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The Role of Microclimate, Vegetation Variety and Land Use in the Formation of Humic Substances

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ABSTRACT

Land use is significantly crucial in determining the supply of soil organic carbon (organic-C), including humic substances derived from plant litter composition. In this context, the lignin content of organic matter is strongly correlated with the formation of humic substances, providing benefits for human well-being. Microclimate is also thought to have a significant relationship in the formation of humic substances, where lower temperature decelerates decomposition. Therefore, this research aimed to investigate the role of microclimate and vegetation on the formation of humic substances. A total of six types of land use, including mixed crop, coffee plantation, and vegetable field, apple plantation, pine forests, and conservation forest were evaluated for temperature, forest humidity, type of vegetation, and organic-C content of plant litter. The results showed that temperature and humidity affected the levels of humic substances. Higher temperature was found to be correlated with lower organic-C content. The type of vegetation significantly affected the quality and quantity of plant litter, influencing organic-C content and humic substances. The use of coffee plantation land showed an increase in organic-C content, which affected the formation of 1.85% humic acids, 6.90% fulvic acids, and 91.25% humin.

Keywords: Organic-C, humic substances, land use, microclimate, vegetation

INTRODUCTION

Land use significantly contributes to soil organic matter, which is affected by the composition of plant litter (Austin & Vivanco, 2006). Based on previous research, plant litter with a high lignin content plays a crucial role in facilitating the formation of productive humic substances (García-Gómez *et al*., 2005). Moreover, the interaction between lignin content and microclimate increases the impacts of land use disparities due to the variation in plant cover caused by diverse plant canopies.

Previous research showed the yield of soil organic carbon (organic-C) at 0.94% in mixed crop and 0.98% in industrial forests that cultivated teak commodities (Edwin, 2016). In contrast, alternative land use such as forests showed a higher soil organic-C content of 3.07%, while dry land has a medium value of 1.03%. These results showed the complex interactions between land use and the impact on organic-C availability in various ecosystems. Furthermore, it was reported that contributors to soil organic-C content include the type of vegetation, causing different levels of decomposition (Kay, 2018).

The untapped potential of organic matter shows that efforts to enhance land quality and productivity are still unexplored (Kunanbayev *et al*., 2022). Consequently, several strategies have been implemented to enhance the development of soil organic matter in maintaining the sustainability of the soil system (Skrypchuk *et al*., 2020). This system is majorly composed of constituent elements such as carbon (C), hydrogen (H), and oxygen (O), which contribute to the fundamental composition and functional significance of soil.

Tan (2014) described that there is a complex composition of soil humic substances, manifesting as humic acids, fulvic acids, and humin capable of retaining moisture. This division shows the insoluble nature of the elements. Alimin *et al.* (2005) comprehensive analysis shows that the structure of humic acids mainly consists of phenolic and carboxylic groups, which are closely related to aromatic and quinone rings interconnected through nitrogen and oxygen bridges. The complex molecular architecture identifies humic acids as compounds that show both aromatic and aliphatic characteristics, facilitating the addition of functional groups such as -COOH, phenolic -OH, and alcoholic-OH, along with quinone groups.

The significant role of humic substances, which are an integral component of organic matter, occupies the most important position (Ponge *et al*., 2011). According to Stevenson (1994), the main function of humic substances enrich the soil by regulating various nutrient distributions. Specifically, the synergistic interaction of the basic elements increases soil fertility and land productivity. This phenomenon shows the essential role of plant litter in initiating dynamic biochemical cascades that culminate in the formation of organic matter and enriching the soil ecosystem.

Tan (2014) has identified the intricate compositions of soil humic substances, manifesting as humic acids, fulvic acids, and insoluble humin. Alimin *et al.* (2005) also conducted a comprehensive analysis explaining that the structures of humic acids are significantly constituted by phenolic and carboxylic groups, correlated with aromatic and quinone rings through nitrogen and oxygen bridges. These intricate molecular structures identify humic acids as compounds showing both aromatic and aliphatic characteristics. Furthermore, the structural attributes facilitate the addition of functional groups such as -COOH, phenolic -OH, and alcoholic -OH, along with quinone groups. Humic substances serve an empirically significant role in biogeochemical cycles, including the storage of carbon, pollutants, nutrients, and water. However, there is a significant knowledge gap due to the limited understanding of the precise molecular structures (Stancampiano *et al.*, 2023).

Plant litter is a variety of organic matter, serving as an important source of soil organic-C content derived from plant elements, including dead leaves, twigs, and root systems. The enzymatic degradation of organic matter results in transformation into simpler compounds, widely known as humus (Suwahyono, 2011). This intricate sequence of events shows the crucial role of plant litter in initiating the dynamic biochemical cascade that culminates in the formation of humus, enriching the soil ecosystem. Consequently, recognizing and exploiting the properties of humus offers a promising opportunity for advancing land management practices and optimizing agricultural productivity (Piccolo *et al.*, 2018). The conversion of plant litter into soil organic matter (SOM) is dependent on the distinctive characteristics of a particular location. Additionally, several factors such as the specific geographical site and soil properties exert a substantial influence on the presence of biotic communities, which determine the pathways of plant litter decomposition. Plant litter situated above the soil surface primarily passes through transformation into humus. Prescott and Vesterdal (2021) and Prescott (2010) also reported that humus is formed when a portion of the decomposed plant litter is transferred into the mineral soil through bioturbation. Over a period of 170 days, the fine root mass significantly reduced the mass loss caused by leaf litter decomposition. The quantity and quality of roots actively control the characteristics of the litter, enhancing the efficiency of nutrient release during the first stages of decomposition. They also intensify mechanical fragmentation through the length of new roots and root tips (Wang *et al.,* 2021).

Regarding soil fertility, coffee plantations are exceptional, showing significantly higher concentrations of humic acids, total nitrogen (N), and organic-C, compared to other land use categories such as apple plantations, secondary forests, mixed gardens, and agroforestry. This is supported by the highest humification index recorded at 4.56 of land use, as determined by the E4/E6 color ratio. Specifically, coffee plantations show superior humic acids characteristics based on acidity, the abundance of -COOH groups, and phenolic-OH group content. The distinctive properties of humic acids are also shown by the humification index or E4/E6 color ratio, along with the low phenolic-OH values, which are indicative of fulvic acids (Chakim *et al.*, 2020). Compost from green composts provides a major insight into the molecular structure of humic substances (Stancampiano *et al.*, 2023).

The decomposition of plant litter to produce humic substances is dependent on microclimate, including temperature, rainfall, humidity, and seasonal fluctuations. The pace of nutrient turnover and other elemental processes in the delicate ecosystem is significantly affected by several factors associated with plant litter degradation methods and practices (Krishna & Mohan, 2017). Therefore, this research aimed to investigate microclimate changes in various land use on organic-C status.

MATERIALS AND METHODS

Research location

The research was carried out from November 2018 to March 2019 on various land uses in Tutur District, Pasuruan Regency. The specific land use types studied were 1) Mixed plantations located in Ngembal Village, 2) Coffee plantations located in Tutur Village, Sumberpitu Village, and Kalipucang Village, 3) Apple plantations located in Andonosari Village, 4) Pine forests, 5) Field vegetables located in Wonosari Village, and 6) Conservation forests located in Kayukebek Village (**Table 1**).

Environmental data collection

Field-based biophysical and environmental assessments were carried out across six types of land use. These included mixed crop, coffee plantation, and vegetable field, as well as apple plantation, pine, and conservation forests. Several parameters that were observed included the measurement of microclimate and soil temperature, along with humidity and soil moisture content. Land biophysical and environmental observations included location, elevation, land slope, main commodities and soil texture classes, vegetation, as well as plant litter. Furthermore, vegetation evaluations were carried out by collecting plant litter for further analysis of organic-C content.

Temperature and moisture levels served as the primary factors exerting significant influence over the initial rates of plant litter decomposition. Moreover, there is the possibility that specific thresholds exist where individual factors assume predominant control over the rate of decay. Prescott (2010) reported that the pace of plant litter decomposition tended to be accelerated in natural environments.

Soil Sampling

Soil sampling for each type of land use was carried out at a depth of 0-20 cm and was taken 5 times as repetition. Subsequently, the soil sample was dried and sieved using a sieve that passed <0.5 mm. Soil sub-samples were analyzed for the content of humic substances at Land Resources Laboratory of the Faculty of Agriculture UPN "Veteran" Jawa Timur. The analysis included soil chemistry and humic acids characterization.

The soil samples were thoroughly mixed to obtain one composite soil sample, ensuring sufficient and representative cost-effectiveness. Laboratory analysis of composite samples or subsamples yielded valid estimates of the means of several population characteristics obtained from a single analysis (Petersen & Calvin, 2018). Schulten *et al.* (1996) has determined humic acids (HA) monomer with the composition $C_{308}H_{335}O_{90}N_5$, which is approximately similar to the Schnitzer (1965) formula. The HA number has a molecular weight of 5478 and a nitrogen content of 1.28%. Several reactions and interactions during the humification process result in non-humification compounds and humic substances forming a mixture of humus in the soil. When soil samples were taken and extracted to obtain humic substances, extreme difficulties were encountered in identifying the characteristic monomers, namely humic acids (Tan, 2003). A practical guide and resource handbook have been documented, explaining several methods, both conventional and state-of-the-art, for analyzing the chemical, biological, biochemical, and physical properties of various types of soil (Carter *et al.*, 2007).

Organic-C analysis

Organic and inorganic carbon are combined to form the total carbon in soil. Due to the breakdown of carbonate minerals in the parent material during soil formation, not all soil contains inorganic C.

In this research, soil sample weighing less than 0.5 mm was carefully weighed, with 0.25 grams being measured using a digital balance. Subsequently, the weighted soil sample was placed into a 100 ml volumetric flask, where 5 ml of $K_2Cr_2O_7$ 2N was introduced, followed by the addition of 10 ml of H_2SO_4 98%. The contents of the volumetric flask were subjected to homogenization. A waiting period of approximately 30 minutes was allowed for the chemical reaction to take place. After this reaction, the addition of distilled water ensued, followed by another homogenization step. The resultant sample was allowed to cool and analyzed using a spectrophotometer at a wavelength of 561 nm.

A significant correlation was observed between the levels of polyphenols found in distinct fractions, including water-soluble, NaOH extractable, fulvic acids, and humic acids, as well as various humification parameters and maturity indices. This correlation was particularly pronounced in relation to Polycyclic Aromatic Hydrocarbons (PAHs), the ratio of Hydrophilic Acidic Compounds (HAC) to Fulvic Acids Compounds (FAC), and the ratio of Hydrophobic Organic Compounds (HOC) to Organic Nitrogen (Organic- N). The observations suggested that polyphenolic compounds were actively included in the synthesis of humic substances. Specifically, the presence of lignocellulosic compounds, including lignin, cellulose, and hemicellulose exerted a significant role in augmenting cationic exchange sites within the organic matter (OM) matrix (García-Gómez *et al.*, 2005).

Humic acids extraction

The process of extracting humic substances, including humic acids and fulvic acids, was conducted using a modified method derived from (Stevenson, 1994). The initial step of the extraction process included applying 100 ml of 0.5 N NaOH in a 1:10 ratio to a 10 g soil sample. This combination passed through 24 hours of agitation before being chilled for 16 hours. To promote separation, 1,500 rpm centrifugation was carried out using Whatman 41 filter paper to separate humic substances. The separated material was treated with 6 N HCl to decrease pH level to 2, which caused the creation of two different layers. Whatman 41 filter paper was used to separate the resulting solution. Subsequently, the resulting precipitate was rinsed with distilled water free of CO_2, removing any remaining chloride component from humic acids. The precipitate was also subjected to additional characterization procedures, including an oven temperature of 105°C to determine the amount of humic acids and a temperature of 60°C for characterization.

Fulvic acids constitute one-eighth of humic acids, the primary component of mud humic substances. Meanwhile, extracellular components comprise 49.3% of humin and 88.9% of fulvic acids sludge. In comparison to humic acids mud, fulvic acids mud contains more oxygen functional groups, fewer hydrocarbons, aliphatic, and aromatic structures, as well as molecules of a smaller size. Previous research has established that approximately 37.7% of fulvic acids and 87.8% of humic acids have molecular weights between 30 and 50 kDa, greater than 100 kDa, respectively. Aromatic rings are also less compressed in small molecular weight fractions compared to aliphatic structures structures (Li, 2013),

Humus is the component of soil organic matter capable of resisting decomposition, possessing an unknown origin and future. The main sources of humus include the lignin and cellulose found in plants, as well as other primary and secondary substances. Various methods have been identified for calculating the amounts of lignin and cellulose in plant material but their use in soil is restricted, difficult, and expensive. For the determination of cellulose and lignin in soil, the spectrophotometric method yields quick results. A connection between cellulose and the quantity of HAC and FAC was found in soil samples from six distinct beechwood trees in Italy, distributed in four levels ranging from 0-5 to 30-40 cm (R2c = 0.675). Furthermore, lignin and cellulose were found to be reliable indicators of humic acids concentration (Danise *et al*., 2018).

Another research investigated the addition of 200 mg leonardite humic acids (HA) to control solutions with pH values of 5, 6, 7, and 7.5, zero. In all solutions, including Zn at pH 7.5, it was discovered that HA significantly increased maintenance in Fe solutions. Plants that were growing without Fe showed a significant Fe shortage. Without Fe and Zn, the addition of HA or fulvic acids (FA) led to a partial improvement in the growth and repair of Fe deficit. This shows that micronutrients rather than phytohormones are responsible for the growth-promoting effects observed in solutions containing Fe, Zn, and HS. However, the addition of Fe, Zn EDTA, HA, or FA resulted in strong, chlorophyll- rich plants growing rapidly. The phrase "hormone-like activity" was used to describe this phenomenon because plants that obtained sufficient amounts of Fe and Zn experienced similar physiological consequences (Chen *et al*., 2004).

Organic matter found in soil is generally comprised of chemically distinct and naturally stable substances. The development of long-lasting and large-molecular-size humic substances in soils is not supported by the evidence currently available. However, soil organic matter is a continuum of organic components that are gradually decaying (Lehmann & Kleber, 2015).

Various methods are available for the quantification of lignin and cellulose content in plant materials. However, their application to soil analysis is constrained by complexity and cost. In soil, humus content can be estimated using the chemical titration method, which measures the carbon content associated with humic acids (HA) and fulvic acids (FA). Although both lignin and cellulose are significant predictors of HA and FA, cellulose shows a comparatively higher conditional coefficient of determination (R2c). The most significant association is observed between cellulose content and the levels of HA and FA, with a coefficient of determination (R2c) of 0.675. Moreover, the use of spectrophotometry for lignin and cellulose assessment offers a reliable and expeditious means of predicting the presence of humic substances in soils within beech forests. Conversion factors are also available for the estimation of HA and FA. Due to the crucial role of humic substances in the global carbon cycle, the spectrophotometric method proves to be a swift and valuable method for evaluating cellulose and lignin in soil. Consequently, lignin and cellulose content serve as essentialindicators for predicting the presence of humic substances in forest soils *(Danise et al*., 2018).

Statistical analysis

Data obtained from observations and measurements regarding biophysical, chemical, geographical aspects, and microclimatic conditions are tabulated. The two aspects included factors such as geographical coordinates, elevation, land slope, primary commodities, and soil texture classification. The process of data collection was carried out across several villages located within the Tutur District. These included specifically included Ngembal, Sumber Pitu, Kalipucang, Tutur, Andonosari, Mesagi, and Kayukebak villages. To evaluate the correlation between parameters, regression correlation analysis was carried out.

RESULTS AND DISCUSSION

Environmental characteristics

The analysis of six distinct land use categories was carried out, comprising mixed crop, coffee plantation, and vegetable field, as well as apple plantation, pine, and conservation forests (**Table 1** and **Figure 1**). Each of land use categories showed unique biophysical attributes, reflecting the interplay of ecological conditions in both biotic and abiotic elements. Specifically, the highest elevation was recorded within the conservation forest land use category, situated at an altitude ranging from 1480 to 1710 meters above sea level. In contrast, the lowest elevation was associated with the mixed crop land use, ranging from 491 to 786 meters above sea level.

Table 1. Biophysical and Environmental Conditions in Several Land Use

Land Use	Location		Elevation (masl)	Main Commodity
	Village	Latitude		
Mixed Crop	Ngambal	7°48'57,46" SL 112°48'18,73" EL	786	Corn
Coffee Plantation	Sumberpitu Tutur	7°50'15,32" SL 112°48'46,36" EL 7°51'41.5" SL 112°48'35,1" EL 7°52’180' SL 112°48’141' EL	956	Coffee
Apple Plantation	Andonosari, Kayukebak	7°54’200' SL 112°50’232' EL 07.55'10,2" SL 112.50'36,1" EL	1415	Apple
Vegetables	Wonosari	07.53'002" SL 112.48'40,4" EL	1039	Carrot
Pines Forest	Wonosari	07.53'00,2" SL 112.48'41,4" EL	1023	Pines
Conservation Forest	Kayukebak	7°55’297' SL 112°51’065' EL	1710	Kaliandra

Note: SL= South latitude, EL=East longitude

The role of soil organic-C in the formation of humic substances

The significance of soil organic-C in the genesis of humic substances is essential, as humus represents a resilient form of organic matter (Lehmann & Kleber, 2015).The status of soil organic-C within a given field is subject to multifaceted influences. The phenomenon is a dynamic equilibrium similar to a bucket model, including inputs, storage, and outputs. The inputs are constituted by plant residues and other organic mattercontributions, while storage entails the gradual settling of organic-C. Simultaneously, the conversion of CO_2 into the atmosphere through the activity of decomposing organic matter constitutes the output (Broos & Baldock, 2008).

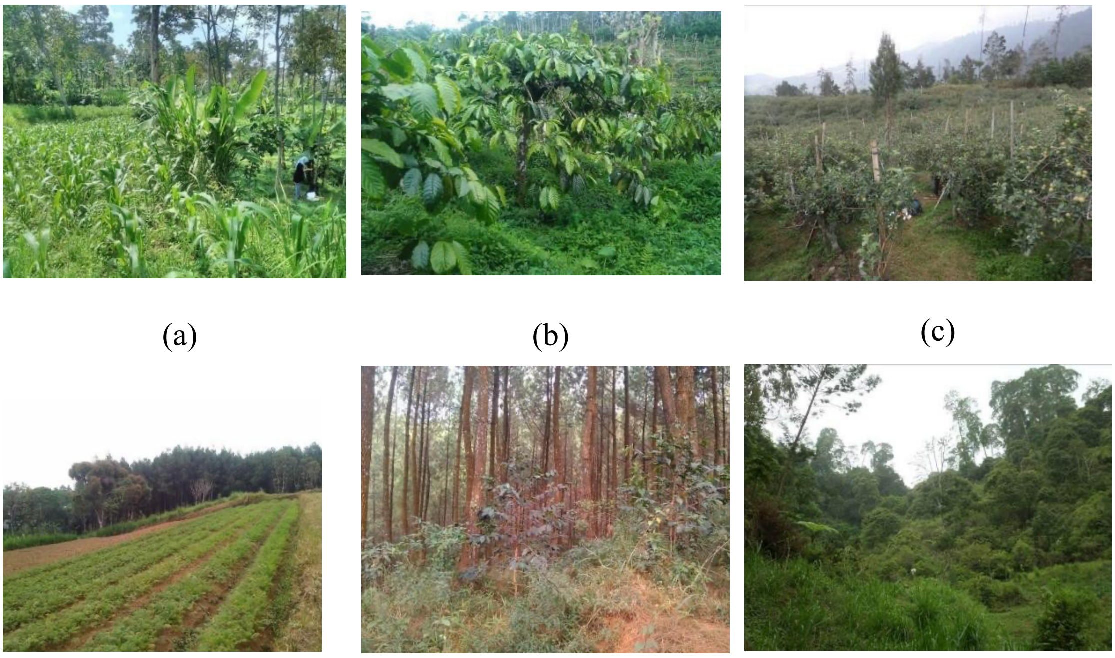

Figure 1. Existing land condition: (a) Mixed Crop, (b) Coffee Plantation, (c) Apple Plantation (d) Vegetable Field, (e) Pines Forest, and (f) Conservation Forests

Alterations in management and land use can cause a decline in soil organic-C content, leading to a reduction in stable carbon availability (Ermadani *et al*., 2018).Moreover, thecontent of organic-C is intricately related to the quantum of humic acids generated withinthe soil matrix. This relationship is illustrated through a linear graph presented in **Figure 2**, showing the direct correlation between augmented organic-C content and high humic acids production. Any diminishment in soil organic-C content will inevitably curtail the abundance of humic acids, due to the reciprocal relationship betweenstable carbon and humic acids content.

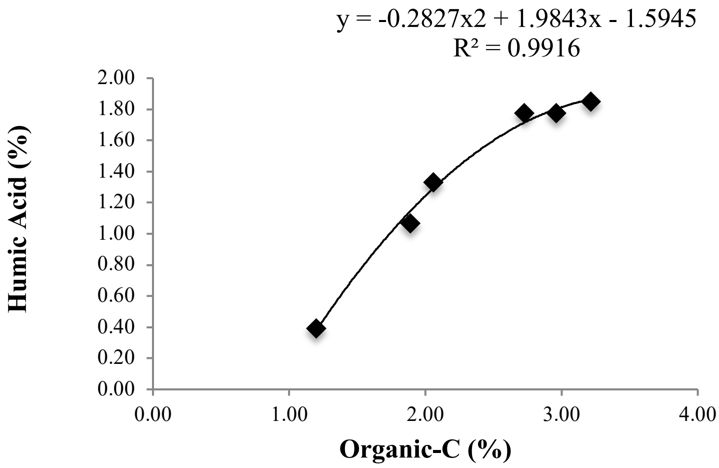

Figure 2. Relationship of organic-C content to humic acids

Humification significantly correlates with the intricate processes of organic matter decomposition, mineralization, and the stabilization of soil organic-C (Zech *et al*., 1997; Zhang *et al*., 2021). Specifically, land use for coffee plantations is conducive to the genesis of humic acids due to the distinct vegetation composition and microclimatic conditions. Based on landscape scale, topographic position affects topsoil SOC buildup, with valley bottoms having the highest values. Regarding topographic control on SOC, there are variances between terrain classes at the scale of a hillside. Topographic wettability index (TWI) and TOC show a positive association on steep slopes, but not significantly on wide pediments. On peaks, steep slopes, and valley bottoms, small-scale spatial variability is high, while SOC distribution is generally uniform. These variations between terrain classes are caused by the presence of vegetation patches as well as different rates of surface flow and sediment transport. Schwanghart & Thomas (2010). Based on the results, it was discovered that humic acids have a molecular weight of 5478 and a nitrogen content of 1.28%. Meanwhile, non-humification compounds and humic substances in all phases of the formation and degradation form a mixture of humus in the soil (Tan, 2003).

The amount of aromatic carbon in humic acids fraction increased with higher depth, suggesting the degree and rate of lignin's oxidative degradation. The loss of phenolic and methoxyl groups was visible in the 13C NMR spectra of humic acids fraction. The humin fraction largely resembled unaltered plant material based on lignin properties and carbohydrate content. Consequently, it was suggested that humic acids were created by the oxidative Adegradation of humin or plant material.

Alkyl and carboxyl carbon increased with increasing depth and decomposition, but C-aromatics remained stable at approximately 25%. O-alkyl carbon decreased in all soils. The amount of carbon classified as a specific chemical class reduces by 20% as depth increases. Furthermore, the quantities of microbial polysaccharides and non- polysaccharides O-alkyl carbon increased with depth. Carbohydrates are present in high proportions in the fulvic acids fraction. Less polysaccharides are present in humic acids fraction, but there are significant amounts of alkyl carbon and aromatic structure. With depth, the proportion of aromatic carbon in humic acids fraction increased, showing the extent and rate of lignin oxidative breakdown. The 13C NMR spectrum of humic acids fraction showed the removal of the phenolic and methoxyl groups. The lignin characteristics and carbohydrate content also showed that the humin fraction resembled unaltered plant materials. All available evidence supports the theory that humic acids are produced by the oxidative breakdown of humin or plant matter (Kögel-Knabner *et al*., 1988).

The selection of coffee gardens as land use fosters an environment that facilitates organic matter decomposition and carbon mineralization. Empirical evidence establishes that coffee gardens have the highest organic-C output (sig. 0.05), exerting a significant influence on the formation of humic acids. Based on quantification coffee gardens showed the most elevated yield among other land use categories, measured at 1.85% humic acids.

This phenomenon is significantly correlated with the processes of decomposing organic matter. The effective management of organic-C within soil systems, particularly in tropical climate regions, becomes progressively challenging due to the rapid decomposition (Anda *et al*., 2010).

Changes in land use results in a decrease in soil organic-C content (**Table 2**). The dynamics of soil organic carbon content are correlated with the function, decomposition, and structure of soil organic matter. Labile organic-C components, such as particulate, are sensitive indicators of soil quality, which are more susceptible to variation in soil management. To evaluate the potential function of soil as a carbon store, the stable organic-C fraction can be observed. Agroforestry systems, the use of organic fertilizer, mulching, and the addition of plant wastes to the soil are all management methods capable of preserving and enhancing organic-C components of the soil. Greater changes in soil management in the wet tropics were observed in the percentages of humic acids and particulate organic-C (Anda *et al*., 2010).

In the context of coffee plantation management, a strategic method was adopted including the incorporation of organic matter in the form of cow dung (40kg/tree) and the reintroduction of plant litter. This practice served to augment the reservoir of stable organic-C, addressing the challenge in management. Similarly, Ermadani *et al*. (2018) stated that the supplementation of organic matter through plant litter contributed to the provisionof humic acids (HA) at a rate of 0.56%.

Table 2. Organic-C content and humic substances in several land use

Land Use	Organic-C	HA	FA	HU
	(%)			
Mixed Crop (MC)	1.20[a]	0.39[a]	3.79[a]	95.82[a]
Coffee Plantation (CP)	3.21[c]	1.85[b]	6.90[a]	91.25[a]
Apple Plantation (AP)	2.72[bc]	1.78[b]	7.33[a]	90.90[a]
Vegetable Field (VF)	1.89[ab]	1.06[ab]	9.50[a]	89.44[a]
Pines Forest (PF)	2.06[abc]	1.33[ab]	7.86[a]	90.81[a]
Conservation Forest (CF)	2.96[bc]	1.77[b]	5.57[a]	92.65[a]

Note: Numbers followed by the same letter in the same column show no significant difference in Tukey's Honest Significant Difference (HSD) test at the 5% level, HA (Humic Acids), FA (Fulvic Acids), HU (Humin)

The role of relief variability in soil organic-C availability

The Tutur District has an undulating topography situated within the Bromo Tengger Semeru mountainous region, thereby engendering various landscape configurations. This geographical context causes several landforms, including a range of altitudes and slopes. The research area spans from Ngembal Village, located at an elevation of 491 meters above sea level (a.s.l.), to Kayukebek Village situated at a higher altitude of 1710 meters above sea level. Furthermore, there are diverse slope gradients, varying from 13% to 46%.

According to Hanafiah (2014), topography represents a foundational element in soil genesis, effectively influencing properties within a given locale. In this context, the pertinent topographic components considered are elevation and slope, which inherently impact the presence of organic-C in soil, yielding both direct and indirect effects on its availability.

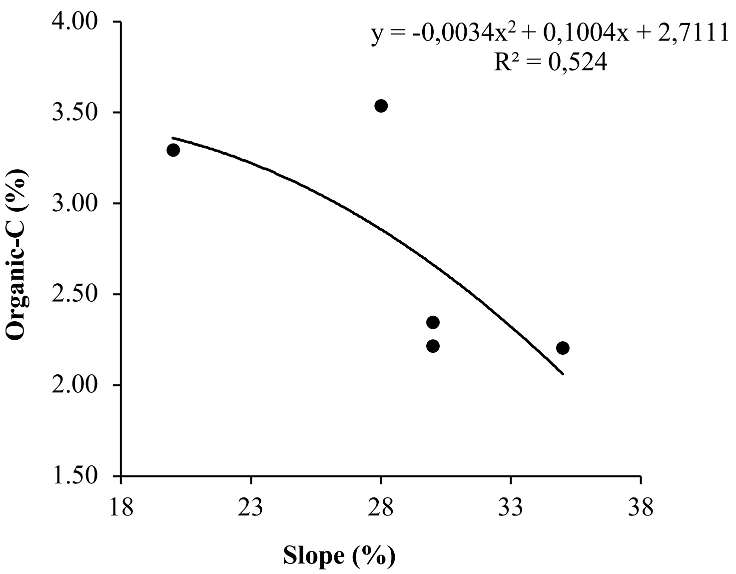

Figure 3. Correlation of slope and soil organic-C

Theoretically, slope exerts an influence on the availability of soil organic-C content. It is understood that an inclining slope can lead to a reduction in organic-C content, potentially exposing subsoil (Zádorová *et al*., 2011).This correlated with the results from an investigation including six distinct land use categories, where a negative relationship is observed. The results showed that an increase in slope inclination corresponded to a decrease in soil organic-C content. To provide perspective, the Andisol Soil Quality Index (SQI) for monoculture land in Sumber Brantas Village, Batu City was 0.42, including the medium criterion. Meanwhile, the SQI for intercropping land was 0.38, including low criteria. Good quality soil will ensure the sustainability of soil functions, both production functions and ecological functions (Juarti, 2016). The other author find that the adoption of conventional tillage (CT) and no tillage with bare soil (NT) did not increase the OC pool in aggregate fractions and therefore it is not always the best option management change to increase SOC in Mediterranean areas (González-Rosado *et al*., 2020).

Land management practices incorporating monoculture land cover resulted in a reduction of soil organic-C content compared to polyculture. This suggestion is supported by the observation that conservation forest slopes do not have diminished organic-C values. The forest's slope is characterized by diverse land cover, thereby facilitating the retention of organic-C and averting nutrient leaching.

A comparable trend is observed in relation to the variation in slope, showing the impact on soil organic matter availability. The slope of land use shows a negative correlation with organic matter. This shows that an increase in slope corresponds to a decline in organic matter content. Meanwhile, altitude is indirectly related to the availability of soil organic-C content due to its influence on temperature disparities. Hodkinson (2005) reported that higher altitudes engender lower air temperature, with a decline ranging between 5.5-6.5°C for every 100-meter increase. Consequently, temperature functions as an external determinant influencing the decomposition of organic matter (Lal, 2005). When compared with natural forests, C org concentrations in the 0-30 cm layer vary between land use types: 8-20% in degraded forests, complex agroforestry, oil palm plantations, and old plantation forest plots, and 25-30% in simple agroforestry, monoculture plantations, and plantation forests, or more than 40% on non-treed land (mostly planted) (Hairiah *et al*., 2020).

The Role of vegetation microclimate on soil organic-C dynamics

Vegetation is a crucial component of landscape, playing a significant role in influencing microclimate. Palilingan *et al.* (2005) stated that the slightest alteration in land use could exert pronounced effects on microclimate with broader implications. This phenomenon is shown by the distinct microclimate measurements across the six varied land use.

Temperature and humidity are integral components within microclimate, influencing organic matter decomposition processes. The configuration of plant canopy systems significantly impacts air and soil temperatures. The density of the plant canopy directly influences solar radiation penetration, regulating local air temperature. According to previous research, a denser canopy cover results in lower air temperatures (Supriyadi, 2008). The result is consistent with empirical evidence, where conservation forest land use shows lower air temperature compared to vegetable gardens. The variation in the result is attributed to the denser canopy cover in conservation forests relative to vegetable gardens. Furthermore, the influence of canopy-related air temperature extends to soil temperature dynamics due to the interaction between sunlight and plant canopy. The interaction between air and soil temperature serves as a supportive factors in organic matter decomposition (Sudaryono, 2004).

Temperature conditions, including both air and soil, hold sway over soil organic-C availability. Carbon within an ecosystem is stored as biomass, necromass at the soil surface, and as soil organic-C within the soil matrix. The activity of microorganisms in organic matter decomposition is significantly influenced by air and soil temperatures. According to Irawan *et al.* (2011), this microorganism-mediated process yields respiration, resulting from metabolic activities, liberating CO_2 into the atmosphere. Siringoringo (2014) reported that the release of carbon into the atmosphere yielded dual consequences. This included a reduction in carbon reserves within the soil and an increase in greenhouse gas (GHG) concentrations, acceleratingglobal warming. Consequently, microbial-driven organic matter decomposition translates into CO_2 release, precipitating a decline in soil carbon reserves.

Elevated air and soil temperatures have been established as accelerants ofdecomposition processes, contributing to the expedited loss of soil organic matter reserves through CO_2 emissions into the atmosphere (Lal, 2005). Among various land use observed in this research, coffee plantations show the highest organic-C content within the soil. Graphicalrepresentation shows that the optimal conditions for organic-C soil formation manifest at an air temperature of 30°C and a soil at 24°C. Conversely, an upward trajectory in both air and soil temperatures corresponds to a decrement in soil organic-C content.

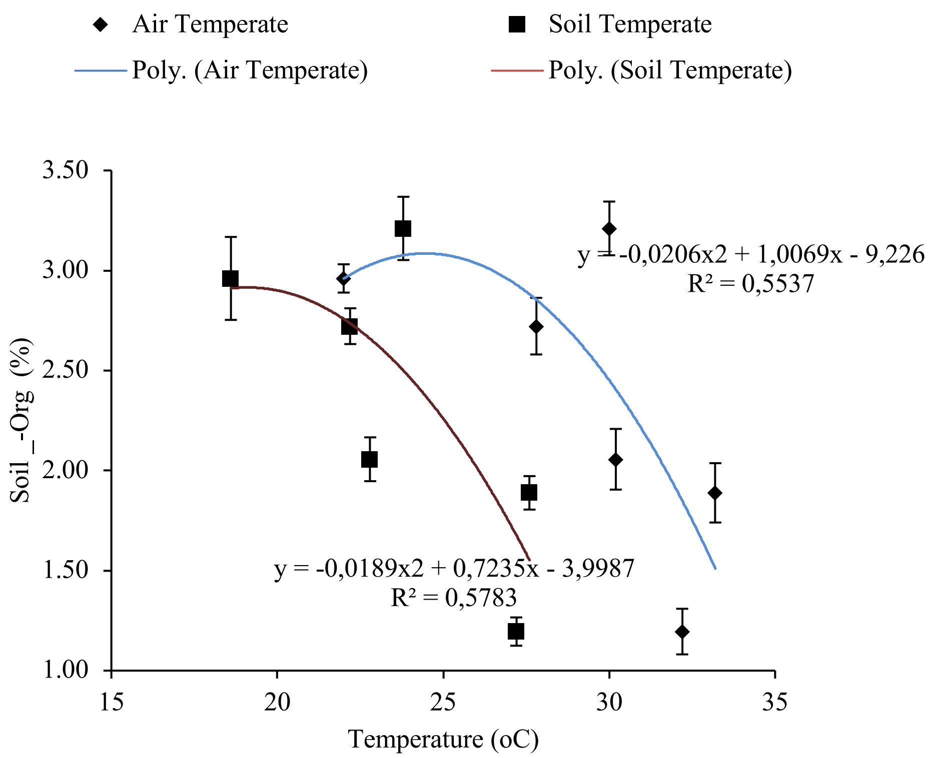

Figure 4. Correlation of temperature & soil organic-C

The selection of land use, specifically in the case of coffee plantations, bears climatic implications that significantly influence soil organic-C content. In coffee plantations, both air and soil temperatures are optimal for the creation of resilient soil Organic-C content. According to Siringoringo (2014), regions characterized by elevated temperatures face challenges in retaining soil organic-C content at a considerable amount. This phenomenon is reflected in land use such as mixed and vegetable gardens, characterized by open canopies, which show diminished organic-C. The variance in canopy systems significantly caused disparities in both air and soil temperatures across various land use types.

The role of tissue quality in the formation of humic acids

The diversity of vegetation exerts varying influences on the process of humic acids formation. Plant detritus that descends to the ground passes through a transformative process into recalcitrant materials. Subsequently, biochemical conditions catalyze the degradation of plant residues, comprising lignin and cellulose compounds, leading to the production of humic acids. Several other constituent components were also found such as amino acids, aromatic groups, lipid acids, and organic acids (Ouni *et al.*, 2014).

Lignin compounds constitute aromatic organic entities with interconnected carbon chain linkages, and their prevalence within plant tissues is highly diverse (Rahman *et al.*, 2013). Moreover, the composition of lignin and cellulose content values depends on the state of vegetation. The deposition of plant litter onto the ground within distinct land use categories is inherently characterized by specific attributes, imparting distinct lignin and cellulose content values.

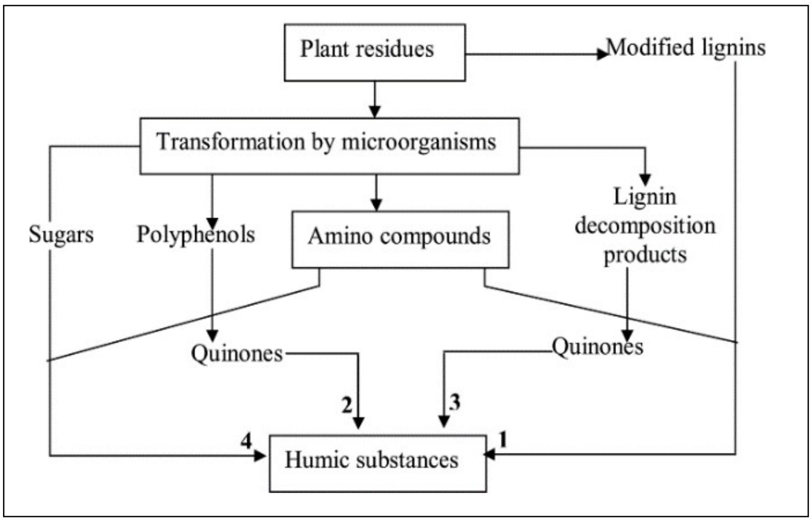

Figure 5. The lignin theory (Waksman, 1932)

Lignin compounds present in plant tissues pass through degradation facilitated by microorganisms. The process commences with the breakdown of the C-C carbon bond, followed by the elimination of the methoxyl compound inherent in the hydroxyphenolic group. This sequence of events is succeeded by aliphatic oxidation, culminating in the configuration of the –COOH group. The results of lignin modification are shown as the formation of intricate carbon chains, denoted as humic acids and fulvic acids.

According to Varadachari & Ghosh (1984) the degradation process of lignin compounds initiates with the liberation of phenolic –OH groups through oxidizing enzymes. This is followed by the rearrangement of –OH phenolic groups within hexagonal rings, leadingto the generation of a –COOH group as the foundational element for humic acids formation. Subsequent steps include the interaction between enzyme compounds and amino acids, followed by the release of the –COOH group. The liberation of the –COOH group signifies a polymerization phase facilitated by soil microorganisms, playing a significant role in decomposition. Specifically, the process culminates in the degradation of carbon bonds by microorganisms, yielding humic acids compounds characterized by intricate carbon chains and elevated molecular weights.

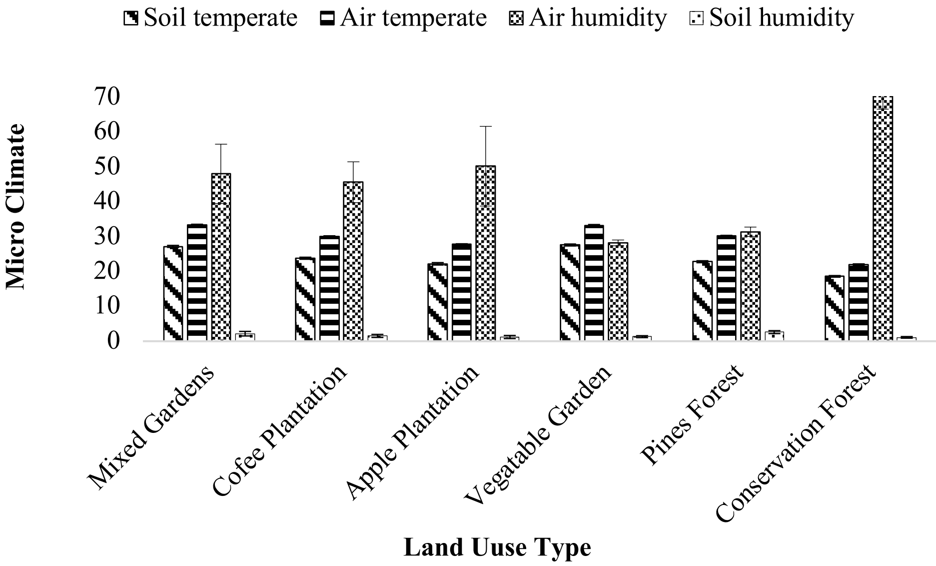

Figure 6. Correlation of land use type and microclimate

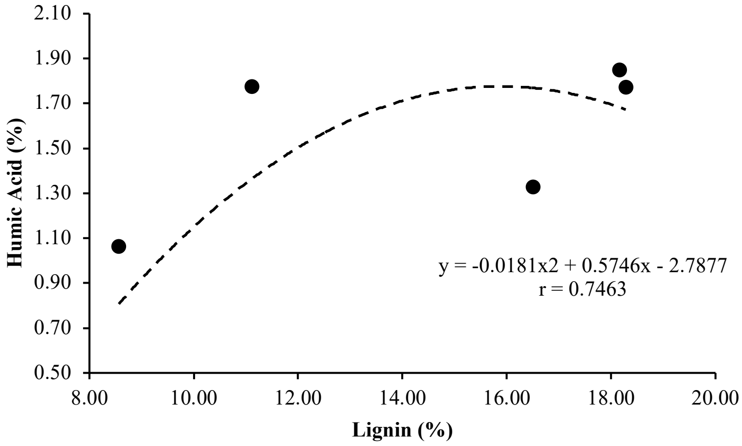

Figure 7. Correlation of lignin and humic acids

The variation in lignin content across different fields depends on the source of plant tissue input. The highest lignin content was observed in conservation forests, followed by coffee plantations, pine forests, apple plantation, mixed crop and vegetable field. Despite conservation forests boasting the highest lignin values, lignin was recognized as a recalcitrant substance due to its resistance to decomposition. Furthermore, previous research has established that lignin compounds are organic entities characterized by limited degradability, subject to degradation through biotic or abiotic means (Rahman *et al.*, 2013).

A group of complex chemical substances known as lignin have amounts that considerably vary between plant species. Lignin is a crucial component of the carbon cycle, capturing atmospheric carbon and storing in the living tissues of perennial woody plants. This phenomenon has a significant effect on other ecological processes and the dynamics of nitrogen in forest ecosystems. Lignin and plant litter decomposition have a strong relationship, where a higher concentration of lignin significantly affects other chemicals. However, chemical testing poses challenges, and different methods may vary based on results. The composition and structure of lignin can be determined analytically using several methods (Rahman *et al.*, 2013).

The lignin content within plant tissues significantly influences the availability of humic acids. As illustrated in the graph showing the lignin relationship pattern, a significant correlation with a value of r=0.7463 was evident. This relationship pattern signified that an increase in lignin content corresponded to a decrease in humic acids.

The management of land has repercussions on stable carbon availability within the soil (Ermadani *et al.*, 2018). Regarding vegetable gardens, the low lignin content is attributed to the prevalence of plants dominated by cellulose-rich constituents. Cellulose, characterized by its highly recalcitrant polymer properties, features within the composition of humic acids (Danise *et al.*, 2018). The presence of cellulose within organic matter originates from carbohydrate breakdown, resulting in a process skewed more towards mineralization than humification (Kögel-Knabner *et al.*, 1988). Consequently, the availability of soil organic-C and humic acids remains limited. Beyond the quality of plant tissue, the environmental conditions of open land also affect organic-C availability, a primary supply for humic acids formation.

Regarding agricultural production, considerations such as water quality and climate play a significant role in the dynamics of nutrient, energy, and carbon flows within soil organic matter, the soil environment, aquatic systems, and the atmosphere. Traditionally, there was a perspective that soil organic matter comprised discrete and chemically stable molecules. However, it has been established that soil organic matter is a continuum of organic molecules passing through gradual decomposition (Lehmann & Kleber, 2015).

Plant litter decomposition in terrestrial ecosystems serves as a crucial process in the intricate biogeochemical cycling of elements within the environment. The rate of decomposition process is significantly influenced by climatic factors such as temperature, rainfall, humidity, and seasonal fluctuations. Specifically, there has been limited research focusing on plant litter decomposition within forest ecosystems, particularly in tropical and temperate regions. Understanding the mechanisms of plant litter degradation is crucial to gaining insights into the turnover rates of essential nutrients and other elements within these environmentally sensitive ecosystems (Krishna & Mohan, 2017).

Soil organic matter represents an essential constituent within the soil matrix and deficiency poses a significant challenge in numerous regions. The inherent diversity of organic matter and the heterogeneous environmental conditions contribute to the development of diverse structures and compositions. Consequently, variations in the properties of humic substances, particularly humic acids, are observed. The results showed that soil amendment with organic matter leads to improvements in both soil and humic acids properties when compared to untreated soils. These observations included **1)** The significant increase in the presence of carboxylic groups within humic acids derived from amended soils. **2)** The predominance of aromatic ring systems in humic acids. **3)** Elevated levels of carbon, nitrogen, hydrogen, and sulfur, coupled with reduced oxygen content relative to control soils. **4)** The introduction of straw resulted in heightened carbon content in humic acids particles, leading to a reduction in the C:H ratio. **5)** The high levels of oxygen functional groups compared to non- treated soils. Further observations indicated that organic matter from straw demonstrated greater resistance to rapid decomposition compared to compos, showing a higher long-term sorption capacity. Consequently, straw may be considered an effective alternative to natural sources of soil organic matter, with potential implications for agriculture and the protection of ecosystems (Kwiatkowska-Malina, 2015).

CONCLUSION

This research showed that the formation of humic substances was influenced by environmentalconditions, namely microclimate and vegetation diversity. The results showed that high and low temperature affected the decomposition of organic matter. High lignin levels in plant litterwere found as the main source of humate formation. Furthermore, coffee plantation land use served as an environment conducive to the formation of humic substances, compared to others.The values of humic acids, fulvic acids, and humin in coffee plantations were 1.85%, 6.90%, and 91.25% respectively. Consequently, to maintain the stability of organic matter in the soil,the example of managing coffee plantations provided valuable information as a guide for various land use types.

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