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Effect of Coffee Ages and Shade Types on Soil Moisture and Soil N, P, K Availability in UB Forest

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ABSTRACT

Water and nutrients is important for plant which has its characteristics. This study has been carried out in the UB (Brawijaya University) forest about soil moisture content during rainy and dry seasons, Total-N, -P, -K from litter on different types of shade and age of coffee plants, and their effect on soil Available-N, -P, and -K. There are P1 (control), P2 (4-year-coffee + pine), P3 (7-year-coffee + pine), P4 (4-year-coffee + mahogany), and P5 (7-year-coffee + mahogany). These treatments affected to total soil moisture storage, Total-N, -P, -K of litter, and Available-N, -P, -K in the soil. The soil moisture storage change between rainy and dry seasons was 36.97 mm. The highest Total-N, -P, and -K of litter was 11.00 kg ha^{-1} y^{-1} at P3, 1.06 kg ha^{-1} y^{-1} at P2, and 4.35 kg ha^{-1} y^{-1} at P3, which was inconsistently associated with high soil nutrients. The highest Total-N was 0.40 (0-20 cm), 0.27 (20-40 cm), 0.30% (40-60 cm) at P4, Available-K was 1.69 (0-20 cm), 1.64 (20-40 cm), 1.87 cmol kg^{-1} (40-60 cm) at P5, and Available-P was 15.21 (0-20 cm), 14.06 (20-40 cm), 12.64 mg kg-1 (40-60 cm) at P1.

Keywords: Coffee, coffee shade, litter, soil moisture content, soil nutrient contribution

INTRODUCTION

Coffee (*Coffea* spp.) is one of the leading commodities in Indonesia, which has high economic value in the national economy. UB forest is an agroforestry coffee area in Karangploso District, Malang Regency. According to Nesper et al. (2019), agroforestry systems can become habitats for biodiversity because many components can be combined. The agroforestry system combines agricultural and forestry crops to become an alternative for the community to provide benefits both in the short term (agricultural products such as coffee beans) and long term (tree crops such as wood). According to Munashiroh and Santoso, (2020), Karangploso District is one of the leading areas for coffee commodities, and Malang Regency is the third largest coffee-producing area in East Java. On the other hand, demand for coffee exports, especially in Malang Regency, has increased by about 11% from 59.10 tons in 2017 to 66.29 tons in 2018. However, it needs to be followed by increasing coffee productivity in this area to fulfill the export demand (Munashiroh and Santoso, 2020).

Water and nutrients are important factors affecting the growth and production of coffee. Nutrients consist of macronutrients and micronutrients. N, P, and K are groups of essential macronutrients. Water is a solvent for nutrients and helps plants' metabolic process, while nutrients are needed as a source of energy to achieve normal plant growth (Yadessa et al., 2019). The existence of soil water in sufficient quantities is an absolute requirement for plants, while the water sources in the UB forest only rely on rainfall to supply the water for plants. It is worrying when there is uncertain climate change and abundant water availability during the rainy season. However, the water plants can use is limited during the dry season. Climate change causes fluctuations in water supplies. According to Haditiya and Prijono, (2018), an increase in temperature of 2-6^{o} increases the water needs of plants by 5-15%, so water stress occurs, especially during the dry season.

A land use change in the UB forest changed the structure and components of plants. Initially, the UB forest was a forest converted into mostly coffee-based agroforestry. The plant diversity is dominated by coffee with pine or mahogany shade, and the coffee age is 3-12 years. Shade plants in coffee agroforestry systems are essential, especially if the land conditions are sub-optimal (Munroe, 2013). Each plant has its characteristics, which will create different growing environmental conditions. The growth of wide and dense canopy increases the percentage of land cover, so the flow of rainfall to the ground becomes more complicated. It must pass through stem flow, escape the canopy, be intercepted, reach the soil surface, and finally be infiltrated. The risk of water loss can be minimized because more water will infiltrate, and there is less chance of runoff or evapotranspiration. Each plant produces various litter as an organic matter which is different in quantity and quality. Organic material as an adhesive can increase water-holding capacity.

One source of nutrients comes from plant litter. Litters have a complex function in improving soil’s physical, chemical, and biological properties. Nesper et al. (2019) stated that the diversity of plants in the agroforestry system affects the nutrient cycle of macro and micronutrients. Jacob et al. (2020) added that the diversity of litter can affect the faster decomposition process to accelerate soil nutrient availability. Each plant has its characteristics, so that it will have a different effect. A high-quality litter with low lignin and polyphenol criteria is generally easy to decompose and quickly provides nutrients (Rahmadaniarti and Mofu, 2020). The availability of nutrients must be able to support the needs of plants. Otherwise, the plants cannot grow and produce optimally. Based on the role of water and nutrient availability, studying the effect of the combination of coffee ages and shade types in UB forests is crucial.

The purposes of the study were to determine the effect of the combination of coffee ages and shade types on (1) soil moisture content during the rainy season and dry season, (2) the Total-N, -P, and -K of litter contribution, and (3) the soil availability of N, P, and K in UB Forest. It can be a guideline and reference in carrying out agricultural practices, especially in UB Forest.

MATERIALS AND METHODS

Study area

The study was located in UB Forest, precisely in Tumpangrejo, Ngenep Village, Karangploso District, Malang Regency (112°36’00”– 112° 37’00”E and 7°49’00”– 7°51’30”S). Sampling was carried out during the rainy season (February-April) and dry season (May-July), based on climate determinations by Schmidt-Ferguson. The highest rainfall in the rainy season was 359.97 mm (February), and the lowest in the dry season was 21.52 mm (September). The research was carried out by observing and continued with laboratory analysis at The Soil Physics and Chemistry Laboratory, Department of Soil Sciences, Faculty of Agriculture, Brawijaya University. There were five plots (20 m × 20 m) based on the type of shade and age of the dominant plants: P1 (control), P2 (4-year-coffee + pine), P3 (7-year-coffee + pine), P4 (4-year-coffee + mahogany), P5 (7-year-coffee + mahogany). The percentage of canopy cover was 76.61 (P1), 64.86 (P2), 63.76 (P3), 70.22 (P4), and 82.76% (P5).

Soil moisture

Soil moisture samples were analyzed by gravimetric method. Disturbed soil for soil moisture samples was taken using a drill every 20 cm depth interval (0-20, 20-40, 40-60 cm) with three replications (Figure 1). There were 12 periods of soil moisture sampling, including the rainy season (6 periods) and dry season (6 periods) every two weeks. In a period, 45 soil moisture samples were taken in all plots.

Total-N, -P, and -K of litter contribution

Kjeldahl analyzed total N, while total P and K were analyzed by HNO_3 + $HClO_4$. The measurement method of litter nutrient contribution refers to Evizal et al., (2008); total litter, N, P, and K samples, were taken from the fallen litter on parents as litter traps (1 m × 2 m). Litter samples were taken compositely in 4 replicates from 4 litter traps

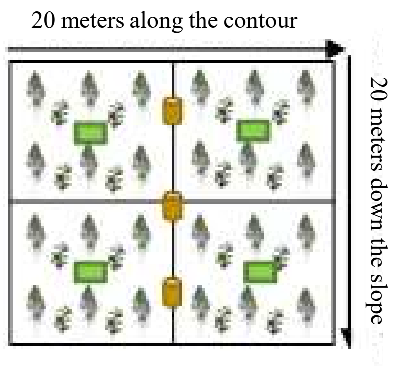

Figure 1. Research plot design (20 m × 20 m). : soil sample, : litter sample.

in each plot (Figure 1). The litter sampling period was once at the beginning of the observation, so 20 samples were analyzed.

Total of litter contribution (kg ha^{-1} Mg h^{-1}) = % nutrient content × litter biomass production per year

N, P, and K Availability in soil

Total N was analyzed by Kjeldahl, Bray 1 for available P, and NH_4OAc 1 N pH 7 for available K. Soil N, P, and K samples were taken every 20 cm interval (0-20, 20-40, 40-60 cm) with three replications (Figure 1). The period of taking soil nutrients twice at the beginning (45 samples) and the end of the research (45 samples) to determine the effect of changes in soil nutrient availability due to treatment.

The data was analyzed using a t-test to determine the difference in soil moisture content between the rainy and dry seasons. Analysis of variance was to determine the effect of treatment on the total soil moisture storage, N, P, and K of litter, and available N, P, and K in the soil. If found a significant difference, then a further LSD 5% test was carried out.

RESULTS AND DISCUSSION

Soil characteristics of the study area

The soil texture is dominated by silty loam and silty clay loam because the soil at the study site developed from volcanic material from Arjuna Mount. With increasing soil depth, micropores increased to >50% (53.76%). Shan et al. (2019) stated that bulk density is related to porosity, organic matter, and soil moisture. According to Chaudhari et al. (2013), bulk density has a strong negative correlation with organic matter (r = -0.89). The presence of trees can maintain organic matter in the soil (Petit-Aldana et al., 2019). The highest organic matter was 3.74%, found in P5 (7-year coffee + mahogany) at 0-20 cm, and the organic matter tends to decrease with increasing soil depth. A soil pH was between 5.0-6.2, classified as moderately acid to acid.

Soil moisture in the rainy and dry seasons

The results of the analysis of variance showed that agroforestry systems with different types of shade and ages of coffee plants had a significant (P<0,05) effect on total soil moisture storage in the rainy and dry seasons. Rainfall is one of the determinants of plant water availability (Manurung et al., 2015). Generally, the highest soil moisture was found in P5 (7-year coffee + mahogany) with a broad and dense crown (82.76%), and the soil surface was covered with litter. The older the plant, the better the hydrological conditions of the soil are (Padmayani et al., 2017). Plant canopy strata can control and reduce the amount of kinetic energy from rainwater to reach the soil surface. Soil moisture content respectively from 0-20, 20-40, and 40-60 cm were 0.56, 0.58, and 0.59 cm^{3}cm^{-3} (rainy season) and 0.50, 0.52, and 0.51 cm^3.cm^{-3} (dry season) (Figure 2). Soil moisture content in the Sumbermajing Wetan community coffee plantation, Malang Regency, also reported that soil moisture content is higher in the rainy season than in the dry season, with an overall value of 0.35-0.45 cm^3 cm^{-3} and 0.25-0.40 cm^3 cm^{-3} (Saraswati et al., 2022). Soil moisture content increases with increasing soil depth in the research location. The deeper the soil, the more water is stored. Soil characteristic conditions support

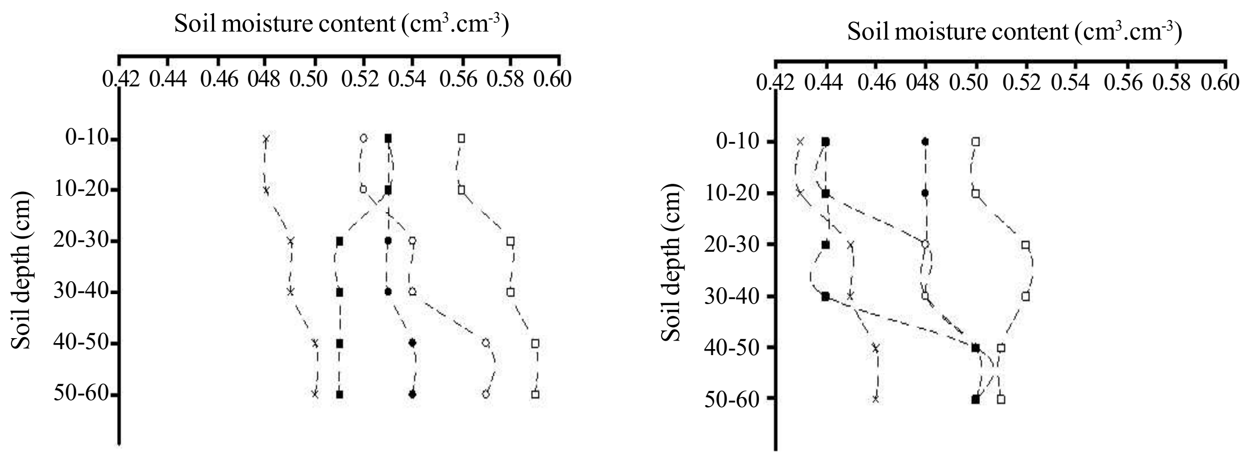

Figure 2. Soil moisture content in research location: (a) rainy season, (b) dry season. P1: —— —✶ ——, P2: —— —● ——, P3: —— —■ ——, P4: —— —○ ——, P5: —— —□ —— .

Table 1. Soil water balance at the research.

Plots	Rainy Season		Dry Season		ΔS (mm)
	P (mm)	S (mm)	P (mm)	S (mm)	
P1	1055.80	292.17 c	403.10	264.82 b	27.35
P2		319.25 a		290.70 a	28.55
P3		313.06 b		268.12 b	44.94
P4		319.88 a		276.27 b	43.61
P5		343.57 a		306.60 a	36.97

Note: P1= control, P2= 4 years coffee + pine, P3= 7 years coffee + pine, P4= 4 years coffee + mahogany, P5= 7 years coffee + mahogany; P= Total rain (mm), S= Total soil moisture storage (mm); ÄS = Total change in soil moisture storage; Numbers followed by the same letter in the same column are not significantly different at LSD 5%.

retaining water in the soil. At a 0-30 cm depth, soil moisture content decreased due to increased evaporation but gradually increased with depth starting at 40 cm to 100 cm (Saputri et al., 2021).

The highest total soil moisture storage in the research location was 343.57 mm (rainy season) at P5 (7-year-coffee + mahogany), which was not significantly different between P4 (4-year-coffee + mahogany) and P2 (4-year-coffee + pine). However, it significantly differed from P1 (control) and P3 (7-year coffee + pine). The highest total soil moisture storage was 306.60 mm (dry season) at P5 (7-year-coffee + mahogany), which was not significantly different from P2 (4-year-coffee + pine) but significantly different from P1 (control), P3 (7-year-coffee + pine), and P4 (4-year-coffee + mahogany). The total change in soil moisture storage from the rainy season to the dry season (ÄS) at P5 was 36.97 mm, but the highest change in total soil moisture storage (ÄS) reached 44.94 mm at P3 (Table 1). Plants have become a factor affecting soil moisture (Malik and Shukla, 2018). The tree characteristics, especially the crown, and roots, affect the distribution of water and nutrients (Murniati, 2009). The amount of water that can be retained in the soil is more, and the loss of nutrients will be reduced due to the nature of the nutrients that are easily dissolved in water (Satibi et al., 2019). The infiltration rate increased when an alley cropping system was applied compared to monoculture, and the maximum infiltration rate could be achieved when the amount of rainwater was high so that the water could be utilized by plants later when the rain began to decrease or be limited (Wang et al., 2015).

Total-N, -P, and -K of litter contribution

One source of nutrients comes from the litter of plants. The agroforestry systems with different types of shade and ages of coffee plants significantly affected litter total-N, -P, and –K ($P<0,05$). Combining the coffee litter and the plant shade support the litter's nutrient content. The difference in litter type and amount in agroforestry systems with various shades in UB forest affect the amount of nutrient content (Putri et al., 2019). Table 2 shows the highest Total-N, -P, -K was found in coffee with pine shade. Total-N was 11.00 kg ha^{-1} h^{-1} at P3 (7-year coffee + pine) was significantly different from all plots. Total-P was 1.06 kg ha^{-1} Mg h^{-1} at P2 (4-year coffee + pine) was not significantly different from P3 (7-year coffee + pine) but different with another plot. Total-K was 4.35 kg ha^{-1} Mg h^{-1} at P3 (coffee 7 years + pine) was significantly different with all plots.

Litter contribution to soil Available-N, -P, and -K

The types of shade and age of coffee plants had a significant effect on the availability of soil nutrients ($P<0,05$). One of the roles of litter is as a source of organic matter that can contribute to nutrient availability. This study, however, showed that the high litter nutrient content did not consistently contribute to the high input of nutrients to the soil.

Figure 3 shows that the total N, in general, was found in coffee with a mahogany shade. Total N at the end of the research was 0.40% (medium) in P4 at 0-20 cm depth, significantly different from all treatments. Total-N was 0.34% (medium) in P5 at 20-40 cm depth which was not significantly different from P1 but significantly different from P2, P3, and P4. Total-N was 0.30% in P4 at 40-60 cm depth which was not significantly different from P5 but significantly different from P1, P2, and P3.

Figure 4 shows that available-P at the end of research in the dry season was found in P1 except

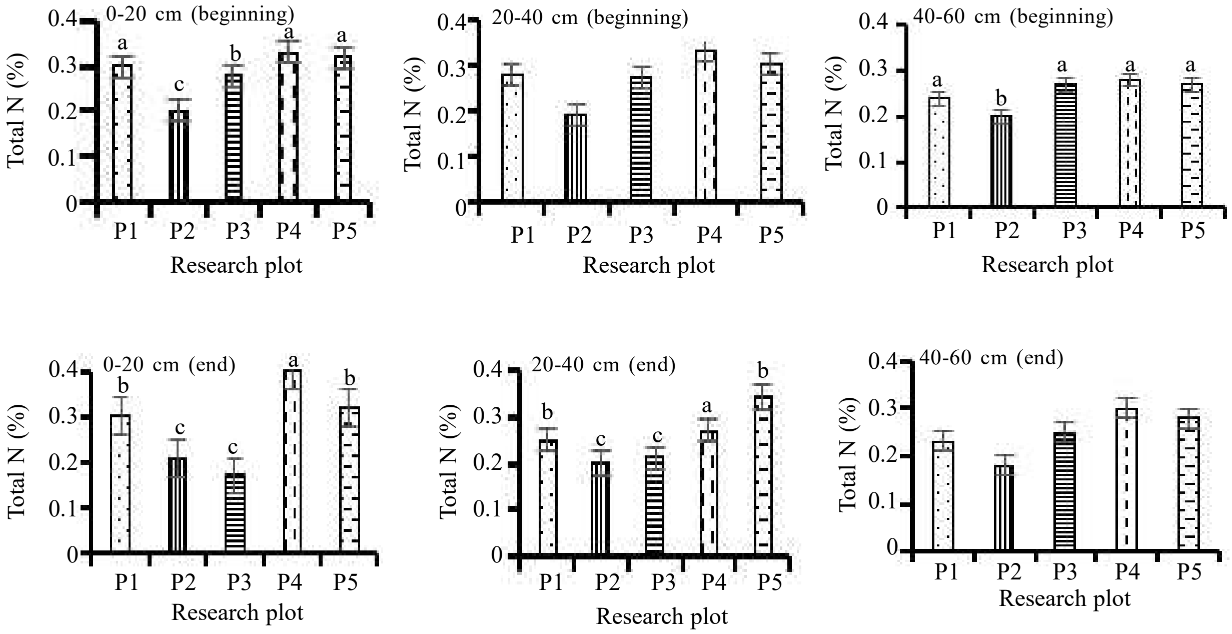

Figure 3. Soil Total-N in the research location. P1= Control, P2= 4 years coffee + pine, P3= 7 years coffee + pine, P4= 4 years coffee + mahogany, P5= 7 years coffee + mahogany; Numbers followed by the same show results that are not significantly different in LSD 5%.

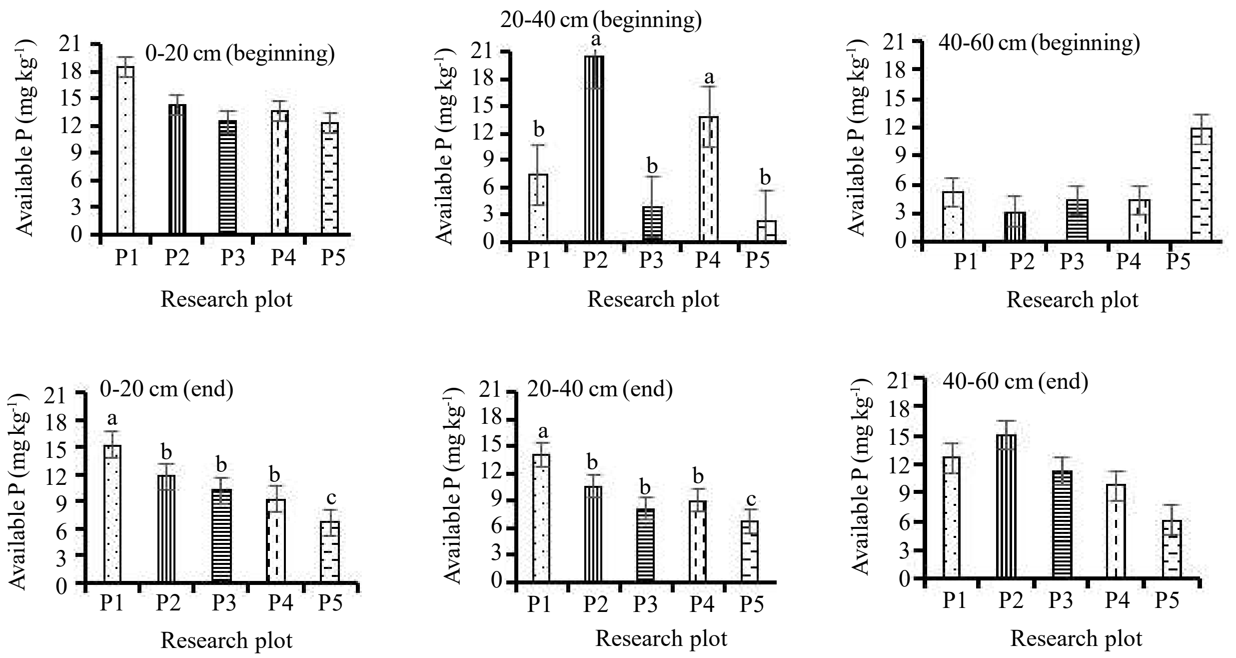

Figure 4. Soil available-P in the research location. P1= Control, P2= 4 years coffee + pine, P3= 7 years coffee + pine, P4= 4 years coffee + mahogany, P5= 7 years coffee + mahogany; Numbers followed by the same show results that are not significantly different in LSD 5%.

at 40-60 cm depth, which was 15.21 mg kg^{-1} (very high) at 0-20 cm depth, 14.06 mg kg^{-1} (very high) at 20-40 cm depth which was significantly different from all treatments. Available-P was 14,98 mg kg^{-1} (very high) in P2 (4-year-coffee + pine) at 40-60 cm, which was not significantly different from P1 and P3, but significantly different from P4 and. Available-K at the end of the research was 2,17 cmol kg^{-1} at 0-20 cm depth in P1 and it was significantly different from all treatments. Available-

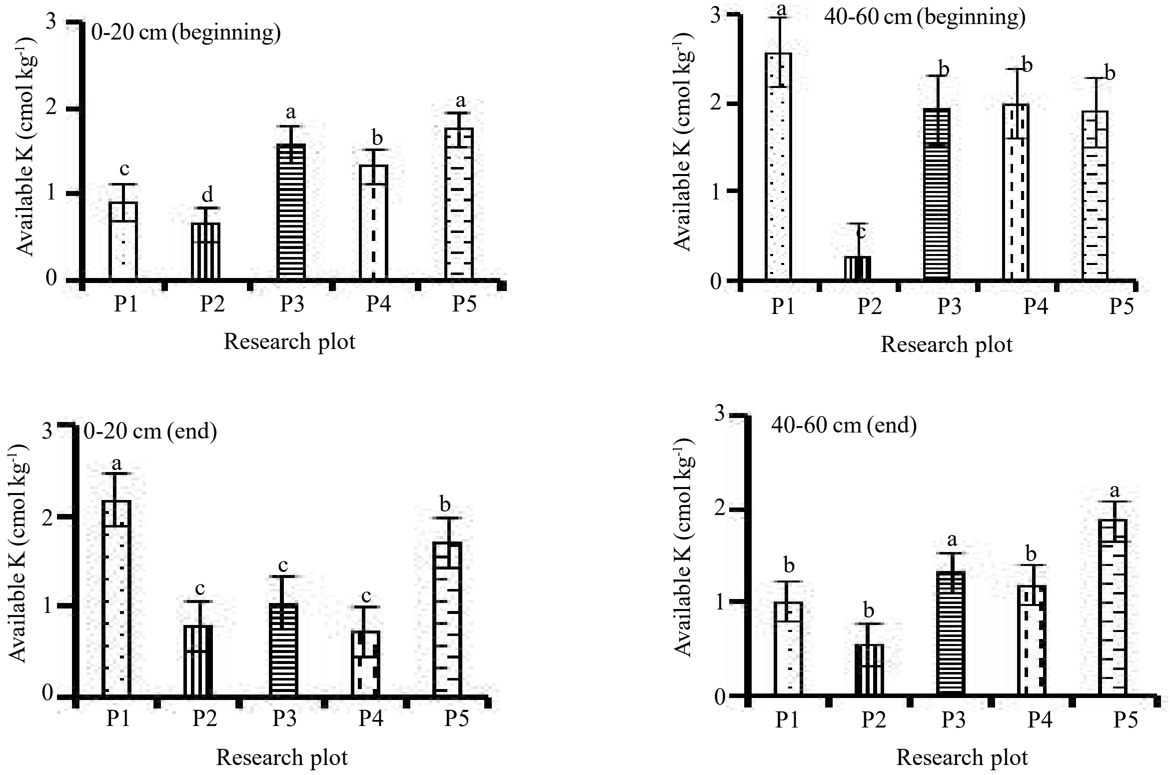

Figure 5. Soil Available-K in the research location. P1= Control, P2= 4 years coffee + pine, P3= 7 years coffee + pine, P4= 4 years coffee + mahogany, P5= 7 years coffee + mahogany; Numbers followed by the same show results that are not significantly different in LSD 5%.

K was 1,87 cmol kg^{-1} in P5 at 40-60 cm depth which was not significantly different from P3 but significantly different from P1, P2, and P4 (Figure 5).

Generally, the highest available N and -K in soil were found in coffee plants with mahogany shade. The characteristics of pine and mahogany leaves were different; mahogany had oval-shaped leaves, while pine had needle-shaped ones. Therefore, mahogany litter was easier to decompose than pine litter. According to Kusumawati and Prayogo (2019), it is because the content of lignin and polyphenols in mahogany leaves is lower (19.46 and 2.84%) than those of pine leaves (29.42 and 6.76%). The high lignin causes litter decomposition into humus slower because lignin is a component of complex compounds (Rahman et al., 2013). The low available P in agroforestry systems with different types of shade was thought to be due to the diversity of plants in the location, pine, and mahogany litters, which were hard to rot and took longer to decompose completely, so it was slower to provide P. Soil pH at the research location was 5.0-6.1 (acid to medium) was thought to facilitate P being firmly bound in the soil with Al and Fe, so P was not available. The available P in each UB forest agroforestry system was not significantly different, containing 0.00-2.16 mg kg^{-1} (low to very low) (Putri et al., 2019).

CONCLUSIONS

The different shade and coffee age types impacted soil moisture, litter Total-N, -P, and -K, and soil Available-N and -K. The highest soil moisture content was found in 7-year coffee under mahogany shade during the rainy season and generally decreased during the dry season. Plant diversity contributed to the high total N, P, K of litter in coffee (4 and 7 years) under pine shade but did not contribute to high soil nutrient availability. The highest available N and K were found in coffee (4 and 7 years) under mahogany shade; the available P, however, was found in control.

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