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Research Article

Humification degree and its relationship with some soil physical characteristics on robusta coffee (*Coffea canephora*) plantation

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Abstract: Soil moisture stress in coffee plant impacts on the productivity of coffee fruit at PT. Perkebunan Nusantara XII, it is because the low ability of the soil to store water. The ability of the soil to store water can be increased by increasing the organic matter content of soil, especially humic substances. Soil organic matter plays an important role in the improvement of soil physical properties, especially the availability of soil moisture for plants. The purpose of this study was to analyze several humification parameters at four age of plantations plots of coffee and its relation to the water distribution potensial on Inceptisol PT. Perkebunan Nusantara XII Malang district. The research was conducted at PT. Perkebunan Nusantara XII were taken soil samples from 8, 28, 40, and 80 years old robusta coffee plots at 0-30 cm and 30-60 cm soil depth. The results showed that the increasing the age of the coffee plantations significantly increased the input of organic matter in the soil, with indicators of increased litter on soil surface, increased levels of soil C-organic and N-total, humic acid and soil pH. Increasing age of coffee plantations until 80 years did not affect to the value of humification parameters (C/N ratio, HA/FA ratio, E4/E6 ratio, and the humification rate (HR)). The age of coffee plantations affected the total acidity, carboxylic groups and phenolic OH, where the values tended to decrease with the older of coffee plantations in the 0-30 cm of soil layers and increased in 30-60 cm. Increasing age of coffee plantations improved the total pores and available water content in the 0-30 cm of soil layer.

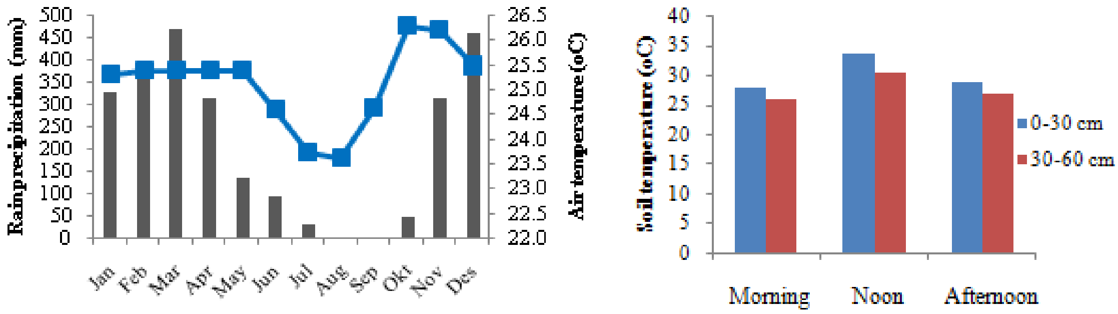
Keywords: *coffee plantation, fulvic, humic, humification, soil water distribution potential*

Introduction

Currently, the production of coffee (*Coffea* spp.) in Indonesia is the fourth largest contributor of foreign exchange worth $521.30 after the production of timber, rubber and oil palm (Wachjar et al., 2002). In 1999, Indonesia was the third Robusta coffee exporter in the world after Brazil and Columbia (International Coffee Organization, 1999). In 2004, total of coffee plantation area in Indonesia reached 1.3 million ha in North Sumatra and South Sumatra, Bengkulu, Aceh, Lampung, East Nusa Tenggara, Sulawesi and Java. Approximately 80-95% of the total area of these are smallholders with an average production of 674,800 Mg in 2005 consisting of 91.05% of Robusta coffee type (*Coffea canephora*) and 8.95% Arabica (*Coffea arabica*) (Susilo, 2008). PT. Perkebunan Nusantara XII at region III of Malang is one of the government agencies specializing in the development and improvement of coffee production, but having a problem that can affect coffee production, that is the lack of water in the dry season. It was affected by low input of organic matter in the soil.

Organic material in particular humic substance has an important role in improving access of water to the soil profile, into a condition where water access can be easily to infiltrated and stored on the soil, protecting from rain salinity, increasing the aggregate stability and soil pores, and make the soil unstable in air and water exchange (Piccolo et al., 1996; Stevenson, 1994; Imbufe et al., 2005). Stress of soil moisture on Robusta coffee plant decrease plant growth, plant biomass, fruit production, number of intact grains, three group of coffee grains, and increase the amount of the empty beans (DaMatta and Ramalho, 2006; Sumirat, 2008; Chemura et al., 2014). The biological properties of Robusta coffee grown under the shade is one of the characteristics of Robusta coffee that makes the coffee plant takes up the organic material from the litter into the soil and affects to the content of the humic substances in the soil (Baon dan Wibawa, 2005; Souza et al., 2012; deAlcantara-Notaro et al., 2014). The presence of humic substances affect the distribution of water in the soil, especially in the storage of water in the soil.

The level of humification of organic material can be detected by testing several indicators, among which (a) the ratio of carbon and nitrogen (C/N ratio), (b) Humic Acid/Fulvic Acid (HA/FA) ratio that is usually used as an index of the polymerization and condensation of organic matter (Seran, 2011), (c) ratio of the colour and the degree of condensation of aromatic by measuring the absorption solution of humic or fulvic in a UV-VIS spectrophotometer by comparing the wavelength of 400 nm and 600 nm (E4/E6 ratio) (Stevenson, 1994), (d) the humification rate (HR) (Iwegbue et al., 2006), and (e) total acidity, carboxylic group and phenolic OH (Pramanik and Kim, 2014). Some of these studies only focussed on each parameter without comparing with other humification parameters that have been done before. Therefore, research is needed to incorporate some of the parameters that have been studied as indicators of humification in conjunction with soil physical properties, especially the potential distribution of water. Therefore, the objective of this study was to understand the relationship between factors influencing formation of humic substances or humification to the distribution in the soil of coffee plantation in PT. Perkebunan Nusantara XII Malang.



A **B**

Figure 1. (a) Average value of rain precipitation and air temperature in 2005 - 2014 (source: BMKG Karangploso, 2016). (b) Average temperature of the soil coffee plantations PT. Perkebunan Nusantara XII in Septermber 2015

Materials and Methods

Location of study

The study was conducted at Robusta coffee plantation of PT. Perkebunan Nusantara XII Bangelan village, Wonosari Subdistrict, Malang Regency from May to December 2015. The plantation is located between 8°04'34.0"S and 112°27'43.4" E. Samples of soil and litter were collected from several plots of coffee plantation i.e. 8 years old plot (A1), 28 years old plot (A2), 40 years old plot (A3), and 80 years old plot (A4) with two soil layers of 0-30 cm (K1) and 30-60 cm (K2). Soil sampling was conducted using the diagonal method with sampling at five points on a diagonal plot of 10 x10 m (ISRI, 2015). Laboratory analyzes of soil chemical and physical properties were carried out at the Laboratory Soil Chemistry and Soil Physics, Soil Science Department, Faculty of Agriculture, Brawijaya University. Analyses of total acidity and carboxylic group were performed at Laboratory of Testing Services Unit (TSU), Faculty of Pharmacy, Airlangga University.

The coffee plantation of PT. Perkebunan Nusantara XII Malang has an average rainfall of 210 mm/year with an average temperature of 25,10 ^{o}C (Figure 1a). The average of soil temperatures in September 2015 at 0-30 cm soil layer were 27,90^{o}C in the morning, 33,45^{o}C in the noon and 28,55 ^{o}C in the afternoon. While at the 30-60 cm soil layer, the average of soil temperature were 25,90 ^{o}C in the morning, 30,30 ^{o}C in the noon, and 26,90 ^{o}C in the afternoon (Figure 1b). The soil type at the study site is Inceptisol with clay loam to silty clay loam texture classes and slope class is between 8-15% and the effective soil depth is 150 cm.

Extraction of organic matter to humic acids (HA) and fulvic acids (FA)

Analyses of soil C-organic and C content of HA and FA were carried out using Walkey and Black method. Analysis of N-total soil was carried out using N-Kjeldahl method. Extraction of HA and FA of the soil was carried out using NaOH extract method (Schnitzer, 1982; Stevenson, 1994). The method of extraction including to mixing 40 g soil (0.5 mm) with 0.5 N NaOH 200 ml, then shake it for 12 hours. Centrifuging the mixed solution at a speed of 10,000 rpm. The sludge residue from centrifuge process is a mixture of soil and humin, and the solution is mixture of humic and fulvic acid content (HF). The separation humic and fulvic acid was conducted by acidification method with H_2SO_4 titration to the HF solution until to pH 2. The precipitate result from the titration is humic acid, and dissolved was the fulvic acid. Several parameters were analyzed using ANOVA (F test) and tested further by using the least significant difference (LSD) at 5% level.

Humification rate (HR)

Humification rate was measured from a percentage of the amount of humic acid and fulvic acid with total soil C-organic (1), with the following formula

$$HR = \frac{HA + FA}{C - org} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where HR is the humification rate, HA is humic acid, fulvic acid is FA, and Corg is a C-organic content at the soil. Parameter HR analyzed using ANOVA (F test) and tested further by using the least significant difference (LSD) at 5% level.

Spectrophotometric measurement (E4/E6 ratio)

Spectrophotometric measurment of HA and FA were obtained by measuring the absorbance of the extract HA and FA that have dissolved with 0.1 M NaOH at 10 times, using the UV-VIS spectrophotometer at a wavelength of 400 nm and 600 nm (Stevenson, 1994; Seran, 2011). The E4/E6 ratio was obtained by comparing the absorbance at a wavelength of 400 nm (E4) and 600 nm (E6) (Chen et al., 1977).

Total acidity, carboxylic groups and phenolic OH

Total acidity and the carboxylic group of HA were measured by the method of $Ba(OH)_2$ and $Ca(CH_3COO)_2$ using potentiometric titration manner (Schnitzer, 1982). The value of total acidity was obtained by mixing 1000 mg of humic acid with a $BA(OH)_2$ 0.1 M, while gas flowed through N in erlenmayer 125 ml. The suspension was filtered with Whatman 42 and the residue was then rinsed with CO_2 free water. Then the mixture was filtrated and washed with water and titrated to pH 8.4 with 0.5 M HCl. Measurement of carboxylate group of HA was obtained by mixing 1000 mg of humic acid and 10 ml $Ca(CH_3COO)_2$ 0.5 M and shaken for 24 hours and centrifuged. The suspension was then filtered with Whatman 42 and titrated with 0.1 M NaOH to pH 9.8. Phenolic OH value was obtained from the difference between the total acidity value with the value of the carboxylic group HA (Stevenson, 1994).

Analysis of soil physical properties

Soil texture was determined using the pipette method. Water saturated condition of soil (WS) was determined using pF 0 method, the condition of field capacity (pF 2.5) using kaolin box method at a pressure of 33 kPa, and the condition of the permanent wilting point water content (pF 4.2) using the pressure plate method at a pressure of 1500 kPa (Piccolo et al., 1996). Analysis of the distribution of potential soil water used ratio pF value of the soil, where

TP = WS..(2)

AWC = (FC-PWP)..(3)

where TP is the total pore, WS is the soil water content of water saturated conditions, AWC is the potential of water available at the soil, FC is the moisture content of field capacity conditions, and PWP is water content in permanent wilting point condition,

Results and Discussion

Litters content

Litter that was a major contributor of organic matter in the formation of humic substances in PT. Perkebunan Nusantara XII coffee plantations, was mostly donated from the coffee plants and *Leucaena* shade. Litters on coffee plantations were dominated by the leaves that came from coffee plants. The coffee plantations of 80 years old accounted for the highest dry weight of leaf litter of 1.50 Mg/ha and total litter of 1.71 Mg/ ha. These values were higher than the leaf litter and total litter on younger coffee plantations. Leaf litter obtained in this study ranged from 0.41 to 1.50 Mg. While the twigs and total litter ranged from 0.10 to 0.21 Mg and 0.51 to 1.71 Mg (Figure 2). The dry weight litter in this study was almost the same with that reported by Hairiah et al. (2010) in which the dry weight of litter on some types of coffee agroforestry has a value that ranged from 1.24 Mg/ha to 1.71 Mg/ha.

Soil texture

The soil texture was dominated by clay and silt fractions both in the layers of 0-30 cm and 30-60 cm (Table 1). In the 0-30 cm layer, the sand fraction increased with increasing age of the plantation where 80 years old coffee plantation had the highest percentage of sand fraction. This was affected by the high litter content in the older coffee plantations that played an important role in keeping the soil surface roughness (Figure 2). In the 30-60 cm soil layer, the clay fraction increased with increasing age of the coffee plantation. This was caused by the clay leaching from the surface layer as the land of coffee had been long opened and converted from forest land.

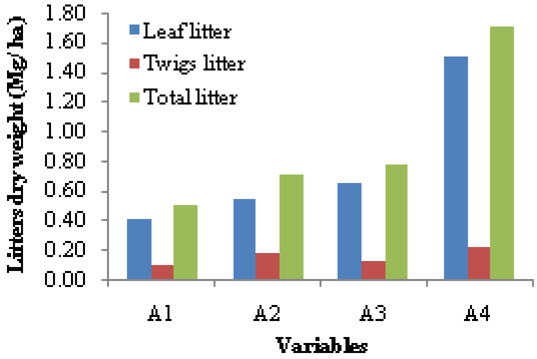


Figure 2. Litter dry weight on some age of coffee plantation. A1 (8 years old coffee plantation), A2 (28 years old coffee plantation), A3 (40 years old coffee plantation), A4 (80 years old coffee plantation), K1 (0-30 cm soil layer), and K2 (30-60 cm soil layer).

Table 1. Characteristics of soil on each plot of coffee pantation

Variables	Sand (%)	Silt (%)	Clay (%)	Soil pH	C-organik (%)	N-total (%)	C/N ratio
A1K1	11.27 a	49.93	38.80	4.39 a	1.26 a	0.80 ab	1.57 a
A2K1	13.38 b	53.07	33.55	4.45 a	1.46 b	0.78 a	1.87 bc
A3K1	12.69 b	49.13	38.19	4.70 b	1.49 b	0.83 b	1.79 b
A4K1	14.55 c	48.88	36.58	4.71 b	1.77 c	0.86 c	2.06 c
LSD 5%	**1.09**	**ns**	**ns**	**0.11**	**0.14**	**0.29**	**0.19**
A1K2	13.10 b	52.38 b	34.52 a	4.52	1.35 c	0.59	2.27
A2K2	13.42 b	49.01 b	37.57 ab	4.57	1.26 bc	0.57	2.23
A3K2	10.09 a	43.52 a	46.39 c	4.57	1.09 a	0.59	1.86
A4K2	11.84 a	43.77 a	44.39 bc	4.67	1.17 ab	0.57	2.04
LSD 5%	**2.38**	**4.84**	**7.46**	**ns**	**0.16**	**ns**	**ns**

Description: A1 (8 years old coffee plantation), A2 (28 years old coffee plantation), A3 (40 years old coffee plantation), A4 (80 years old coffee plantation), K1 (0-30 cm soil layer), and K2 (30-60 cm soil layer). The numbers on the same line followed by the same letter show no significant difference in LSD 5%. ns = not significant difference in the LSD 5%

Soil pH

The highest soil pH value (4.71) was obtained by 80 years old coffee plantation at 0-30 cm soil layer (Table 1). The increase of soil pH was caused by the high value of humic acid that plays an important role in maintaining soil pH as the buffer function (Stevenson, 1994). The increase of soil pH was also affected by the value of total acidity of humic acid that tended to decrease with increasing age of coffee plantation. According to Stevenson (1994), the presence of humic acids can increase the negative charge in soil about 20-70% greater than the negative charge of mineral soil so as to accommodate more base cations. In the 30-60 cm layer, soil pH values ranged from 4.52 to 4.67 and tended to be higher than that of 0-30 cm soil layer. This was caused by the higher density of coffee roots at 30-60 cm soil layer, that donate base cations from decomposition process (Allison, 1973).

C-organic

The 80 years old coffee plantation produced the highest value of soil C-organic (1.77%) in 0-30 cm soil layer. This happened because the oldest coffee plantation (80 years old) had litter inputs that was significantly greater than the younger coffee plantations (Figure 2). Hairiah et al. (2006) reported that the high input of litter on coffee agroforestry in Sumatra was directly proportional to the increase in soil C-organic with determination coefficient R^2 = 0.889. In the 30-60 cm soil layer, the highest soil C-organic (1.17%) was found in the youngest age of coffee plantation (8 years). This is presumably probably because the 8 years old coffee plantation was the newest land from forest conversion. The results of this study were similar to that reported by Reddy et al. (2014) that soil C-organic contents on coffee pantations was equal to 1.26%, while the natural forest land that was equal to 1.32% and the land conversion from forest land will reduce the value of soil C-organic.

N-total

The highest soil N-total content (0.86 %) was found at the 80 years old coffee plantation and this was significantly different from N-total of younger coffee plantations (Table 1). The high value of N-total in the soil was affected by the presence of *Leucaena* shade plants containing high N where *Leucaena* leaves had the high level of N-total amounted to 5.31% (Baon and Wibawa, 2005). In addition, annual fertilization activity by PT. Perkebunan Nusantara XII also contributed to the high level of N-total in the coffee plantation soil. In the 30-60 cm soil layer, the N-total value of each coffee plantation tended to be lower than that of the surface soil (0-30 cm) with values ranging from 0.57 to 0.59%. Values of N-total in the 30-60 cm soil layer were obtained from the remains of the coffee plant and *Leucaena* roots that have died and decomposed in the soil. The high value of N-total in the both soil layers donates the N structure in the humic substances in particular amino acid that has a proportion of 30-45% of the total soil N, especially in mineral soils (Bracewell and Robertson, 1984).

C/N ratio

The highest C/N ratio (2.06) was produced by 80 years old coffee plantation at the 0-30 cm soil layer. While at the 30-60 cm soil layer, the C/N ratio did not significantly differ between variables and has values ranging from 1.86 to 2.27. The values of C/N ratio in this study was lower than the value of C/N ratio of Stevenson (1994), where the value for mineral soil, C/N ratio has a value more than 10. The low values of C/N ration was influenced by the high N fertilization to soil.

Humic acid

The highest value of humic acid (1.03 g/kg with 5.82% proportion to the SOM) was observed in 80 years old coffee plantation at the 0-30 cm soil layer (Table 2). It was influenced by the time length of litter decomposition on soil surface. According to Stevenson (1994), time is one of the five factors affecting humification process, where the average of humic substance production is about 110 years old on the loamy texture, and 1500 years on the sandy texture (good drainage). At the 30-60 cm soil layer, the values of humic acid ranged from 0.41 to 0.53 g/kg and hah higher proportion to SOM than that at the 0-30 cm soil layer. The increased proportion of humic acid at the 30-60 cm soil layer seemed to be affected by the decomposition process of the coffee plant roots. Results of this study was lower than that of Reddy et al. (2014) where the value of humic acid in the coffee plantation was 3.20 g/kg and had a proportion of 19.60% to SOM.

Fulvic acid

The values of fulvic acid in this study ranged from 0.41 g/kg to 0.53 g/kg with 1.73% to 2.33% proportion to SOM in both of soil layers (Table 2). In the 30-60 cm soil layer, the proportion of fulvic acid to SOM was higher than that in the 0-30 cm soil layer. The fulvic acid content at the 30-60 cm was influenced by fulvic acid leaching from the 0-30 cm soil layer and the result from humification process of plant roots at the subsurface layer. These results were lower than that of Reddy et al. (2012) which showed that the coffee plantation had fulvic acid content of 4.90 g/kg with 29.6% proportion to SOM, and that of Seran (2011) with fulvic acid content of 1.05 g/kg. The low fulvic acid content in this study, seemed to be affected by high litter inputs at the soil surface, so that the proportion of SOM dominated by labile fraction of organic matter or non-humic (Stevenson, 1994).

The HA/FA ratio

The value of HA/FA ratio in this study ranged from 1.78 to 2.36 in both soil layers (Table 2). This result was higher than some studies. Seran (2011) reported the value of HA/FA ratio in forest was 1.51, while Reddy et al. (2012) reported the value of 0.66 on the coffee plantations. Rivero (2004) reported a HA/FA ratio was 2.50. According to Stevenson (1994), mineral soils of natural forest (Alfisols, Spodosols, and Ultisols) have lower HA/FA ratio than organic soils such as Mollisols and peat, where humic acid in mineral soils have lower aromatic chain, so that have a similar structure with fulvic acid.

Table 2. Value of soil organic matter (SOM), humic acids (HA), fulvic acids (FA) and the HA/FA ratio on each plot age of coffee plantations

Variables	SOM (%)	HA (g/kg)	Proportion of HA to SOM	FA (g/kg)	Proportion of FA to SOM	HA/FA ratio
A1K1	2.18	0.72 a	5.76%	0.41	3.23%	1.78
A2K1	2.53	0.88 a	6.01%	0.44	3.01%	2.00
A3K1	2.58	0.88 a	5.92%	0.47	3.16%	1.87
A4K1	3.06	1.03 b	5.82%	0.53	3.00%	1.94
LSD 5%		**0.18**		**ns**		**Ns**
A1K2	2.34	0.41	3.23%	0.47 b	3.73%	2.00
A2K2	2.18	0.44	3.01%	0.34 a	2.35%	2.36
A3K2	1.89	0.47	3.16%	0.44 b	2.99%	2.00
A4K2	2.02	0.53	3.00%	0.47 b	2.65%	2.00
LSD 5%		**ns**		**0.08**		**ns**

Description: A1 (8 years old coffee plantation), A2 (28 years old coffee plantation), A3 (40 years old coffee plantation), A4 (80 years old coffee plantation), K1 (0-30 cm soil layer), and K2 (30-60 cm soil layer). The numbers on the same line followed by the same letter show no significant difference in LSD 5%. ns = not significant difference in the LSD 5%

The E4/E6 ratio

The E4/E6 ratio of humic acid in coffee plantation ranged from 4.06 to 4.79 (Table 3). But, the E4/E6 ratio of fulvic acid in this study was higher than the ratio E4/E6 of humic acid that ranged from 8.43 to 12.11. This indicates that fulvic acid in this study had lower molecular weight and aromatic condensation than humic acid (Stevenson, 1994). The E4/E6 ratio in this study was higher than that reported by by Reddy et al. (2014) where the E4/E6 ratios of humic and fulvic acids at the coffee plantation had average values of 2.79 (humic acid) and 9.97 (fulvic acid).

Table 3. E4/E6 ratio, humification rate (HR), total acidity (TA), carboxilic group (COOH), dan phenolic OH on each plot of age coffee plantation

Variables	E4/E6 AH ratio	E4/E6 AF ratio	HR (%)	TA (cmol/kg)	COOH (cmol/kg)	OH fenolat (cmol/kg)
A1K1	4.06	4.09	8.97	56.58 c	1.65 c	54.93 c
A2K1	4.65	4.08	9.02	54.34 c	1.06 b	53.28 c
A3K1	4.57	4.69	9.06	16.80 b	0.91 a	15.89 b
A4K1	4.79	4.67	8.82	12.93 a	1.12 b	11.82 a
LSD 5%	**ns**	**ns**	**ns**	**3.67**	**0.14**	**3.71**
A1K2	8.44	8.72	10.48	16.92 a	1.14 a	15.78 a
A2K2	10.17	11.92	9.2	33.90 b	0.94 a	32.96 b
A3K2	10.09	12.11	12.09	39.10 b	1.16 a	37.94 b
A4K2	8.68	11.33	12.01	34.65 b	1.55 b	33.10 b
LSD 5%	**ns**	**ns**	**ns**	**10.74**	**0.37**	**10.91**

Description: A1 (8 years old coffee plantation), A2 (28 years old coffee plantation), A3 (40 years old coffee plantation), A4 (80 years old coffee plantation), K1 (0-30 cm soil layer), and K2 (30-60 cm soil layer). The numbers on the same line followed by the same letter show no significant difference in LSD 5%. ns = not significant difference in the LSD 5%

Traversa et al. (2014) reported that Alfisols in Italy had E4/E6 of humic acid values that ranged from 1.2 to 2.5. Hur et al. (2009) reported that lake sediments had a E4/E6 ratio of humic acids that ranged from 4.01 to 4.86. Seran (2011) showed that the E4/E6 ratio in forest stands had values of 8.97 (humic acid) and 7.43 (fulvic acid). These results showed that the humic acid in coffee plantation had the higher aliphatic carbon chain and had low molecular weight that was affected by the higher litter inputs on soil surface than the results from humification process (Zhang et al., 2015). The low E4/E6 ratio indicates the high level of aromatic condensation and low aliphatic chains as well as the high molecular weight (Stevenson, 1994; Purmalis, 2003). The E4/E6 ratio of fulvic acid in this study was higher that that of humic acid that ranged from 8.43 to 12.11. This indicates that the fulvic acid had lower molecular weight and aromatic condensation than the humic acid (Stevenson, 1994).

Humification Rate (HR)

The HR values at 0-30 cm soil layer were ranged from 8.82% to 9.06% and the HR value at 30-60 cm soil layer were 9.20% to 12.09%. The higher HR value indicate that greater formation of humic and fulvic acid content in soil than fresh organic matter input in soil. HR value at 0-30 cm, was lower than HR value at 30-60 cm. This is according to Seran (2011), that at the subsurface layer, the humic and fulvic acid content was higher than surface layer at the forest soil. This showed that the subsurface layer of soil was having a higher degree of humification than the soil surface. The HR value in this study was lower than the value of HR from Moraes et al. (2011), which the HR in some agroforestry were ranging from 17% to 69%. The low value of HR affected by the low level of humification on a coffee plantation.

Total acidity, carboxylic groups, and phenolic OH

Total acidity, carboxylic groups, and OH phenolics (Table 3) were much smaller than some research results reported before by several workers (Maie et al. 2002; Senesi et al., 2007; Fukushima et al. 2009; Reddy et al., 2014; Baidoo et al., 2014). The low value of total acidity in this study was affected by the domination of amino acid content at humic acid which was marked by the high N-total content of the soil (Stevenson, 1994). The low value of total acidity, carboxylic groups and phenolic OH in this study were affected by low levels of humification with the indicator of low humic acid and fulvic acid content. According to Stevenson (1994), humic substances is an organic material which is stable and largely formed from lignin, polyphenols, and cellulose which needs more than 100 years for its establishment. Phenolic OH value was higher than the carboxylic group. This was in accordance with research conducted by Biyantoro et al. (2006), that mineral soil has lower total acidity than organic peat soil, but had higher phenolic OH than carboxylic group.

Soil bulk density

In the 0-30 cm soil layer, soil bulk density not significant different between age of coffee plantations and has a values ranging between 1.11 g/cm^3 to 1.20 g/cm^3. This is influenced by the low activity of soil tillage, so with the same of soil type, the age of coffee plantations did not affect to the soil bulk density. This result is not accordance with the research from Helmi (2008) which showed that the increasing of organic matter in the soil was significantly able to reduce the soil bulk density and improving the soil porosity. In the 30-60 cm soil layer, the value of soil bulk density on 8 years old coffee plantation was 0.90 g/cm^3, smallest than all ages coffee plantation. The low value of soil bulk density at 8 years old of coffee plantation affected by the low density of the coffee roots (AAK, 1988).

Potential water distribution

In the 0-30 cm soil layer, the ages of the coffee plantation affected the value of the total pore and avalaible water content (AWC) of the soil. This happened because of the increase of the litter input on the soil surface which played an important role in increasing soil organic matter content and improving the biological activities (Blair et al., 2003). While in the 30-60 cm soil layer, the ages of the coffee plantation significantly affected AWC and permanent wilting point (PWP). The older age of the coffee plantation had lower total pores in 30-60 cm soil layer than 0-30 cm layer. This was influenced by the increase of clay fraction in the 30-60 cm soil layer and the decrease of sand fraction that led to total pore space filled by clay (Table 1).

In the 0-30 cm soil layer, the highest value of AWC (25.66%) was observed at 80 years old coffee plantation This was probably influenced by the contents of organic matter and humic acid where the oldest coffee plantation had highest content of soil organic matter (Juarez et al., 2005). Dahlan et al. (2008) and Nugroho (2013) showed that the increase of soil C-organic would increase soil moisture content as an indicator of improving water holding capacity and soil pores. According to Greenland and Hayes (1978), soil organic matter, especially humic substances plays an important role in improving soil agregation and aeration, because organic material has the important role as stabilizers of agregate and metal ions fixaion into the material soluble. The highest value of AWC at the 30-60 cm soil layer (25.43%) was observed at 8 years old coffee plantation. This seemed to be influenced by soil organic matter content of coffee plantation where the 8 years old coffee plantation had the highest value of the organic material at the 30-60 cm soil layer (Table 2).

Table 4. Bulk density, total pores, availaible water content, and permanent wilting point on each plot of age coffee plantation

Variables	Bulk Density (g/cm^3)	Total pores (%)	Available water content (%)	Permanent Wilting Point (%)
A1K1	1.11	60.79 a	24.22 bc	17.27
A2K1	1.2	61.51 a	19.42 a	16.11
A3K1	1.17	65.44 ab	21.51 ab	17.15
A4K1	1.15	69.45 b	25.66 c	16.59
BNT 5%	**ns**	**5.9**	**4.17**	**ns**
A1K2	0.90 a	70.83	25.43 c	16.75 a
A2K2	1.14 b	61.39	19.81 ab	16.78 ab
A3K2	1.06 b	62.21	17.27 a	20.37 c
A4K2	1.01 ab	61.95	21.41 b	18.76 bc
LSD 5%	**0.13**	**ns**	**3.79**	**2.18**

Description: A1 (8 years old coffee plantation), A2 (28 years old coffee plantation), A3 (40 years old coffee plantation), A4 (80 years old coffee plantation), K1 (0-30 cm soil layer), and K2 (30-60 cm soil layer). The numbers on the same line followed by the same letter show no significant difference in LSD 5%. ns = not significant difference in the LSD 5%

The water content at permanent wilting point conditions (PWP) at the 0-30 cm soil layer ranged from 16.11 to 17.27%. The existence of PWP in both soil layers was smaller than AWC. It showed that the water that fell to the soil surface was largely able to be stored in the soil and provided to the coffee plant. In the 30-60 cm soil layer, the highest PWP (20.37%) was observed at 40 years old coffee plantation. This was probably influenced by the clay content which affected the micropores on the soil.

Conclusion

Age of coffee plantation affected the contents of organic matter and humic substances, where the oldest coffee plantations had the highest C-organic (1.77%), N-total (0.86%), humic acid (1.03 g/kg) and fulvic acid (0.4 g/kg). Age of coffee plantation did not affect the humification degree (C/N ratio, AH/AF ratio, E4/E6 ratio, HR). The value of total acidity, carboxylic groups and phenolic OH tended to decrease with increasing input of organic matter to the soil. The highest total pores (69.45%) and AWC (25.66%) were observed in the 0-30 cm soil layer of the 80 years old coffee plantation. The highest PWP value (18.76%) in the 30-60 cm was also observed at the 80 years old coffee plantation.

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