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Research Article

Soil chemical properties in agroforestry and cassava cropping systems in Pati, Central Java

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Abstract

Changes in natural land use for monoculture cropping systems may affect the soil properties over a certain period of time. In an attempt to evaluate soil chemical properties in the cassava cropping system, the research was conducted in Pati Regency, Central Java. Four land use systems were compared, i.e. monoculture cassava (cultivated for 5, 10, and 15 years) and agroforestry systems in two different slopes (i.e., 8-15% and 16-40%), with four replications. Soil samples from each location were taken at a depth of 0-20 and 21-40 cm for soil chemical analysis (pH, cation exchange capacity, organic C, total N, available P, exchangeable K, Ca, and Mg). Soils in agroforestry systems had higher pH, CEC, the content of organic C, total N, exchangeable K, Ca and Mg than in cassava cropping systems, especially on the slope of 8-15%. The soil under 15 years cassava and on the slope of 16-40% had the most degraded soil chemical properties, as reflected by the lowest content of organic C, total N, exchangeable K, and slightly lower CEC and the content of exchangeable Ca and Mg. Soil chemical properties on the slopes of 8-15% were significantly better than on the slopes of 16-40%, especially in CEC and the content of organic C, total N, exchangeable K and Mg. However, there was an unclear pattern of the available P content, which was possibly due to the application of P fertilizer in cassava cropping systems.

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Introduction

Population increase at a rate of 1.49% per year requires an increase in the need for food (Mulyani et al., 2014), which so far still relies on food from rice and corn. The increasing need for food and limited land for crops lead to intensive land use change from forest to agriculture. Land use change affects the sustainability of agricultural systems because of degrading soil properties and decreasing soil fertility (Pinho et al., 2012; Willy et al., 2019). Cultivation practices with intensive tillage and continuous planting can accelerate the mineralization of soil organic matter and depletion of nutrients in the soil (Chen et al., 2019) so that the agricultural system becomes unsustainable. Effective management of soil fertility improves soil properties, including soil organic matter, and ensures the sustainability of soil functions which are very important in maintaining sustainable agricultural productivity (Mairura et al., 2022). Changes in different land use types can be measured by monitoring the soil organic C content, total N, and soil acidity (Recha et al., 2022). Land use change significantly affects the dynamics of total organic carbon (TOC) in such a way that the conversion of natural soils to agricultural land or grasslands affects C storage (Yang et al., 2012).

Pati Regency is well known for the central production of cassava in Central Java, which experienced rapid land use change from natural land use to a cassava cropping system. Cassava (*Manihot utilissima* Pohl.) is one of the food sources of carbohydrates and non-food raw materials for the food industry, chemical industry, medicine, and bio-energy (Roesmiati et al., 2018). Cassava is a food ingredient that has physiological and functional functions, containing the bioactive component of scopoletin to support physiological functions in the human body as an antioxidant, lowering blood pressure, cholesterol levels, and blood sugar levels, as well as a stimulant for calcium absorption (Herlina and Nuraeni, 2014). Cassava can grow well in areas having air temperature 22-28 ^{o}C, rainfall of 1000-2000 mm year^{-1}, good drainage, very low erosion rate, land slope less than 8%, crumb soil structure, soil solum deeper than 100 cm, base saturation higher than 20%, soil pH ranges from 5.2-7.0, and organic C content higher than 0.8% (Wijanarko and Purwanto, 2018).

Cassava productivity is generally low (< 30 t ha^{-1} wet weight) and lower than its potential production. The low productivity of cassava is caused by poor plant management, pest and disease infection, low inherent soil fertility, and low soil moisture (Kintche et al., 2017). Cassava cultivation is thought to be the cause of soil fertility degradation because cassava adsorbs greater nutrients in the soil which will impoverish the availability of nutrients in the soil (Ispandi, 2002; Howeler, 2008). Moreover, cassava is generally cultivated on dry land, which is generally poor in humus and nutrients (Ispandi, 2002), hence more fragile to soil degradation. Therefore, it is interesting to study whether soils with long periods of cassava cropping system have relatively poor chemical properties. As a comparison, the agroforestry system, which is known as an example of a sustainable agricultural system (Pinho et al., 2012), was also studied.

Materials and Methods

The research was conducted in Gembong District, Pati Regency, Central Java Province, which is one of the districts with the highest potential for cassava production. Gembong district was dominated by Inceptisols, which developed on volcanic parent material from Mount Muria. In this area, cassava is mostly cultivated on slopes of 8-15% and 16-40% (BPP Gembong, 2019). The study used survey methods to determine the research location and soil sampling sites. Extension workers, farmers and land owners were interviewed to have correct sampling sites. Cassava cultivation is still conventional and monoculture with a spacing of 1.2 m x 1.2 m. Fertilization was carried out twice (1 and 4 months after planting) at the rate of 217 kg N ha^{-1}, 31 kg P_2O_5 ha^{-1}, and 31 kg K_2O ha^{-1}. Four systems were studied, i.e. agroforestry, monoculture cassava with three different periods of cultivation (5, 10 and 15 years), on two different slopes, namely 8-15% (Slope 1) and 16-40% (Slope 2). Each observation site was replicated four times, totalling 32 sites. The observation site is presented in Table 1 and Figure 1.

Soil samples in each observation plot (20 m x 20 m) were taken at five points diagonally. Soil samples were taken at two different depths (0-20 cm and 21-40 cm). The soil samples were air-dried, mashed, sieved through a 2 mm sieve, and made into composites. Soil samples were analyzed for measuring soil pH-H_2O and pH-KCl (1:2.5, electrode method), cation exchange capacity (NH_4OAc saturation method pH 7), the content of soil organic C (spectrophotometry method), total N (Kjeldahl method), available P (Bray 1 method), exchangeable K, Ca, Mg (NH_4OAc saturation method pH 7), based on Eviati and Sulaeman (2012).

The collected data were analyzed statistically using the open-source program. Analysis of variance was used for the significant difference from the model and continued with the analysis of Tukey's HSD (honestly significant difference) test at a significant level of 5% to determine the significant difference among treatments.

Table 1. Observation plots and location for sampling site.

Land use	Slope 1 (8-15%)	Latitude	Longitude
Agroforestry	P1L1	6^{0}42'12.24"S	110^{0}59'37.32"E
Cassava monoculture for 5 years	P2L1	6^{0}42'46.05"S	110^{0}59'42.08"E
Cassava monoculture for 10 years	P3L1	6^{0}43'1.04"S	110^{0}59'25.12"E
Cassava monoculture for 15 years	P4L1	6^{0}42'1.14"S	110^{0}59'2.34"E
	Slope 2 (16-40%)		
Agroforestry	P1L1	6^{0}40'50.02"S	110^{0}56'5.51"E
Cassava monoculture for 5 years	P2L1	6^{0}41'12.34"S	110^{0}56'5.96"E
Cassava monoculture for 10 years	P3L1	6^{0}41'18.00"S	110^{0}56'11.14"E
Cassava monoculture for 15 years	P4L1	6^{0}41'21.45"S	110^{0}56'48.02"E

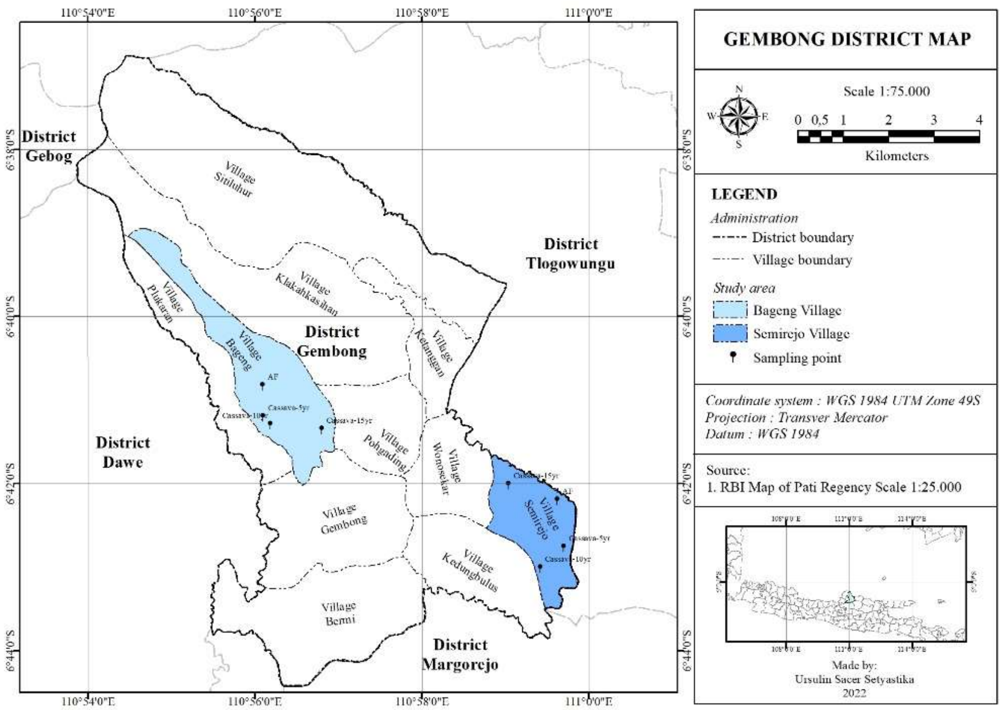

Figure 1. Research locations in agroforestry and cassava cropping systems in Pati regency, Central Java.

Results and Discussion

Soil pH and cation exchange capacity

The land use system significantly affected the actual acidity of the soil (pH-H_2O) both at a depth of 0-20 cm and 21-40 cm ($p < 0.05$), while slope and its interaction with land use had no significant effect (Table 2). The actual acidity refers to the amount of free H^+ concentration in the soil solution. The pH-H_2O values ranged from 4.2-4.9 and were categorized as very acidic (pH-H_2O<4.5) and acidic (pH-H_2O 4.5-5.5) (Eviati and Sulaeman, 2012). The soil pH-H_2O in agroforestry was higher than in cassava cultivation for 5, 10, and 15 years. Continuous cultivation of seasonal crops leads to the acidification of soils (Tanimu et al., 2013). Both land use and slope significantly affected the potential soil acidity (pH-KCl) at both soil depths with $p < 0.05$, while the significant interaction was only shown at a depth of 0-20 cm ($p < 0.01$) (Table 2). Potential acidity indicates the amount of H^+ adsorbed on the surface of the adsorption complex in the soil. The potential acidity of the soil ranges from pH-KCl 3.9-4.5. The pH-KCl on a slope of 8-15% was significantly higher than on a slope of 16-40%. The soil pH-KCl in agroforestry was higher than in cassava based systems.

Table 2. Soil pH at different land use and slopes in the study area.

Land use	Slope (%)	pH-H_2O		pH-KCl	
		0-20 cm	21-40 cm	0-20 cm	21-40 cm
P1 = Agroforestry	L1 = 8-15%	4.8 a	4.9 a	4.3 ab	4.2 a
P2 = Cassava for 5 years		4.4 ab	4.3 b	3.9 c	3.9 b
P3 = Cassava for 10 years		4.4 ab	4.5 b	3.9 c	3.9 b
P4 = Cassava for 15 years		4.4 ab	4.3 b	3.9 c	3.9 b
P1 = Agroforestry	L2 = 16-40%	4.7 a	4.8 a	4.3 a	4.5 a
P2 = Cassava for 5 years		4.2 b	4.3 b	4.0 bc	4.1 ab
P3 = Cassava for 10 years		4.4 ab	4.6 ab	4.1 abc	4.2 a
P4 = Cassava for 15 years		4.7 ab	4.7 ab	4.3 a	4.3 a
P		**	**	**	**
L		ns	ns	**	**
P x L		ns	ns	*	ns

Notes: mean in the same column followed by the same letter is not significantly different at Tukey 5%, * = significant at p<0.05, ** = significant at p< 0.01, ns = not significant.

The cation exchange capacity of the study soils is generally low, with a range of 5-16 cmol kg^{-1} (Eviati and Sulaeman, 2012). The low CEC may be attributed to low clay and humus content as well as low pH value (Munawar, 2011; Okorie et al., 2022). Many researchers have observed that the CEC of tropical soils is related to their organic matter content (Okorie et al., 2022). Table 3 shows that land use, slope, and their interactions significantly affect the cation exchange capacity at a soil depth of 21-40 cm, while at a depth of 0-20 cm only slope has a significant effect ($p< 0.05$).

Soil CEC on slopes of 8-15% is significantly higher than on slopes of 16-40%. The soil under cassava for a longer period has a lower CEC, especially on slopes of 8-15%.

Table 3. Cation exchange capacity of the soils at different land use and slopes in the study area.

Land use	Slope (%)	Cation exchange capacity (cmol kg^{-1}) 0-20 cm	21-40 cm
P1 = Agroforestry	L1 = 8-15%	14.53 a	14.77 ab
P2 = Cassava for 5 years		16.59 a	17.25 a
P3 = Cassava for 10 years		12.63 ab	13.28 abc
P4 = Cassava for 15 years		12.08 ab	9.69 cd
P1 = Agroforestry	L2 = 16-40%	8.63 b	8.62 d
P2 = Cassava 5 years		10.19 b	10.17 cd
P3 = Cassava 10 years		10.34 b	11.74 bcd
P4 = Cassava 15 years		10.28 b	11.36 bcd
P		ns	*
L		**	**
P x L		ns	**

Notes: mean in the same column followed by the same letter is not significantly different at Tukey 5%, * = significant at p<0.05, ** = significant at p<0.01, ns = not significant.

Nutrient content in the soil

Table 4 shows that land use, slope, and their interaction significantly affect the organic C content in the soil at two soil depths, except for slopes which are not significantly different at a depth of 0-20 cm. Soil organic C content is generally less than 1%, categorized as very low (Evati and Sulaeman, 2012). Organic C content in the soil layer of 0-20 cm is generally higher than in the layer of 21-40 cm. Organic C content on slopes of 8-15% tends to be higher than on slopes of 16-40%. Loss of organic matter can occur due to the degradation process through soil erosion, where surface runoff water carries soil erosion from the top and accumulates at the bottom. As a result, organic matter and nutrients accumulate at lower slopes (Wubie and Assen, 2020).

Organic C content was relatively high in agroforestry, although it was not significantly different from 5-year cassava, especially in the soil layer of 0-20 cm. The organic C content was lowest in 15 years cassava system (Table 4), especially in the slope of 16-40%. Before planting cassava, farmers generally mechanically till the soils using tractors. The loss of organic matter mainly occurs through continuous annually cropping with removing stubble, biomass, or burning and is accelerated by frequent tillage. Loss of SOC and nutrients is due to intensive tillage to establish annual crops (Chen et al., 2019). In cassava cropping systems, nutrients are removed over time through harvested products (roots) and the removal of soil during the harvesting of cassava. Off-site losses of nutrients can also occur through soil erosion, runoff, leaching and burning of crop residues. Reduced-tillage increases crop production and profitability by minimizing soil disturbance, improving soil quality, and creating a more consistent soil environment for microbial growth and activity (Chen et al., 2019). Land use did not affect the total N content at depths of 0-20 cm and 21-40 cm, while the slope and its interaction with land use had significant effects with $p<0.05$ and $p < 0.01$, respectively (Table 4). The total N content in the 0-20 cm soil layer is generally higher than in the 21-40 cm layer. The total N content at 8-15% slopes is in the range of 0.21-0.50%, while on slopes of 16-40% is significantly lower (0.10-0.20%), categorized respectively as moderate and low (Eviati and Sulaeman, 2012). Poor soil management practices and the nature of tropical soils account for heavy nutrient losses through soil erosion and nutrient leaching (Okorie et al., 2022). Agroforestry contained a higher total N than cassava cultivation. The contents of organic matter and total nitrogen (N) of the soil could decline due to deforestation and continuous cultivation (Wubie and Assen, 2020). The results showed that the total N content in the 10 or 15 years of cassava cultivation was lower than in 5 years of cassava, indicating that continuous cultivation of cassava tends to decrease total N (Table 4). The intensification of the cropping system depleted organic matter and total N in the soil (Tanimu et al., 2013). This could be due to soil nitrogen removal during cassava harvesting, which amounted to 1.51 kg N ha^{-1} $harvest^{-1}$ (Sumithra et al., 2013) to 1.71 kg N ha^{-1} $harvest^{-1}$ (Isabirye et al., 2007).

Table 4. Soil organic C and total N content at different land use and slopes in the study area.

Land use	Slope (%)	Organic C (%)		Total N (%)	
		0-20 cm	21-40 cm	0-20 cm	21-40 cm
P1 = Agroforestry	L1 = 8-15%	0.86 a	0.71 a	0.35 a	0.27 a
P2 = Cassava for 5 years		0.78 ab	0.68 a	0.28 ab	0.26 ab
P3 = Cassava for 10 years		0.65 bc	0.59 ab	0.20 b	0.15 abc
P4 = Cassava for 15 years		0.62 bc	0.57 ab	0.28 ab	0.27 ab
P1 = Agroforestry	L2 = 16-40%	0.66 abc	0.44 bc	0.18 b	0.14 bc
P2 = Cassava for 5 years		0.86 a	0.66 a	0.21 b	0.17 abc
P3 = Cassava for 10 years		0.82 ab	0.58 ab	0.20 b	0.17 abc
P4 = Cassava for 15 years		0.51 c	0.36 c	0.16 b	0.12 c
P		**	**	ns	ns
L		ns	**	**	**
P x L		**	*	*	*

Notes: mean in the same column followed by the same letter is not significantly different at Tukey 5%, * = significant at p<0.05, ** = significant at p<0.01, ns = not significant.

Table 5 shows that the significant effect on the availability of P extracted from Bray 1 was only shown by land use, slope, and interactions at a depth of 21-40 cm. The available P content at a slope of 8-15% is categorized as moderate, but at a slope of 16-40%, it is high, with the range of 11-15% (Eviati and Sulaeman, 2012). The high level of available phosphorus may be attributed to intensive P fertilization (Okorie et al., 2022). In an agroforestry system, usually, no additional fertilizer is applied. The fertilization is provided from pruning and litter that fall to the soil surface. However, inorganic fertilizer may also be applied in some agroforestry (Norrlin et al., 2020); for example, in coffee agroforestry in Kpe´le´-Amou districts, Southwestern Togo, 400 kg ha^{-1} of NPK fertilizer was applied every three years (Dossa et al., 2008). At a depth of 21-40 cm, the available P content in cassava for five years was higher than in cassava for 10 and 15 years. Continuous cropping accompanied by frequent tillage causes the loss of some nutrients, including phosphorus; this is exacerbated by the transport of plant biomass from the land (Wubie and Assen, 2020).

The exchangeable K content at both 0-20 cm and 21-40 cm depth was significantly affected by land use, slope, and their interaction with $p < 0.05$ (Table 5). Fitria et al. (2021) also reported that land use systems and slope positions affected soil exchangeable K content within 0-100 cm soil depth. The exchangeable K content on 8-15% slopes is significantly higher than on 16-40% slopes. Compared to cassava cropping systems, agroforestry contains the highest content of exchangeable K (0.61 cmol kg^{-1}), classified as high (Eviati and Sulaeman, 2012). Volcanic materials from Mount Muria are rich in potassium-sourced silicate minerals such as leucite, muscovite, and orthoclase. The mineral leucite can be used as raw material for potassium fertilizer because it contains K_2O ranging from 7.68-7.98% (Agung et al., 2019). However, a long period under cassava cultivation reduces the exchangeable K content, especially on slopes of 8-15%. Land use and slope only had a significant effect on exchangeable Ca content at a depth of 21-40 cm, where the interaction between the two had no significant effect (Table 6).

Table 5. Available P and exchangeable K content in the soil at different land use and slopes in the study area.

Land use	Slope (%)	Available P (ppm)		Exchangeable K (cmol kg^{-1})	
		0-20 cm	21-40 cm	0-20 cm	21-40 cm
P1 = Agroforestry	L1 = 8-15%	7.49 a	7.43 ab	0.59 a	0.61 a
P2 = Cassava for 5 years		14.10 a	16.15 a	0.46 ab	0.56 a
P3 = Cassava for 10 years		4.49 a	1.54 b	0.58 a	0.57 a
P4 = Cassava for 15 years		9.58 a	9.71 ab	0.20 c	0.24 b
P1 = Agroforestry	L2 = 16-40%	13.11 a	16.78 a	0.26 bc	0.25 b
P2 = Cassava for 5 years		12.74 a	11.54 ab	0.21 c	0.20 b
P3 = Cassava for 10 years		10.01 a	10.45 ab	0.22 c	0.23 b
P4 = Cassava for 15 years		11.38 a	11.50 ab	0.23 bc	0.24 b
P		ns	*	**	**
L		ns	*	**	**
P x L		ns	*	**	**

Notes: mean in the same column followed by the same letter is not significantly different at Tukey 5%, * = significant at p<0.05, ** = significant at p<0.01, ns = not significant.

Table 3. Exchangeable Ca and Mg contents in the soil at different land use and slopes in the study area.

Land use	Slope (%)	Exchangeable Ca ($cmol\ kg^{-1}$)		Exchangeable Mg ($cmol\ kg^{-1}$)	
		0-20 cm	21-40 cm	0-20 cm	21-40 cm
P1 = Agroforestry	L1 = 8-15%	5.23 a	5.89 a	1.09 a	1.25 a
P2 = Cassava for 5 years		3.50 a	3.01 b	0.90 a	0.80 ab
P3 = Cassava for 10 years		3.84 a	3.40 b	0.99 a	1.05 ab
P4 = Cassava for 15 years		4.16 a	3.52 b	0.92 a	0.96 ab
P1 = Agroforestry	L2 = 16-40%	4.72 a	5.72 a	0.99 a	0.89 ab
P2 = Cassava 5 years		4.14 a	3.57 b	0.89 a	0.83 ab
P3 = Cassava 10 years		4.58 a	4.97 ab	0.70 a	0.71 b
P4 = Cassava 15 years		4.14 a	4.72 ab	0.73 a	0.78 b
P		ns	**	ns	ns
L		ns	**	ns	*
P x L		ns	ns	ns	ns

Notes: mean in the same column followed by the same letter is not significantly different at Tukey 5%, * = significant at $p<0.05$, ** = significant at $p<0.01$, ns = not significant.

In general, the exchangeable Ca content in the soils is in the range of 2-5 $cmol\ kg^{-1}$ or low. The exchangeable Ca content at 8-15% slopes is relatively lower than at 16-40% slopes. Agroforestry contains higher exchangeable Ca than cassava cultivation. The exchangeable Mg content was only significantly affected by the difference in slope ($p<0.01$), especially at a depth of 21-40 cm (Table 6). The content of Mg exchangeable in the soils is low, with a range of 0.40-1.00 $cmol\ kg^{-1}$. In contrast to the exchangeable Ca content, the content of exchangeable Mg at 8-15% slopes is significantly higher than at 16-40% slopes. In sloping areas, nutrient losses, including magnesium in eroded sediment and runoff, can be substantial (Howeler, 2002).

Conclusion

Agroforestry systems tend to have better soil chemical properties than cassava cropping systems, reflecting that agroforestry is more sustainable. Soils in agroforestry systems had higher pH, CEC, the content of organic C, total N, exchangeable K, Ca and Mg than in cassava cropping systems, especially on the slope of 8-15%. The soil under 15 years cassava and on the slope of 16-40% had the most degraded soil chemical properties, as reflected by the lowest content of organic C, total N, exchangeable K, and slightly lower CEC and the content of exchangeable Ca and Mg. Soil chemical properties on the slopes of 8-15% were significantly better than on the slopes of 16-40%, especially in CEC and the content of organic C, total N, exchangeable K and Mg. These results could be related to higher removal of the nutrient by leaching, erosion or biomass harvesting and a lesser nutrient returning to the soil in cassava cropping systems compared to agroforestry systems. However, there was an unclear pattern of the available P content, which was possibly due to the application of P fertilizer in cassava cropping systems.

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