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SOIL CHARACTERISTICS OF SIX FOREST MANAGEMENT REGIMES IN LOMBOK, INDONESIA

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ABSTRACT

A good quality top soil is important for optimum plant growth in any land-use type. The landscape in Karang Sidemen Village, located at the bottom of Rinjani volcano, consists of a mosaic of management regimes. This study assessed the soil profile and properties of six management regimes under different governing bodies, namely, secondary forest, monoculture stand, agroforestry in KHDTK Rarung, agroforestry in community forest, banana-dominant landscape in Hortipark Tastura, and mixed planted forest. Soil profile and pH data were collected from a two-dimensional soil wall (100 cm depth). Soil samples from 30 cm depth of each forest were analyzed for the soil properties (soil organic carbon, bulkdensity, soil water content, litter biomass). The results showed that the vertical pH in the soil profile is generally increasing or steady from top to bottom except for the secondary forest. The pH value ranged from 5.0 to 7. The soil colors are mostly in the yellow-red category. The soil in the six management regimes is still ideal for plant growth indicated by its low bulk density and ideal pH range for plant growth. Soil organic carbon is highest in the secondary forest which corresponds to 7.5YR 3/1 and lowest in the monoculture stand (10YR 2/2). Soil water content is highest in the secondary forest and lowest in the agroforestry in KHDTK Rarung. The litter biomass in the secondary forest is two times higher than in agroforestry sites and four times higher than in banana-dominant landscape, monoculture stand and mixed planted forest.

Keywords: *Landscape-based approach, Rinjani volcano, soil organic carbon, soil profile*

INTRODUCTION

Upstream-downstream linkages occur at different scale and in many aspects including the socioeconomic, environment, institutional and cultural aspects (Nepal et al., 2018). The upper stream communities often face challenges in ensuring their livelihoods. On one hand, the forests in the upstream areas are important for water catchment and carbon sequestration, hence must be protected. On the other hand, livelihood strategy choices are limited (Afifah *et al.*, 2021; Ansharyani, 2018; Ichsan *et al.*, 2013; Hidayati, 2012). Communities living around Rinjani volcano in Lombok, Indonesia, are expected not to perform livelihood activities that may pose adverse impacts on the environment such as clear cut of the forest because the catchment areas located at the bottom of the Rinjani volcano plays a key role in regulating water flow (source of water) for the downstream communities (FAO, 2013; Nini, *et al*., 2022).

Landscape approaches seek to accommodate balance in economic, ecological and socio-cultural aspects (Svensson, *et.al*., 2020). Embracing integrated land-sharing philosophy, the landscape approaches have been promoted as an alternative to conventional, sectoral land-use planning, policy, governance, and management (Reed and Deakin, 2015). A multi-functional landscape simultaneously meets a broader range of local needs including ensuring water availability and regulation; providing biodiversity for crop pollination and tourism; producing nutritious and profitable crops and at the same time meeting global target commitment such as climate change mitigation (UNEP, 2017; Kim, Y.S. *et al.,* 2018). A good soil quality is important to achieve the various needs that a multi-functional landscape tries to meet. Soils provide essential contributions to life like food, clean water, and are a major carrier for biodiversity and is significant for the realization of Sustainable Development Goal (Keesstra, *et.al*., 2016) .

Karang Sidemen is one of the villages located at the buffer zone of the Mount Rinjani National Park (MRNP). The landscape in Karang Sidemen village consists of a mosaic of management regimes with different governing bodies such as the Mount Rinjani National Park (MRNP), Forest Park Conservation Area (Tahura) Nuraksa, Hortipark Tastura, Forest for Specific Purpose (*Kawasan Hutan Dengan Tujuan Khusus-KHDTK*) Rarung, and Community Forestry. Within each governing body, different land-use types also exist. Each governing body has their own purpose(s).

A recent global study shows that more than 90 per cent of the conventionally farmed soils were thinning and 16 per cent had lifespans of less than 100 years (Evans *et al*., 2020). Therefore, it is important to study the soil properties of different management practices. Previous study in Karang Sidemen village, focusing on one management practice (i.e. community forestry), evaluated the impacts of community forestry on runoff and erosion from 2007 to 2015 (Nandini, *et.al*., 2019) . Their study shows that there is a slight decrease in runoff and erosion rate from 2007 to 2015. Studies to analyze the soil properties of different management practices over time have not been conducted. This study will assess the soil profile and properties as the baseline data in six different management regimes in the buffer zone of Mount Rinjani National Park (MRNP), North Lombok, Indonesia. The results of this study will enrich the information needed to assess management practices' impacts on the environment particularly the soil over time.

METHOD

Site description

This study was carried out in 2020-2021 in Karang Sidemen Village, located at the buffer zone of Mount Rinjani National Park (MNRP), Lombok, Indonesia (Figure 1). Six management regimes purposively selected in this study were (i) Secondary tropical dry forest, (ii) Monoculture stand of *Diospyros malabarica*, (iii) Banana-dominant landscape in Hortipark Tastura, (iv) Agroforestry in KHDTK Rarung, (v) Mixed planted forest, and (vi) Agroforestry in Community Forestry (*Hutan Kemasyarakatan*). These management practices are all found in Karang Sidemen Village but managed by different actors/institutions. The secondary tropical dry forest in this study is under the management of Forest Park Conservation Area (Tahura) Nuraksa. The monoculture of *D. malabarica* stand and mix planted forest are within KHDTK Rarung (also owned and managed by the government). The *D. malabarica* were planted in 1994. The banana-dominant area is within the Hortipark (owned by the government but partly managed by the community group). One agroforestry site is owned by KHDTK Rarung but managed by the community group. One agroforestry site is under the Community Forest Management scheme.

Soil sampling and analysis

To study the soil profile, a two-dimensional soil vertical cross-section with 100 cm depth (Smith, 1960) was used in each management regimes. The spot in each site was selected randomly (Figure 2). The soil profile data were collected on September 2021. Soil pH for each horizon was gained using soil pH meter. To assess some soil properties, soil samples (0- 30 cm) were collected at each site, mixed thoroughly, homogenized and stored. These sample soils were air-dried, ground and then passed through a 2-mm sieve to remove gravel and boulders. To obtain SOC content, soil samples are processed and analyzed using spectrophotometer and calculated with the following formula (Sulaeman, *et al*., 2006):

$$\%C = \text{ppm curve} \times (100/\text{weight}) \times 0.0001 \times \text{Correction factor}$$

Bulk density and soil water content were determined using volumetric ring method (Grossman, 2002). To identify the soil color, a portion of soil in each soil horizon was hold up to the Munsell chart. The soil dry color was identified under all full sun. First, the hue was identified, then the value, and lastly the chroma. The Red Index (RF) of the A Horizon was determined according to Santana (1984).

$$RF = (10 - H) + C/V$$

Where:
RF = Red Index of soil
H = Value of Hue (Munsell Chart)
C = Value of Chroma (Munsell Chart)
V = Value of Value (Munsell Chart)

Figure 1. Karang Sidemen Village

Karang Sidemen Village

Source: Google Map 2021. Scale 1: 2,000,000

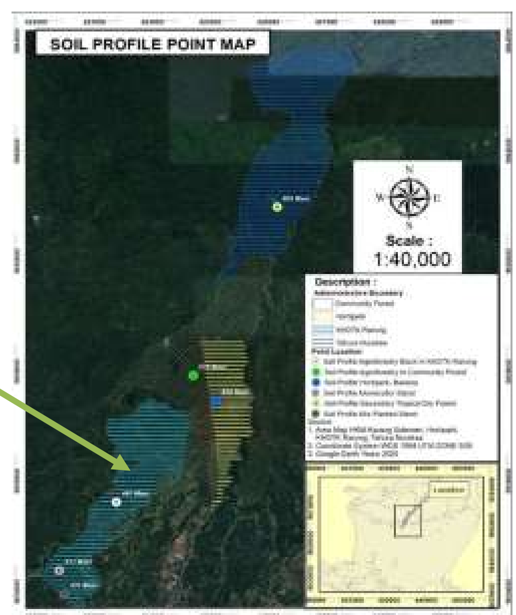


Figure 2. Soil Sampling Location

Forest litter biomass

Forest litter samples were collected from a 50 cm x 50 cm plot selected randomly in each study site to acquire 300 grams of litter (Randi, 2018). Forest litter biomass were estimated by measuring the wet weight and constant oven dry weight (Manuri, *et.al.*, 2011). The litter biomass figure in this study is the constant oven dry weight.

RESULTS AND DISCUSSION

Soil Profile and pH

Six soil profiles studied show that the soil colors can be easily differentiated, most notably for the secondary forest and agroforestry in community forest soil profiles (Figure 3a-f). Table 1 presents some morphological soil features. The colors are mostly in the Yellow Red spectrum. The top soil depth of the secondary forest (around 15 cm) is significantly different from the other profiles (around 4 cm). Fine roots can be found up to the B3 horizon. The top soil in the secondary forest is also darker (7.5 YR 3/1) than all other sites' topsoil.

Table 1. The descriptions of the soil profiles in six management practices

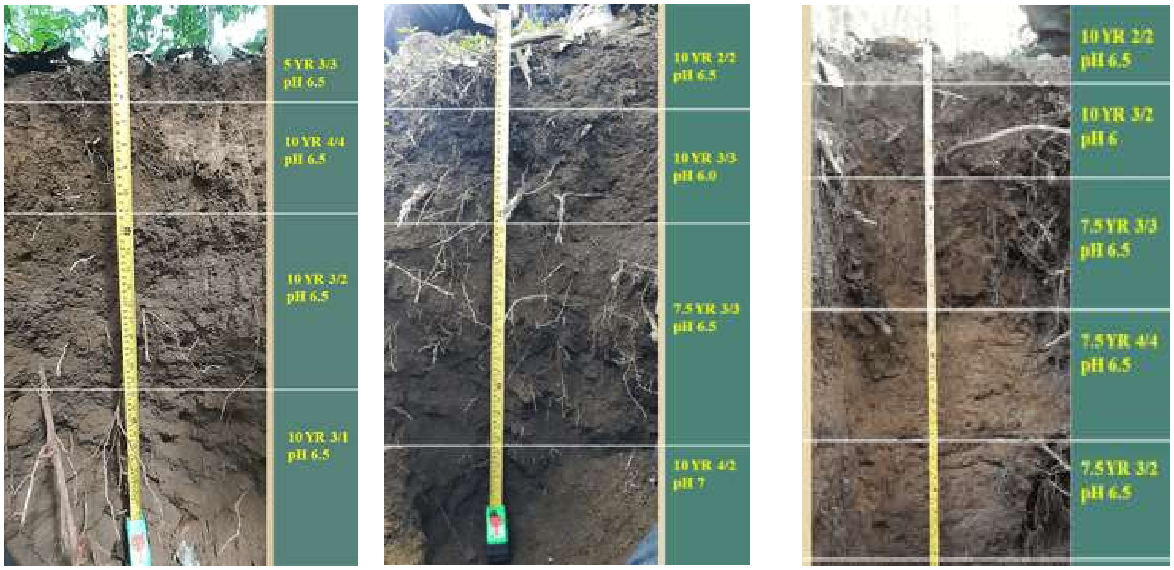
Horizon	Depth (cm)	Color	Structure
	Soil Profile 1 (Secondary forest)		
A	0-15	7.5 YR 3/1	Granular
B1	15-47	7.5 YR 3/2	SB
B2	47 - 70	7.5 YR 3/4	SB
B3	70 - 100	7.5 YR 2/3	SB
	Soil Profile 2 (Agroforestry in CF)		
A	0-4	10 YR 2/2	Granular
B1	4-12	7.5 YR 3/5	SB
B2	12-40	10 YR 4/6	SB
B3	40 -70	10 YR 5/6	SB
C	70 - 100	2.5 Y 4/4	Blocky
	Soil Profile 3 (Hortipark - banana)		
A	0-8	7.5 YR 5/2	Granular
B1	8-21	5 YR 3/2	SB
B2	21-50	7.5 YR 3/4	SB
B3	50-100	7.5 YR 5/4	SB
	Soil Profile 4 (Agroforestry in KHDTK Rarung)		
A	0-7	10 YR 2/2	Granular
B1	7-32	10 YR 3/3	SB

B2	32-74	7.5 YR 3/3	SB
B3	74-100	10 YR 4/2	SB
	Soil Profile 5 (Mix planted stand)		
A	0-7	5 YR 3/3	Granular
B1	7-40	10 YR 4/4	SB
B2	40-70	10 YR 3/2	SB
B3	70-100	7.5 YR 3/1	SB
	Soil Profile 6 (Monoculture stand)		
A1	0-4	10 YR 2/2	Granular
B1	4-24	10 YR 3/2	SB
B2	24-50	7.5 YR 3/3	SB
	50-90	7.5 YR 4/4	SB
B3	90 - 126	7.5 YR 3/2	SB

[1]The descriptions of soil color followed the Munsell Soil Color Charts; [2] Code for types of soil structure was used: SB-Subangular blocky.

Soil pH is generally increasing from the top of the soil profile to the bottom, except for secondary forest. The pH values are between 5 (strongly acidic) to 7 (neutral) (Figure 3a-f). Soil pH was steady or increased with soil depth in five soil profiles, which was consistent with what many studies have found (Crane and Balerdi, 2019; Zhang, 2019) . In soil profiles of humid environments with parent materials containing appreciable concentrations of bases, it is common to observe increasing values of soil pH with depth in the profile due to the leaching of soluble bases (Singh, 2014) .

(a) (b) (c)



(d) (e) (f)

Figure 3. Soil profile and its pH. (a) Secondary forest, (b) Agroforestry in Community Forest Management, (c) Hortipark Tastura – banana (d) Agroforestry in KHDTK Rarung (e) Mixed planted stand in KHDTK Rarung, (f) Monoculture stand of *D. Malabarica* in KHDTK Rarung

While for the secondary tropical dry forest, the soil pH decreased with soil depth. This is consistent with other studies in the tropical forest where this paradoxical relationship is commonly observed between massive biomass production and low soil pH (Terborgh,1992), for example, in Bornean tropical forest, soil acidification is promoted by plants and microorganisms as a nutrient acquisition strategy, while plant roots and fungi can develop rhizosphere and enzymatic processes that promote tolerance of low pH (Fuji, 2014).

According to their pH value, soils can be classified as neutral (6.5 – 7.5), alkaline (7.5), acidic (less than 6.5) and strongly acidic (less than 5.5) (Q., 2016). Some nutrients are more available under acid conditions while others are more available under alkaline conditions (Q., 2016) but most minerals and nutrients are more soluble or available in acid soils than in slightly alkaline soils (Bickelhaupt, 2020). pH 6 to 8 is the general range where nutrient availability is optimal (Läuchli and Grattan, 2012).

This study indicates that the soil pH in almost all management regimes (ranges from 5.0 to 7.0) are suitable for plant growth. However, attention should be directed to hortipark where the dominant species is banana. Bananas do best on flat (slope 0–1%), well drained, deep soils high in organic matter with a pH of 5.5–7.0 (Crane and Balerdi, 2019) . The pH in the banana-dominant soil profile in this study from top to bottom is 5.5; 5.4; 6.4 and 6.3. It shows that planting banana is suitable for the soil condition. While this range is still optimal for banana, the pH needs to be monitored as the top soil's pH is right at the lower bound of the optimum range and study has shown that banana perform better with higher pH above 5.7 (Segura, *et.al*., 2015). This is important because income from banana comprises the biggest portion of their income which is around 54,8% (Nandini, *et.al*., 2019) . As they don't use fertilizers, the low pH might be natural due to parent material or leaching. To improve productivity, they might want to look at the soil pH and texture.

Soil RF index , BD, SWC, SOC and Litter Biomass

Soil BD, SWC, and SOC are varied among the management practices (Table 2). The SWC is highest in the secondary forest and lowest in the agroforestry (KHDTK Rarung). The Bulk Density is highest in the agroforestry (KHDTK Rarung) and lowest in the secondary forest. The SOC in highest in the secondary forest (10.56%) and lowest in the monoculture stand of *D. malabarica* stand (3.7%). While five other management practices are approximately half of the secondary forest value. The litter biomass in the secondary forest is two times higher than in agroforestry sites and four times higher than in banana-dominant landscape, monoculture stand and mixed planted forest.

Table 2. Soil properties in six management practices

Management Practices	**SWC (%)**	**BD (g/cm^3)**	**SOC (%)**	**Litter Biomass (ton/ha)**	**pH Topsoil**	**RF index**
Secondary forest	81.31	0.39	10.56	4.84	6.5	2.8
Agroforestry (CF)	61.48	0.54	4.26	2.8	5.9	1
Hortipark Tastura	43.67	0.61	5.16	1.48	5.5	2.9
Mixed planted forest	40.82	0.59	4.19	1.2	6.5	6
Monoculture stand	36.91	0.65	3.7	1.2	6.5	1
Agroforesty (KHDTK Rarung)	31.72	0.75	4.31	2.04	6.5	1

Source : primary measurement (2021)
Note: Soil Water Content (SWC), Bulk Density (BD), Soil Organic Carbon (SC)

Pearson correlation performed on soil properties (Table 3) shows some significant correlation among the soil properties.

Table 3. Correlation among soil properties

	SWC	*BD*	*SOC*	*Litter Biomass*	*pH*
SWC	1.000				
BD	-0.954*	1.000			
SOC	0.841**	-0.808**	1.000		
Litter Biomass	0.881**	-0.732	0.880**	1.000	
pH	-0.041	0.028	0.155	0.174	1.000

*correlation is significant at the 0.01 level
**correlation is significant at the 0.05 level

SWC and BD directly influence plant performance because they affect the chemical and biological properties of soil (Bonfante et al. 2019; Chakraborty and Mistri, 2017). Soil bulk is often regarded as one of the soil health indicators (Bonfante et al. 2019). Lower bulk density allows more optimum plant growth (Anda, 2021). This study observed a strong reciprocal relationship between soil water content and bulk density (R = -0.954) at significant level 0.01. This finding is consistent with other studies conducted on fields (Anda, 2021) and in laboratories (Abidin *et al*. 2013; Ghosh, 2013). Increase in soil bulk density will reduce the soil water content. The BD value in this study ranges from 0.39 g/cm^3 (in secondary forest) to 0.75 g/cm^3 (in Agroforestry KHDTK Rarung). This value is inversely correlated to the SWC values where the SWC is highest in the secondary forest (81.31%) and lowest in the Agroforestry KHDTK Rarung (31.72%).

Research in the subtropics by Cao *et al.* (2020) shows that plant leaf litter is more important than root in maintaining the balance of the SOC. There is a strong positive correlation between litter biomass and SOC (R=0.88) at significant level 0.05. This research hints that plant leaf litter is important factor in maintaining the SOC. In this study, litter biomass in agroforestry sites (2 ton/ha) are between the monoculture site (1.2 ton/ha) and the secondary forest site (4.48 ton/ha). Studies by Pertiwi *et al.* (2021), Wulandari *et al.* (2021), Latifah *et al.* (2020), and Ivando *et al.* (2019) suggest that there is a correlation between plant richness and the litter biomass. A more complex agroforestry cropping pattern stored 100% more total above ground biomass than the simple cropping (Wulandari *et al.* 2021). There is no significant correlation between the RF index and the SOC content (R=0.129) suggesting that the soil color in this study is influenced more by the organic materials than by the minerals consistent with finding from Minh *et al.* (2020). Therefore, we suggest that agroforestry sites should enrich the plant diversity to improve the SOC and carbon stocks.

In hilly areas, SOC is mainly governed by vegetation and altitude (Ramesh *et al.,* 2019). Several studies have reported the positive correlation between altitude and SOC concentration mainly due to changes in temperature and vegetation characteristics (Massacessi, *et al*., 2020; Ramesh *et al*., 2019; Cardelli *et al*., 2019; Kobler *et al*., 2019; Tsozué *et al.,* 2019). In this study, increase in elevation corresponds with increase in SOC concentration. The SOC concentration is between 3.7% (at 417 masl, monoculture stand) to 10.56% (at 803 masl, secondary forest).

Top soil organic carbon (SOC) is a significant factor influencing soil physical and chemical properties (Büneman *et al.,* 2018) including soil fertility (King *et al.,* 2020). Different land use affects SOC stocks (Ghimire *et al.* 2018; Sainepo *et al.* 2018). Improving SOC should be considered if the management goals include carbon sequestration, water regulation and improving productivity as SOC increases soil adsorptive capacity for nutrients and water and improves soil structure and its stability (Keesstra, *et.al*, 2016) by binding particles together into aggregates, which keeps the soil stable thereby increasing water infiltration and assisting in preventing soil compaction (Q., 2016).

According to Evans *et al.* (2020), the best measure to lengthen soil lifespans was to convert arable land to forest or to apply soil conservation measures such as cover cropping and hillslope terracing. The agroforestry in community forest and hortipark sites in this study were previously abandoned logged areas. Their soil properties are half of the secondary forest but better than a monoculture stand. This suggests that agroforestry may provide solution to lengthen soil lifespans and can be enhanced with soil conservation measures. Future studies can conduct experiment on various conservation measures and assess the impacts of such measures to soil properties.

CONCLUSIONS AND RECOMMENDATIONS

Of the six management regimes studied, the secondary tropical dry forest poses the best soil properties (low BD, high SWC, high SOC, high litter biomass). Agroforestry soil properties figures are approximately half of the secondary forest. Improving the diversity of plants and applying conservation measures in agroforestry may enhance the soil properties particularly the SOC. This study indicates that understanding the soil properties might provide valuable information to improve the benefits of land sharing and better inform the landscape approach. We recommend further studies to assess more soil properties as they will provide better information for management intervention to enhance soil resources for generations to come.

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