storage in forests was approximately 70% (Table 1). Meanwhile, there was no significant difference in the belowground carbon among land covers. This outcome is not surprising because several publications have explained the essential role of vegetation in climate change mitigation (Setiahadi 2017; Matatula et al. 2021; Wirabuana et al. 2021). Furthermore, the highly dense forest canopy can absorb greenhouse gas emissions, particularly carbon dioxide (CO_2), because it is more effective in photosynthesis than shrubs and grasses (Xie et al. 2021).

Table 2. Pearson's correlation analysis between soil parameters and carbon storage

Soil parameter	AGC		BGC		TCS	
	r	p-value	R	p-value	r	p-value
pH	−0.562	0.051^{ns}	−0.282	0.461^{ns}	−0.694	0.037*
SOC	0.398	0.287^{ns}	0.595	0.057^{ns}	0.477	0.193^{ns}
TN	0.488	0.181^{ns}	0.394	0.293^{ns}	0.533	0.138^{ns}
Av-P	0.525	0.071^{ns}	0.392	0.295^{ns}	0.670	0.048*
Exc-K	0.546	0.059^{ns}	−0.238	0.536^{ns}	0.619	0.075^{ns}
CEC	0.537	0.053^{ns}	0.218	0.571^{ns}	0.762	0.016*

Note: pH: soil acidity, SOC: soil organic carbon, TN: total nitrogen, Av-P: available phosphorus, Exc-K: Exchangeable potassium, CEC: cation exchange capacity, AGC: aboveground carbon storage, BGC: belowground carbon storage, TCS: total carbon storage, ^{ns}: not significantly different, *: significantly different

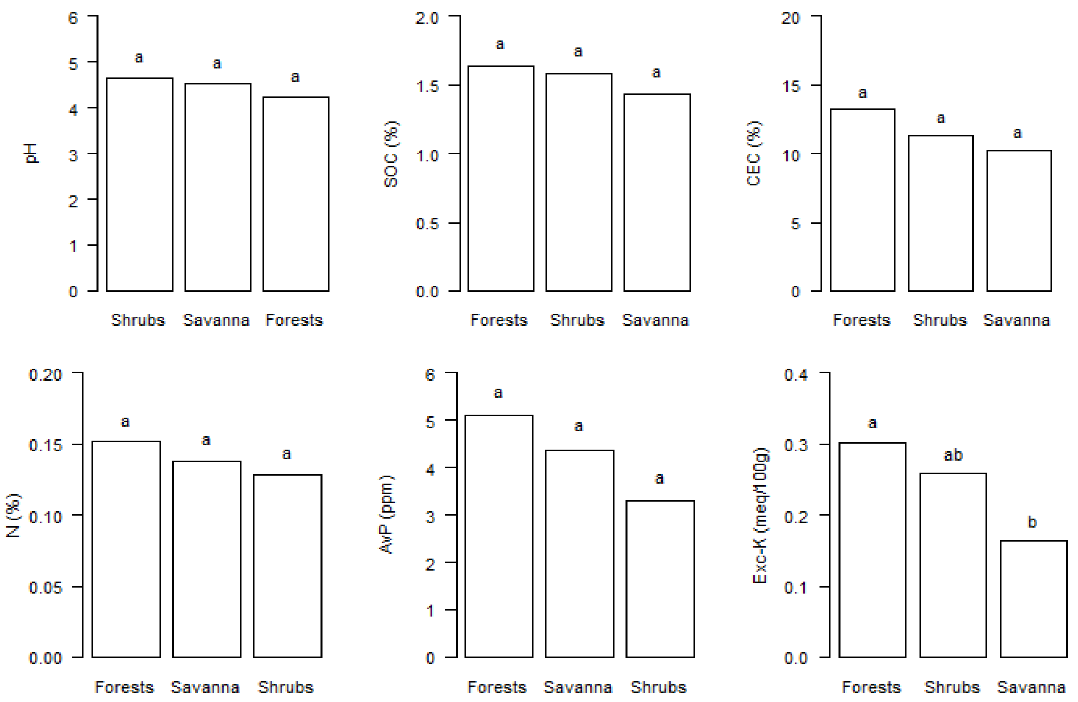

Figure 2. Comparison means the soil quality among land cover types. A similar letter above the bar graph indicates a non-significant difference

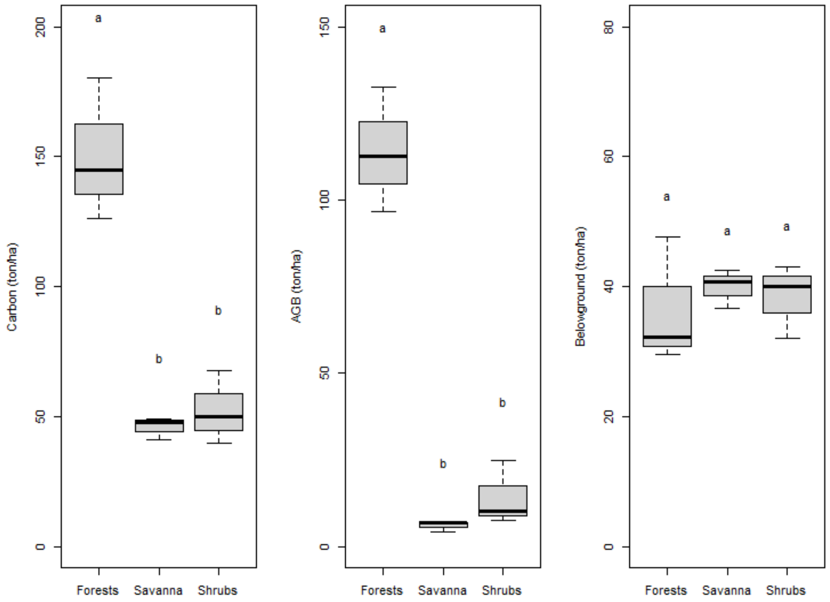

Figure 3. Comparison means of the carbon storage among land cover types. A similar letter above the boxplot indicates a non-significant difference

Moreover, this study recorded a significant correlation between soil characteristics and total carbon storage (Table 2) - three soil parameters are significantly correlated to the whole carbon storage, i.e., pH, Av-P, and CEC. However, the relationship among these parameters was relatively different. The total carbon storage improved along with the increasing Av-P and CEC. In contrast, a negative correlation was demonstrated in the relationship between carbon storage and pH. The correlation between soil characteristics and total carbon storage in the landscape occurs because soil generally supplies nutrients for the vegetation above it (Dignac et al. 2017; Schjoerring et al. 2019; Silva and Lambers 2020). Furthermore, the life cycle of vegetation will provide the amount of litterfall that becomes organic matter inputs to soil (Giweta et al. 2020; Sales et al. 2020). pH has a negative correlation to total carbon storage because a high pH would reduce nutrient availability. At the same time, a similar condition is found at the low pH level (Feng et al. 2022). Therefore, most plants prefer to grow in soil with a pH of 6.5. A high CEC increases the total carbon storage because it facilitates the mineralization process to make nutrients available (Doetterl et al. 2015; Costa et al. 2020). Meanwhile, a high Av-P is significantly correlated to the total carbon stock because the natural soil characteristics in the study site are classified into further weathered soils having low Av-P (Alam et al. 2020). As one of the macronutrients, P is substantially required by plants to support their growth, mainly for supporting photosynthesis (Carstensen et al. 2018).

Implications

Overall, this study confirmed a significant influence of land cover types on soil quality and carbon storage in MEE, wherein the highest soil quality and carbon storage were found in forests. Although this location was allocated to develop integrated farming systems, a wise scheme should be formulated to minimize the impact of environmental degradation due to the land conversion activity. Based on the results, we suggest conducting a step-by-step land transition from the land cover types with the lowest fertility and carbon storage: starting from savannas and then from shrubs. We strongly recommended converting forests lastly because of their potential function in this site as a high carbon pool.

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