

**Research Article**

**Land-use changes and slope positions impact on the degradation of soil functions in nutrient stock within the Kalikungkuk micro watershed, East Java, Indonesia**

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Received 2 December 2020, Accepted 28 December 2020

**Abstract:** Degradation of soil functions in storing and cycling nutrients may be related to topography and land-use change. The research aimed to analyze the impact of land-use changes and slope positions on soil function in nutrient stock within Kalikungkuk micro watershed of East Java, Indonesia. Four different land-uses such as vegetable crops, agroforestry, shrub and forest were selected with three slope positions (e.g. ridge, slope, and valley), and three replications of each. Soil samples were collected at 0-10, 10-30, 30-50, and 50-100 cm depth of soil. Variables measured included soil properties (e.g. bulk density, soil texture, pH, CEC, soil nutrients). Slope positions impact on differences in soil physical (i.e. soil bulk density, soil texture) and chemical (i.e. total N, exchangeable K) properties. In addition, forest conversion to other land-uses (i.e. agroforestry, shrub, vegetable crops) decreased soil nutrient concentration (i.e. total C, total N, Ca, Mg, Na), and consequently resulted in degradation of soil nutrient stocks of especially C and N. The strong positive correlation between soil nutrient stock (e.g. C and N) and vegetation cover such as canopy cover, basal area, and litter ( $r = 0.63 - 0.78$ ,  $r$  table 1% = 0.39) showed the benefit of biodiversity in maintaining soil function on the nutrient stock.

**Keywords:** *agroforestry, land-use change, slope positions, soil characteristics, soil nutrient stocks*

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**To cite this article:** Fitria, A.D., Sudarto, and Kurniawan, S. 2021. Land-use changes and slope positions impact on the degradation of soil functions in nutrient stock within the Kalikungkuk micro watershed, East Java, Indonesia. *J. Degrad. Min. Land Manage.* 8(2): 2689-2702, DOI: 10.15243/jdmlm. 2021.082.2689.

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**Introduction**

Soil plays an important role in sustaining biodiversity, storing and cycling nutrient, and regulating water and solute flow in the watershed. However, the functions of soil for the environment in the watershed area has decreased naturally (due to topography and climate effects) and/or mismanagement in the land (due to forest conversion to other land-uses) during the past fourth decades. Consequently, degradation of soil function will affect the sustainability of land productivity.

Naturally, with the similar climate condition, degradation of soil function especially on nutrient

stock and cycling under unmanaged land (i.e. forest, shrub) in the upstream watershed is mainly related to the variation of topography. Rodenburg et al. (2003) reported that topography (i.e. the level of slope and slope position) have an effect on the level of surface runoff and soil erosion. In addition, the previous research that was conducted in the upstream Brantas watershed showed the increases of runoff coefficient in the steep of topography with disturbed area by agricultural and human activities (Witjaksono et al., 2018). The runoff and soil erosion will carry water from the highest point to the lowest point along with different amounts of nutrients and parts of the topsoil. Consequently, the lower areas have an increase in soil nutrient

concentration, while the upper areas have an increase in soil compaction. This was supported by the result of Moges and Holden (2008) who reported that soil organic C, total N, base cations (i.e. Ca and Mg) and cation exchange capacity (CEC) are significantly lower in the upper slope or ridge position compared to slopes and valley. Also, Mbonimpa et al. (2015) reported that surface runoff increased soil compaction the upper slope, indicated by the higher soil bulk density in the upper slope as compared to middle and foot slopes. Nevertheless, soil degradation under un-managed lands such as forest and shrub have occurred slowly.

Degradation of soil function on nutrient stock and cycling increase rapidly during the past fourth decades due to forest conversion to other land-uses. Kalikungkuk micro watershed is one of the areas in Indonesia that had experienced in land-use change.

According to the evaluation of the land capability class in the upstream part of the Brantas watershed, the land use mismatch was 25.67%, while the mismatch according to the regional spatial plan was 32.05%. This land-use mismatch is due to the development of intensive agriculture and tourism sectors, around 3289,756 ha of the upstream watershed area were allocated for agriculture (Rahadi, 2013; Lusiana et al., 2017). Meanwhile, according to Badan Lingkungan Hidup Jawa Timur (2009), the forest area in the upstream area of the Brantas River Basin from 2000-2008 decreased by 80,938 ha to 42,683 ha. In addition, based on analysis using Landsat imagery (Table 1), Kalikungkuk micro watershed had forest loss of approximately 607,5 ha (27%) during the period of 1995 to 2019. In the other hand, the area of agricultural land, shrubs, and settlement increased dramatically during that period.

Table 1. Land-use change in the Kalikungkuk watershed.

Land use	Year of 1995		Year of 2006		Year of 2019	
	ha	%	ha	%	ha	%
Conservation Forest	2268.80	64.69	173.17	49.36	1661.28	47.37
Plantation	377.62	10.77	203.21	5.79	151.48	4.32
Crop	687.15	19.59	1174.99	33.43	883.20	25.18
Shrub	168.12	4.79	297.39	8.48	371.80	10.60
Settlement	5.44	0.16	103.00	2.94	197.68	5.64
Agroforestry	0	0	0	0	241.68	6.89
Total of area	3507.13	100	3507.13	100	3507.13	100

Forest conversion to other land-uses affects the decrease in canopy cover, understorey, litter input (Hairiah et al., 2006), and plant root diversity. As consequently, the ability of plants and litter to intercept rainwater is decreased, resulted in increased high surface runoff and soil erosion. Soil erosion causes nutrient losses, especially nitrogen and phosphorus that are very important for plants. The study in Gedeo dan Borena watershed, south Ethiopia, reported that land-use change during the period of 1986 and 2006 caused changes in soil fertility, where agroforestry had higher soil organic C as compared to agricultural practices, shrub and grassland (Worku et al., 2014). Further, farmers usually apply a high number of inorganic fertilizers to increase nutrient availability and plant production. However, fertilization practices on annual crop-land (after forest conversion) only influence in the short-term period after conversion (Ngoze et al., 2008). In the long-term period from forest conversion to agricultural land, nutrient content and nutrient return to the soil is continues to decline (Corre et al., 2006; Davidson et al., 2007). Therefore, understanding of current condition on soil characteristics and factors

affecting soil degradation is important as a basis to determine proper soil management practices. This study aimed to analyze the impact of slope positions and land-use on soil function for the nutrient stock within Kalikungkuk micro watershed - Indonesia.

## Materials and Methods

### Study area

The study was carried out in the Kalikungkuk micro watershed, Batu City – East Java, Indonesia (112°17'10.90" - 122°57'11" E and 7°44'55.11" - 8°26'35.45" S; Figure 1). The watershed located in the elevations between 1000 - 3000 m above sea level (a.s.l). Soil parent material in the Kalikungkuk micro watershed is generally derived from volcanic material of Mount Anjasmoro, Arjuno, and Wilerang, but the location under this study is influenced by the geology of Mount Anjasmoro. The forest site is located in the Raden Soerjo Grand Forest Park (TAHURA), whereas the agroforestry systems and shrub land are in the Perhutani Coban Talun area, especially in the plots

41A, 43D, and 43E. The average annual rainfall of Batu City for the last 10 years (2008-2018) is between 1200-2700 mm per year. Soil types in the research location are dominated by Andisols (USDA classification).

Based on digital elevation model (DEM), topography in the Kalikungkuk micro watershed consist of steep areas (slope > 25 %, 1956 ha), medium slope (slope 8-15 %, 666 ha), high slope (slope 15-25 %, 545 ha), and the low slope (slope 0-8%, 340 ha). During the period of 1995 and 2019

(Table 1), Kalikungkuk micro watershed had experienced in land-use change. Around 27% of forest area (607.5 ha) was changed into other land-uses such as crop (395.36 ha), shrub (100.16 ha), and agroforestry 112.07 ha). The land uses that were selected as research locations consisted of conservation forest, agroforestry, shrubs and crop. In each land-use, the study was conducted in the three slope positions, including ridge (15-20% slope), sloped (30-35% slope) and valley (3-5% slope).

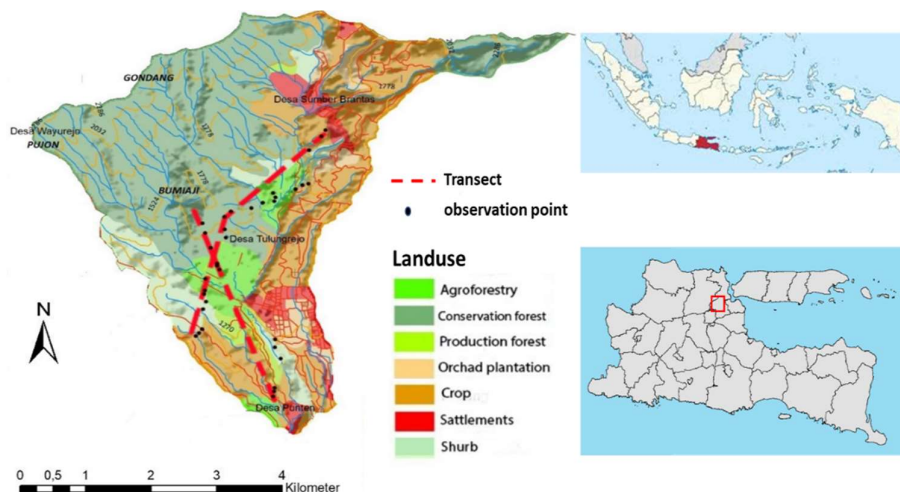


Figure 1. Location of Kalikungkuk Watershed, Batu City, East Java - Indonesia (112°17'10.90 " - 122°57'11" E and 7°44'55.11" - 8°26'35.45" S).

### **Research design**

The study was started by preparing of working map, including 1) land-use map using Landsat 4 and 8, 2) geological map sheet of Malang (1608-1) with a scale of 1: 100,000, 3) topographic map from the SRTM DEM (ASTGTM2 S08E112). Then, the land use and topographic maps were combined to determine the transect of the research location. The transect of this research location determined the research point for taking intact soil samples, composites and land characteristics (Figure 2). Research transects were made at locations affected by rocks from Anjasmoro (Qpva and Qpat). Prior to collecting soil samples, the preliminary field survey or ground-check was carried out to equalize land use through images with actual conditions in the field.

The results of the land map units (LMU) and field ground-check determined 3 transects which were used as replications. In each transect, there is a combination of three slope positions (i.e. ridge, sloped, and valley) and four land-uses (i.e. forest, agroforestry, shrub, and crop), totally 36 research

plots. The distance between the research plots in each transect is approximately  $\pm 200$  m.

The forest area was selected in the Grand Park, named as Taman Hutan Raya R. Soerjo (Tahura R. Soerjo) due to human activities in this forest is limited. Tahura R. Soerjo covers an area of 1731 ha or 49 % of the area of the Kalikungkuk micro watershed. The forest is using for the conservation of collecting natural or artificial plants and/or animals, native or non-native species, which are used for research, science, education, tourism, etc. (Pemerintah Provinsi Jawa Timur, 2002). The forest plots are characterized by high tree density (1120-1389 trees ha<sup>-1</sup>), canopy cover (78.71-82.34%), standing litter mass (8.51-11.50 t ha<sup>-1</sup>), and basal area (31.12-36.17 m<sup>2</sup> ha<sup>-1</sup>). The plot characteristics, including tree density, canopy cover, surface litter mass, and the basal area is comparable among slope positions (i.e. ridge, sloped, valley) within forest plots. Tree species that dominantly grow in all slope positions within the forest include *Trema orientalis*, *Dipterocarpus*, *sindora*, *Pterocarpus indicus*, *Ficus sp.*, *Eucalyptus sp.*, *Lithocarpus sundaicus*, *Persea*

*americana*, *Engelhardia spicata*, *Microcos tomentosa*, etc. Dipterocarpus species grow more in forest areas with slope class of 0-8% compared to other slope classes. While, shrub covers an area of 371.8 ha (10.6 % of the watershed). The shrub has vegetation including *Habitus*, *Phyllanthus niruri*, *Solanum nigrum*, *Leea indica*, *Oldenlandia corymbosa*, *Ayapana triplinervis*, *Tithonia diversifolia*, with surface litter mass between 0.36 and 2.15 t ha<sup>-1</sup>. Agroforestry covers 241.68 ha (6.89% of Kalikungkuk micro watershed) and mostly located in the production forest under-managed by Perum Perhutani and the local community. Agroforestry systems in this study site are mainly classified as simple agroforestry composed by trees (e.g. pine, avocado, eucalyptus) and crops (e.g. carrot, lily flower, onion, hortensia). The agroforestry sites are characterized by medium tree density (335 – 535 trees ha<sup>-1</sup>), canopy cover (17.56 – 47.65 %), standing litter mass (1.48 – 4.83

t ha<sup>-1</sup>), and basal area (10.12 – 26.24 m<sup>2</sup> ha<sup>-1</sup>). There were no significant differences in plot characteristics among slope positions within agroforestry systems. Agroforestry farmers commonly apply inorganic fertilizer for the crop with doses 45-90 kg N ha<sup>-1</sup> planting season<sup>-1</sup>, 15-30 kg P ha<sup>-1</sup> planting season<sup>-1</sup>, and 12-30 kg K ha<sup>-1</sup> planting season<sup>-1</sup>. Seasonal crops are intensively cultivated in an area of ± 883 ha (25% of the total Kalikungkuk area). In 2019, the crop land area increased by 28% as compared to those in 1995. The crops which are dominantly cultivated are carrots (*Daucus carota*), mustard greens (*Brassica chinensis*) and broccoli (*Brassica oleraceae* var. *Italica*). Carrots are planted two times per year, with a potato as a crop rotation system. In each planting season, farmers applied 57 – 98 kg N ha<sup>-1</sup>, 21.6 – 45 kg P ha<sup>-1</sup>, 18 – 75 kg K ha<sup>-1</sup>, and 20 kg Ca ha<sup>-1</sup> to supply nutrient for the crop. In addition, farmers also applied manure 10 – 15 t ha<sup>-1</sup> year<sup>-1</sup>.

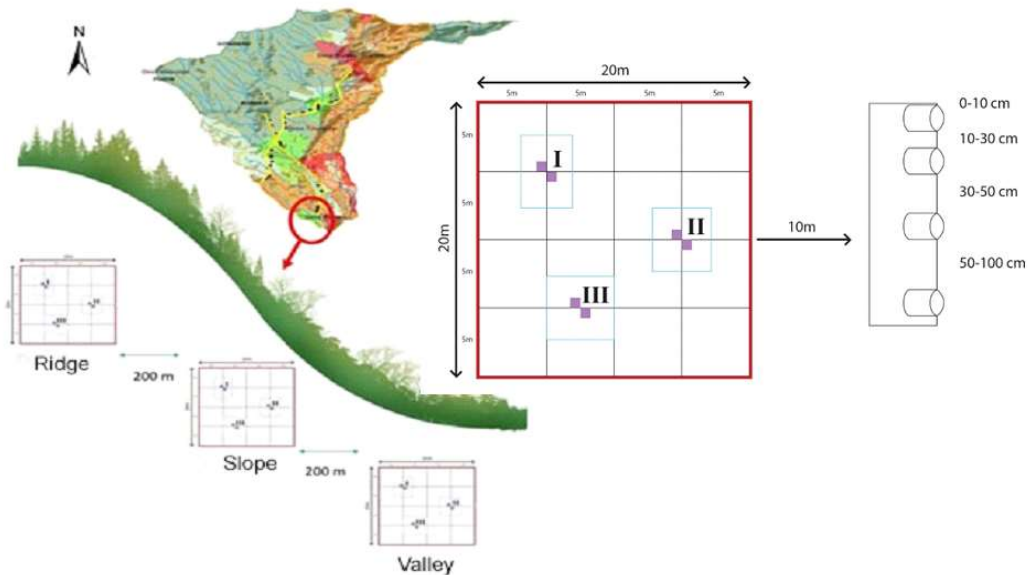


Figure 2. Research location.

### **Plot and soil sampling design**

Characterization of plot and collection of soil samples was conducted on 36 plots. In each study plot (size 20 x 20 m), 3 representative subplots of 5 x 5 m were randomly determined (Figure 2). Soil samples were collected in each subplot at four soil depths, i.e. 0-10 cm, 10-30 cm, 30-50 cm, and 50-100 cm using a soil auger, except for soil bulk density which was taken by using soil core. Then, soil samples were placed in plastic bags and coded according to land use and slope positions. Then, the soil samples were brought to the Department of Soil Science, Faculty of Agriculture, Brawijaya

University, air-dried for ± 7 days, and ground to pass through a 2 mm sieve. Plot characterization was conducted by measuring basal area, tree density, and canopy cover on a plot area of 20 m x 20 m within agroforestry and forest plot; if there are trees with a diameter > 30 cm, the area of the plot was expanded to 20 m x 100 m. Standing litter mass was measured in all 36 plots. In addition, an interview survey was also done to obtain information on land management systems and fertilizer applied by farmers. Farm interviews were conducted on seasonal crops and agroforestry which combined trees with seasonal crops.

### **Laboratory and data analysis**

Laboratory analysis of soil chemistry includes pH H<sub>2</sub>O, total N using Kjeldahl method (Kjeldahl, 1883), P available with Bray, soil exchangeable base cations (i.e. K, Ca, Mg, Na) and CEC with NH<sub>4</sub>OAC buffer solution pH 7 (Indonesia Soil Research Institute, 2005), organic C using the Walkley-Black method (Walkley and Black, 1934). Meanwhile, laboratory analysis for soil physical properties was conducted to measure soil texture using the pipette method (Gee and Bauder, 1986) and bulk density the pycnometer method. The soil nutrient stock expressed in g m<sup>-2</sup> was obtained from the following calculation (Allen et al., 2016; Kurniawan et al., 2019):

$$\text{Sol nutrient stock (g m}^{-2}\text{)} = \frac{E_c (\text{g kg}^{-1}) \times \text{BD (g cm}^{-3}\text{)} \times \Delta D (\text{cm}) \times 1000 \text{ cm}^2 \text{cm}^{-3}}{1000 \text{ g kg}^{-1}}$$

where:  $E_c$  = soil nutrient concentration,  $BD$  = bulk density (the value was used from forest area), and  $\Delta D$  = soil depth. Then, the soil nutrient stocks (g m<sup>-2</sup>) were converted to kg ha<sup>-1</sup> or t ha<sup>-1</sup> as a final unit.

Calculation of soil nutrient stock in all land-uses (forest, shrub, agroforestry, vegetable crops) used soil bulk density from the average of forest site because 1) the forest site is used as the reference site (Allen et al., 2016); and 2) soil compaction was not reflected in soil carbon stock (Hairiah et al., 2020). Statistical analysis was done to determine the effect of differences in land-uses and slope positions on soil characteristics at each soil depth (0-10 cm, 10-30 cm, 30-50 cm, and 50 – 100 cm). The normality test was performed using the Shapiro Wilk's test for all parameters. Data analysis was conducted using the Linear Mixed Effects (LME) model to determine the effect of land use and slope position factors, where each factor was compared as a fixed factor and a random factor (Crawley, 2009). Fisher's least significant difference (LSD) test was used at the 5% level to find significant differences between 4 land-uses and 3 slope positions (i.e. forest and shrub). The difference was considered statistically significant if  $p \leq 0.05$ .

The relationships among soil characteristics, as well as the correlation among soil nutrient stocks with vegetation characteristics (i.e. basal area, standing litter mass, canopy cover) and soil properties (e.g. soil fraction such as sand, silt, and clay contents), were analyzed by averaged replicate plot, then weighing averages of soil depth in each land-use system to minimize the spatial effect (replication). All statistical analyzes were carried out using R statistics software.

### **Results and Discussion**

#### ***Effects of slope positions on soil physical and chemical characteristics***

Analysis of the effect of slope positions (i.e. ridge, sloped, valley) on soil properties was performed for un-managed lands such as forest and shrub to exclude the effect of human activities on soil management. Soil management, such as fertilization and terracing can affect soil properties and nutrient stock. The previous research by de Blécourt et al. (2014) reported that the existence of terraces has an effect on decreasing carbon stocks, especially in the parts where the land was cut due to the construction of terraces. Differences in soil physical and chemical properties among slope positions (i.e. ridge, sloped and valley) at various soil depth (i.e. 0-10 cm, 10-30 cm, 30-50 cm, 50-100 cm) were more pronounced in the forest than that of in the shrub lands. Within the forest, the effect of slope positions on forest conservation in soil characteristics is more evident in physical properties as compared to the chemical properties of the soil (Table 2). This was shown by differences in soil bulk density ( $BD$ ) and percentages of sand, silt and clay ( $p \leq 0.05$ ) among three slope positions (e.g. ridges, slopes, and valley) at soil depths of 0-10 cm, 10-30 cm, 30-50 cm and 50-100 cm.

The soil in the forest area within Kalikungkuk micro watershed is characterized by low soil bulk density (0.6-0.9 g cm<sup>-3</sup>) and high silt content at 0 - 50 cm depth of soil (49.65 - 74.83 % of silt), which are mainly found in andic soil. This result is comparable to the soil bulk density value from Andisol in Indonesia (0.80 ± 0.05 g cm<sup>-3</sup>) which was reported by Shofiyati et al. (2010). Within the forest area, the ridge position has a higher silt content at 0-10 cm and 10-30 cm depth of soil and sand content at 30-50 cm depth of soil as compared to those in the sloped and valley positions (Figure 3). While, the sand content on the other soil depth (i.e. 0-10, 10-30, and 50-100 cm) was higher in the sloped area than that of in the ridge position. In addition, slope position was also had higher (11-15%;  $p \leq 0.05$ ) soil bulk density as compared to the ridge and valley positions at a depth of 10-30 cm. In contrast, the valley area had higher (57% on average) of clay content than that of in the other slope positions (i.e. ridge and sloped) at 0-100 cm. Also, the valley area had higher soil bulk density at 30-50 cm depth of soil as compared to those in the other slope positions. The variability of soil physical properties among slope positions was expected due to differences in the thickness of material deposition from volcanic eruptions; supported by the positive correlation between clay fraction and soil bulk density at depth

10-30 cm and 30-50 cm ( $r = 0.58$  and  $0.77$ ,  $p \leq 0.05$ ). Agustina et al. (2016) reported that the amount of clay increased along with the increase in soil depth was found in the forest land. In addition, the positive correlation between BD and clay

content was also found from the previous research conducted in Croatia forest, the western edge of the Pannonia Basin by Rubinić and Safner (2019), which means that the addition of clay is accompanied by an increase in soil BD.

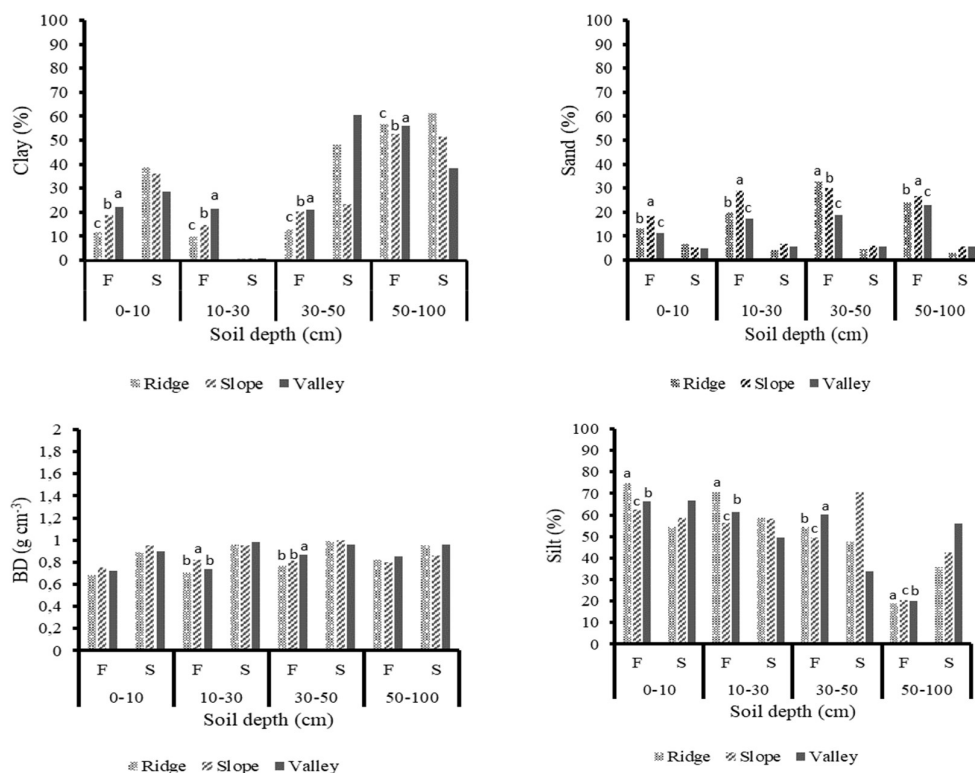


Figure 3. Effect of topography on soil physical properties in the forest. F = Forest, S = Shrub.

Soil chemical properties at various depth in the forest land was mainly comparable (Table 2) among slope positions (i.e. ridge, sloped, valley), except total N (i.e. at 10-30 cm depth) and soil exchangeable K (i.e. 10-30 cm, 30-50 cm, and 50-100 cm depth). The result shows that the topography soil chemical properties in the unmanaged land (e.g. forest and shrub) was not significantly affected by slope positions. This was probably due to the forest land in all slope positions is still tightly closed and have a high input of litter as a source of nutrients (nutrient cycling). Results of this study are similar to that reported by Chidowe et al. (2019) that pH and base saturation (BS) in forests are not significantly different on the upper, middle and lower slopes. Another study in China conducted by Scholten et al. (2017) also reported that the effect of topography on soil fertility under forest land is lower than vegetation cover. The findings are certainly different from the research conducted by Ofori et al. (2013) which stated that many nutrients are available in the foot-

slope due to the process of leaching and depositing the material so that it has a higher fertility level compared to the up-slope and middle-slope position. However, the land-uses in this study is different from Ofori et al. (2013), which may affect soil development. This is because the research of Ofori et al. (2013) was conducted on fallow land-use, seasonal fields and oil palm land where soil management (i.e. fertilization, soil tillage) is applied and potentially difficult to see the effect of slope positions. In contrast, this investigation on the effect of slope positions was conducted on unmanaged lands such as forest and shrub lands. In addition, the results obtained in this study was also not entirely the same as those conducted by Dessalegn et al. (2013) in the Ele River Basin, southern Ethiopia which reported that topography such as upper, middle and lower slopes are one of the factors that control soil development and characteristics such as soil structure, BD, organic carbon, total N, C/N ratio, available P and cation exchange capacity (CEC).

Table 2. Chemical properties of forest and shrub lands within Kalikungkuk micro watershed, East Java. Indonesia.

Topography position	Soil Depth (cm)	OC (%)	SOM (%)	TN (%)	BS (%)	AP (ppm)	Exchangeable Cation (me 100 g <sup>-1</sup> )				CEC (me 100 g <sup>-1</sup> )	pH
							K	Ca	Na	Mg		
<b>Forest</b>												
Ridge	0-10	6.12	10.58	0.77	41.36	2.29	0.44	13.66	0.31	1.09	34.51	5.42
Slope		4.98	8.62	0.62	41.61	2.09	0.38	11.74	0.34	6.70	29.97	5.35
Valley		6.13	10.60	0.71	53.12	3.42	0.56	16.34	0.31	1.18	31.34	5.58
Ridge	10-30	6.43	11.13	0.71 a	48.27	1.78	0.43 b	10.41	0.12	2.11	27.05	5.38
Slope		3.95	6.84	0.50 b	49.15	1.48	0.47 a	12.44	0.05	7.47	41.14	5.50
Valley		6.01	10.39	0.54 b	41.65	2.20	0.39 b	10.64	0.07	2.99	33.77	5.48
Ridge	30-50	2.84	4.91	0.44	44.14	1.91	0.24 a	8.53	0.01	7.16	34.90	5.40
Slope		2.76	4.77	0.35	39.26	1.47	0.76 ab	9.30	0.04	5.40	39.03	5.34
Valley		4.55	7.81	0.46	55.82	2.36	0.32 b	7.69	0.04	6.80	26.64	5.50
Ridge	50-100	2.94	5.09	0.33	54.32	1.60	1.80 a	7.76	0.10 a	9.64	35.65	5.59
Slope		2.88	4.97	0.28	41.45	1.05	1.23 ab	7.06	0.07ab	8.39	40.45	5.40
Valley		3.14	5.44	0.33	46.10	2.12	0.41 a	7.67	0.02 b	10.01	40.31	5.50
<b>Shrub</b>												
Ridge	0-10	3.14	5.44	0.30	42.53	2.63	1.13	8.68	0.49	1.15	24.67	5.34
Slope		0.21	0.36	0.36	44.05	1.45	1.40	9.41	0.28	2.66	25.78	5.27
Valley		0.88	1.52	0.24	47.02	2.25	1.54	8.46	0.28	1.68	22.29	5.31
Ridge	10-30	1.25	2.17	0.30	37.56	1.87	1.33	9.56	0.02	1.75	33.37	5.35
Slope		0.79	1.37	0.32	38.35	1.22	1.57	7.85	0.02	2.27	29.77	5.36
Valley		1.03	1.78	0.25	47.85	1.65	1.97	8.57	0.02	1.34	25.92	5.44
Ridge	30-50	1.62	2.80	0.23	40.16	1.40	1.47	11.61	0.02	0.89	35.13	5.24
Slope		1.24	2.14	0.33	45.15	1.12	2.06	10.28	0.03	1.84	31.76	5.24
Valley		2.74	4.74	0.30	41.70	1.05	1.64	7.55	0.10	3.01	29.78	5.39
Ridge	50-100	0.64	1.11	0.18	39.09	0.91	1.54	10.03	0.01	3.01	36.91	5.29
Slope		0.42	0.73	0.28	40.63	0.90	1.62	9.61	0.01	2.29	32.95	5.28
Valley		1.84	3.19	0.27	43.91	1.31	1.67	10.75	0.03	1.87	35.07	5.30

Remarks: OC = Organic Carbon, SOM = Soil Organic Matter, TN = Total N, AP = Available P, BS = Base Saturation, CEC = Cation Exchange (CEC), pH = soil acidity.

The insignificant differences of soil fertility among slope positions in this study were supported by the result of Moges and Holden (2008) who is stated that the nutrients at the bottom of the slope or humming higher is not always higher than that of in the ridge position. This was due to soil erosion occurs on the eroded soil, as consequently, the material that is carried down is part of the subsoil, while the topsoil is deposited on the lower slope. The low effect of slope positions on soil chemical properties under un-managed lands (e.g. forest and shrub) was probably due to the low nutrient losses through runoff and erosion, leaching, and harvest export. In the forest and shrub lands, there have not soil tillage which can disrupt soil structure and accelerate surface runoff and soil erosion. Wijayanti et al. (2019) reported that soil tillage increased N loss through runoff and erosion up to 7 times higher as compared to no soil tillage. In addition, the dense canopy cover (78.71 – 82.34 %) and high standing litter mass (8.51-11.50 t ha<sup>-1</sup>) in the forest sites have a role to minimize nutrient losses through surface runoff and erosion and source of nutrient cycling. Van Noordwijk et al. (2004) stated that canopy of tree intercepts a large part of rainfall and decreased the rainfall quantity in the surface soil, whereas the litter layer decreases 'splash' effects of raindrops that can lead to a dispersal of clay particles from soil aggregates, resulted in low surface runoff and soil erosion. Similar to the forest, soil surface in the shrub land is also covered by vegetation a whole year, and therefore can reduce surface runoff and soil erosion. Differing from forest and shrub lands, soil surface in the agricultural sites (e.g. simple agroforestry and vegetable crops) is temporary open especially at after harvesting until the vegetative phase. Consequently, nutrient losses through runoff and erosion are higher in the vegetative phase compared to that of in the generative phase (Wijayanti et al., 2019). Since the effect of slope positions on soil fertility was not mainly found in the un-managed land-uses (i.e. forest and shrub), for the next discussion, the differences in fertility among land-uses were carried out in all topographies.

#### ***Land-use effect on the soil characteristics***

Soil texture in all land-uses is mainly classified as Silty Loam. Differences in soil particle size distribution among land-uses were found on sand content ( $p \leq 0.01$ ) at a depth of 0-100 cm, clay content ( $p \leq 0.01$ ) at a depth of 0-30 cm and 50-100 cm, and on silt content ( $p \leq 0.01$ ) at a depth of 0-10 and 50-100 cm (Figure 4). Shrub land had a lower sand fraction (at 0-100 cm), and higher clay (at 0-10 and 10-30 cm) and silt (at 50-100 cm) contents as compared to other land-uses (i.e. forest,

agroforestry, crop). Differences in soil particle size distribution may allow further weathering of primary minerals (Buol et al., 2003). Besides that, there are differences in the parent material between shrubs and other land uses where the shrubs are more influenced by the parent material from the geology of the old Mount of Anjasmoro.

Land-uses gave a significant effect ( $P < 0.01$ ) on soil bulk density at 0 – 100 cm depth of soil. In 0-10 cm depth of soil, forests with higher standing litter mass and without soil tillage had lower soil bulk density as compared to agroforestry, shrub, and crop (Figure 4). Whereas in the deeper layer (10-100 cm), forest and agroforestry had lower soil bulk density as compared to shrub and crop lands. The lower soil bulk density in the forest and agroforestry was due to the higher ( $p \leq 0.05$ ) soil organic matter in the forest and agroforestry than that of in the shrub and crop lands (Table 3) and the strong negative correlation between soil organic matter and soil bulk density ( $r = -0.48$ ,  $p \leq 0.01$ ) at depth 0-100 cm. Celik (2005) reported that the increases in soil organic matter would increase soil pore resulted in a decrease in soil bulk density. The high SOM in the forest and agroforestry systems may be related to the vegetation cover. The correlation test between soil organic C (SOC) with the basal area, standing litter mass, and canopy cover at top 10 cm depth of soil showed strongly positive correlations ( $r = 0.657, 0.751, 0.741$ , respectively;  $p \leq 0.01$ ).

In addition, differences in land-uses strongly affected to a significantly different ( $p \leq 0.01$ ) on Total N, available P, soil exchangeable K and Ca, and soil pH on 0-10, 10-30, 30-50, and 50-100 cm soil depths (Table 3). In addition, differences in soil management practices among land-uses resulted in a significantly different ( $p \leq 0.05$ ) in soil exchangeable base cations (i.e. Mg and Na) at a depth of below 10 cm, CEC and BS at 0-10 cm and 50-100 cm depth of soil. The study detected a strongly positive correlation of soil exchangeable Ca with the basal area, standing litter mass, and canopy cover ( $r = 0.335, 0.46, 0.486$ ;  $p \leq 0.01$ ).

Forest conversion into other land-uses (i.e., agroforestry, shrub, and crop) within Kalikungkuk micro watershed decreased 43-66% of total N in the top 10 cm depth of soil, as well as decreased 10-59 % of total N in the depth of 10-100 cm. Similarly, Kurniawan et al. (2019) reported that changes of the forest into agroforestry systems (i.e., pine with crop, mahogany with coffee, and mahogany with taro) in volcanic soils decreased total N concentration at 0-10 cm depth of soil. The high concentration of total N in forest land was caused by the high input of organic matter such as leaf and stem litter which contributed 7-19% of the total N in the soil.



Table 3. Chemical properties from four different land-uses within Kalikungkuk micro watershed of East Java, Indonesia.

Topography position	Soil Depth (cm)	OC (%)	SOM (%)	TN (%)	BS (%)	AP (ppm)	Exchangeable Cation (me 100 g <sup>-1</sup> )				CEC (me 100 g <sup>-1</sup> )	pH
							K	Ca	Na	Mg		
Forest	0-10	5.74 a	9.93 a	0.70 a	45.36 a	2.60 b	0.46 c	13.91 a	0.32	2.99	31.84 a	5.45 a
Agroforestry		2.83 b	4.89 b	0.40 b	32.49 c	3.26 ab	1.48 a	8.25 b	0.29	5.90	31.04 a	5.07 b
Shrub		1.41 c	2.44 c	0.30 b	44.53 ab	2.11 b	1.36 ab	8.85 b	0.35	1.83	24.25 b	5.31 a
Crop		1.83 bc	3.17 bc	0.24 b	35.30 bc	5.25 a	0.69 bc	9.69 ab	0.37	2.67	31.96 a	5.09 b
Forest	10-30	5.47 a	9.45 a	0.59 a	46.36	1.82 b	0.43 b	11.16 a	0.08 a	4.19	33.99	5.46 b
Agroforestry		2.94 b	5.08 b	0.45 ab	39.28	2.86 b	0.87 b	6.88 b	0.05 ab	3.62	29.67	5.22 a
Shrub		1.03 c	1.77 c	0.29 bc	41.26	1.58 b	1.62 a	8.66 b	0.02 b	1.79	25.54	5.38 b
Crop		2.00 bc	3.45 bc	0.24 c	43.19	5.01 a	0.72 b	10.93 a	0.03 b	1.99	31.64	5.05 a
Forest	30-50	3.37	5.83	0.42 a	46.40	1.92 b	0.44 b	8.51 ab	0.03	6.46	33.52	5.41 a
Agroforestry		2.32	4.01	0.35 ab	35.60	2.23 ab	0.92 b	6.70 b	0.04	3.84	29.67	5.11 b
Shrub		1.87	3.23	0.28 ab	41.11	1.19 b	1.72 a	9.81 a	0.05	1.91	25.54	5.29 a
Crop		1.45	2.50	0.20 b	37.86	3.37 a	0.64 b	8.62 ab	0.01	2.90	32.78	5.00 b
Forest	50-100	2.99 a	5.17 a	0.31 a	47.29 a	1.59 b	1.15 ab	7.03 c	0.06 a	9.35 a	38.80 a	5.55 a
Agroforestry		1.88 ab	3.25 ab	0.28 b	35.55 b	2.24 ab	1.39 a	7.72 bc	0.03 ab	2.77 b	33.78 b	5.13 b
Shrub		0.97 b	1.68 b	0.25 c	41.21 ab	1.04 b	1.61 a	10.13 a	0.02 b	2.39 b	34.98 ab	5.29 ab
Crop		1.29 b	2.23 b	0.18 ab	37.60 b	2.79 a	0.35 b	9.04 ab	0.01 b	2.48 b	31.79 b	5.16 b

Remarks: OC = Organic Carbon, SOM = Soil Organic Matter, TN = Total N, AP = Available P, BS = Base Saturation, CEC = Cation Exchange (CEC), pH = soil acidity.

Plant litter is broken down through biochemical cycles or decomposition into various types of nutrients, one of which is total N (McCLAugherty et al., 1985; Marty et al., 2017). This was supported by the positive correlation of total N with the basal area, standing litter mass, and canopy cover ( $r = 0.691, 0.774, 0.761$ , respectively;  $p \leq 0.01$ ).

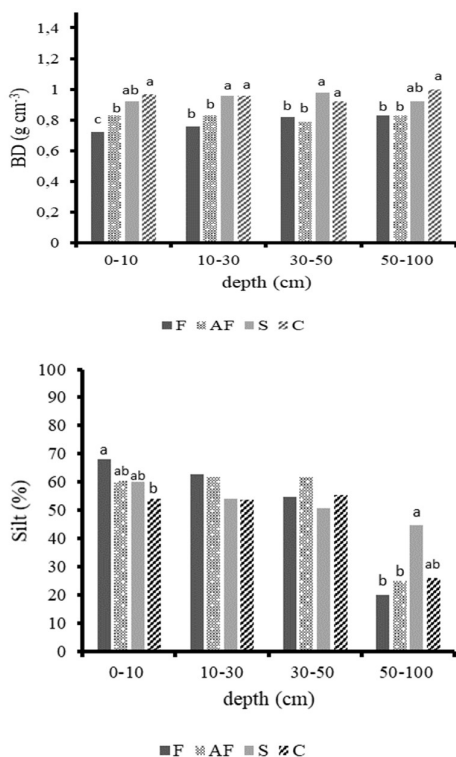


Figure 4. Characteristic of soil physics in various landuse. F = conservation forest, AF = agroforestry, S = shrub, C = crop.

Vegetation cover and soil management practices (i.e. fertilization, liming, soil tillage) play an important role on the variability of soil exchangeable base cations, base saturation (BS), and cation exchange capacity (CEC) at a depth of 0-10 cm. The high concentration of Ca and BS in the forest soil probably due to decomposition of litter from various vegetation released a high amount of Ca, resulted in an increase of BS; shown by the strongly positive correlation of soil exchangeable Ca with the basal area, standing litter mass, and canopy cover ( $r = 0.335, 0.46, 0.486$ ;  $p \leq 0.01$ ). In addition, vegetation cover is also controlled CEC through soil organic C that was resulted from litter decomposition. The increases of soil organic C will increase soil capacity to adsorb cations due to soil organic matter have a high surface area and surface negative charge. This

was supported by the positive correlation between soil organic C and CEC ( $r = 0.306, p \leq 0.05$ ). In comparison, fertilization and liming in agricultural lands (i.e. agroforestry and crop) controlled the concentration of soil exchangeable K and CEC. Statistical analysis showed that agroforestry and crop lands had comparable CEC with forest. This may relate to the result of previous research conducted by Ogundijo et al. (2014) who reported that fertilization (e.g., the combination of NPK 100-120 kg ha<sup>-1</sup> and manure 5-10 t ha<sup>-1</sup>) increase the base cation exchange rate (i.e., Na, Ca, Mg) in the topsoil. While in the deeper layer (50-100 cm depth), the weathering of the parent material is expected as a factor that influenced the higher concentration of Na and Mg in the forest than that of in the other land-uses. The previous research reported that the soil development in this study site might be influenced by the weathering of plagioclase minerals from Mount Anjasmoro with high contents of Ca and Na nutrients (Prasetyo et al., 2004; Purwanto et al. 2019). Another possibility is that the closed cycle in forests makes Na exchange, which is a mobile nutrient in forest land, can be caught by forest root nets so that leaching can be reduced (Weil and Brady, 2017).

Forests and shrub lands have a higher ( $p \leq 0.05$ ) soil pH than crops at a depth of 0-10 cm and 10-30 cm. This was probably caused by a closed cycle in the forest, which can produce nutrient input from organic matter so as to stabilize the soil pH (Dechert et al., 2004). The correlation test showed that soil pH strongly correlated to standing litter mas and canopy cover ( $r = 0.543$  and  $0.441$ ,  $p \leq 0.01$ ). In addition, the higher soil pH in the forest and shrub land is also expected due to the low base cations losses through harvest export and leaching (Kurniawan et al., 2018).

The decreases of BS in agricultural lands (i.e., agroforestry and crop) compared to the forest at 0-10 cm and 50-100 cm depth indicated the higher base cations leaching losses in the agricultural lands. Kurniawan et al. (2018) reported that fertilization (i.e. N, P, K) and liming in agricultural land (e.g. oil palm) increased base cations leaching losses in the loamy Ultisol. Besides, the vegetation in the agroforestry system and crop probably could not control the high nutrient losses through leaching, as rooting systems of the crops. Another research conducted by Dechert et al. (2004) showed a similar result with results of this study that soil exchangeable base concentration can decrease significantly years after land-use conversion.

Agroforestry system which is characterized by lower tree cover and input of fertilizers (organic and inorganic), has soil exchangeable K around 2 times greater than forest and crop lands at a depth

of 0- 10 cm. Conversion of forest to shrubs led to an increase in base cation leaching losses. This is indicated by the larger soil exchangeable K at a depth of 10-30 cm and 30-50 cm in shrub than that of in forest land (2.7 times and 2-9 times, respectively). Soil management such as application of chicken manure and inorganic fertilizers (SP-36) in crop land has an impact on the larger soil available P concentration (increased by 75-175%) as compared to available P in the forest at various

soil depths (0- 10, 10-30, 30-50, and 50-100 cm). In addition, cow manure increases the P content of 0.35 ppm in the soil (Hartatik et al., 2015; Lourenzi et al., 2014) and the addition of cow manure can increase P efficiency by 57% (Eckhardt et al., 2018). However, almost all indicators of soil fertility (especially nutrient content) in crop land are lower than forest; shown by the low level of organic C, total N, CEC, and soil pH at various depths in the crop when compared to forest.

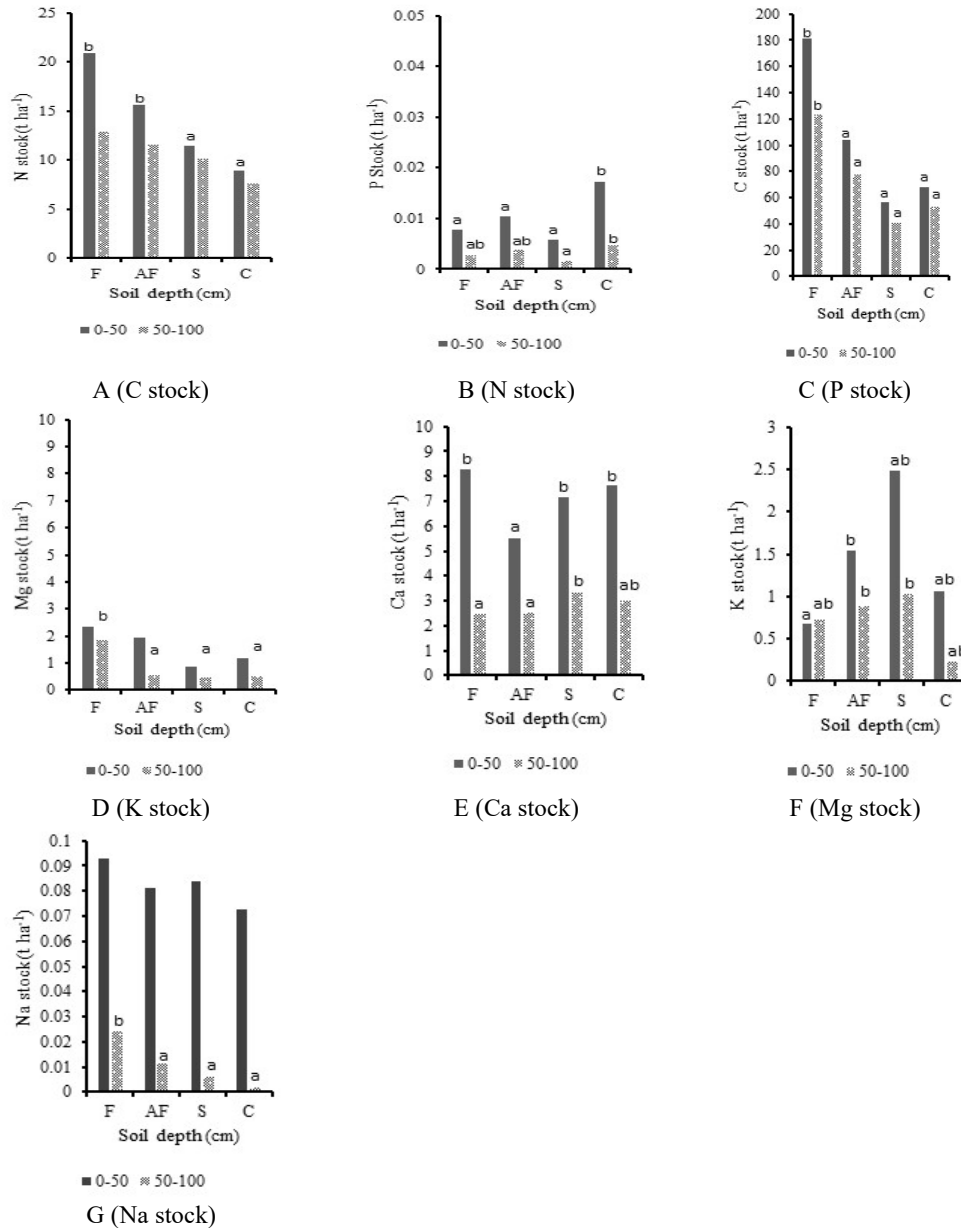


Figure 5. Comparison of nutrient stock at depth 0 F-50 cm and 50-100 cm. F = conservation forest, AF = agroforestry (AF), S = shrub, C = crop.

This is presumably because the loss of nutrients through harvesting, leaching, erosion, and volatilization in the crop is larger than the nutrient input through rain, organic and inorganic fertilization, and crop residues. Blinkova and Lavrov (2017) stated that non-woody plants have a high risk of nutrient leaching, erosion and runoff.

#### ***Effect of land-use change on the degradation of soil nutrient stock***

Nutrient elements in various land use in each soil depth are then converted into nutrient stock, where the value of a nutrient stock is an illustration of the amount of nutrients stored in the soil. Comparison of nutrient stock between land uses was conducted at a depth of 0-50 cm and 50-100 cm (Figure 5). At a depth of 0-50 cm, soil nutrient stock of C, N, K and Ca are very significantly different ( $P \leq 0.001$ ), and P significant different ( $P \leq 0.05$ ). Whereas in the deeper layer (depth 50-100 cm) soil nutrient stock of C, P, K, Na, Ca and Mg were significantly different ( $P < 0.05$ ; Figure 5). Forests had larger C and N stock than agroforestry, shrub and crop at 0-50 cm depth of soil due to the high vegetation cover. This was supported by strongly positive correlation of vegetation cover (i.e. canopy cover, basal area, standing litter mass) with soil C and N stocks ( $r = 0.63 - 0.78$ ;  $r$  table 0.01% = 0.39). Meanwhile, the highest P stock was found in crop and K within shrub land. At a depth of 50-100 cm, the forest has higher C stock than the three other land uses. However, the highest P stock was found in the crop land and K stock higher in shrub land.

This research showed that the largest stock of C and N was found in conservation forests with a depth of 0-50 cm. The value of C and N stocks reached  $180 \text{ t ha}^{-1}$  and  $21 \text{ t ha}^{-1}$ , whereas at a depth 0-10 cm the C and N stocks are around  $40.6 \text{ t ha}^{-1}$  and  $4.96 \text{ t ha}^{-1}$ , respectively. This is certainly in line with research conducted by Dechert et al. (2004) in the uplands of Central Sulawesi, which stated that the stock of C and N in the natural forest is greater than in other land uses. The value of C and N stock in the natural forest is around  $100 \text{ t ha}^{-1}$  at a depth of 0-10 and 30-40 cm. Besides that, Kurniawan et al. (2019) stated that protected areas in UB forest have a higher value of N stock ( $28.4 \text{ t ha}^{-1}$ ) compared to land use that combines mahogany, coffee, pine and crops. In addition, it was also explained that the N stock was higher at a depth of 0-50 cm compared to a depth of 50-100 cm due to the soil carbon and nitrogen is mainly accumulated in the topsoil. The low P stock in forest, agroforestry and shrub at a depth of 0-50 cm and 50-100 cm probably due to the type of soil in the study location are Andisols where the soil has high P retention. Many studies conducted in andic soils reported that the low available P in Andisols due to

P absorbed by organic materials that form humus Al and Fe complexes (Breemen and Buurman, 2003; Hashimoto et al., 2012). In addition, intensive fertilization (i.e. NPK, SP-36, chicken manure) in the crop land can increase the availability of P. The high C and N reserves in forest land, apart from being caused by input from organic matter, can also be caused by the type of Andisol which can store and absorb organic C (Anda and Dhalgren, 2020).

#### **Conclusion**

Soil fertility both chemical and physical properties of soil in the Kalikungkuk micro watershed is different among slope positions within unmanaged lands (forest and shrub) and four different land-uses (forest, agroforestry, shrub, and crop) in all slope positions. The depth of material deposition from a volcanic eruption is expected to control soil fertility among slope positions (ridge, sloped, valley). Vegetation cover is a factor determining degradation of soil function on nutrient stock, especially C and N. This study found the benefit of canopy cover, basal area, and standing litter mass in the forest, and fertilization in the crop for maintaining soil fertility level in the Kalikungkuk micro watershed of East Java, Indonesia.

#### **Acknowledgements**

The study was partly funded by PNPB research fund of the Faculty of Agriculture, Brawijaya University 2019 and 2020. The author would like to thank Perum Perhutani Divisi Regional Jawa Timur, Taman Hutam Raya R. Soerjo Jawa Timur, and the landowner for the permission to collect soil samples, Sri Padmini Wulandari and Wahyu Indrayanto for soil laboratory analysis.

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