

Research Article

Labile fraction changes of soil organic matter along the gradients of altitude in drylands with dry climate

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Abstract: Labile fraction plays a crucial role in maintaining soil fertility. Until recently, the information on the labile fraction of soil organic matter in dry lands with dry climates of Indonesia is very limited. Therefore, the experiment was conducted to study the changes of a labile fraction of soil organic matter in those drylands. The soil samples were obtained from 4 sub-districts (Kanatang, Haharu, Pandawai, and Matawai La Pawu) of Sumba Timur District. Those sub-districts have different altitudes, i.e. from 25 m – 900 m above sea level (asl). Soil samples were taken at 0-20 cm soil depth. Chemical analysis on soil pH, total N, organic C, and labile fractions analysis (water-soluble fraction, microbial biomass C, particulate organic matter, and microbial biomass N and water-soluble N) was done at The Plant and Soil Analytical Laboratory of ILETRI. The results indicated that altitude affected the availability of total N and organic C in soils. The higher the altitudes, the lower were N concentrations and conversely for the concentration of organic C and C:N ratio. Labile fraction N (water-soluble N and microbial biomass N) was reduced by increasing the altitudes. The ratio of labile fraction/organic C at altitudes >700 m asl was higher. This meant that the concentration of the active carbon pool was higher compared to that at altitudes <700 m asl. The ratio of MBC/SOC, as the indicator for the rate of biological activity, at altitudes >700 m asl was also high. The high value of MBC/SOC showed that the conversion of soil organic matter to microbial C was efficient.

Keywords: *altitude, dry lands with dry climates, labile fraction of organic matter*

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Introduction

According to its function, soil organic matter comprises of labile, stable and inert fractions or pools (Strosser, 2010), but most publications generally classify into two fractions, i.e. labile and stable fractions. The half-life of the labile fraction is between days to few years, while the half-life of stable fraction will be from several years up to decades (Strosser, 2010; Larionova et al., 2011; Sequeira et al., 2011). Based on the composition, a labile fraction is mostly composed of microbial biomass, fungal mycelia, soil fauna and plant residues (Kolář et al., 2009). The labile fraction consists of protein and carbohydrate, and the stable fraction is lignin, suberin, lipids, resin and wax

(Rovira dan Vallejo, 2002). All these materials are the ones that rapidly decompose at the initial process of mineralization, or the accumulation of residual materials that do not decompose during the earlier mineralization process, which those processes release energy, CO₂ and mineral nutrients (Kolář et al., 2009). The labile fraction plays an important role in maintaining soil fertility through its role as a nutrients source for plants because of its chemical composition and its fast rate of decomposition, as well as an important source of energy for soil microorganisms (McLauchlan and Hobbie, 2004). Despite these benefits, the labile fraction is the first compound to disappear because of soil tillage or soil

management changes (McLauchlan and Hobbie, 2004; Soon et al., 2007). In the other side, stable fraction such as humic acid, takes a role as (1) biological ameliorant to toxic component especially heavy metals (Angelova et al., 2013), (2) component of soil aggregates, and (3) cation binding in the soil (Hairiah et al., 2000; Kolář et al., 2009).

Since of its composition, labile fraction is more sensitive to any soil physical, chemical, and biological changes such as soil tillage, various soil management such as fertilization, amelioration that principally there is change in C supply, and therefore the labile fraction is a good indicator of soil quality, soil productivity, and soil health (Zhang, 2010; Sequeira et al., 2011). This also means that the change of soil management is observable sooner in the labile fraction, and later on in total soil organic matter. This is because there is a strong correlation between the labile fraction of organic matter and total organic matter (Zhang et al., 2006; Soon et al., 2007; Strosser, 2010). While in comparing the organic and conventional soil management systems, the labile fraction of soil organic carbon (LFSOC), microbial biomass carbon (MBC), and water-soluble carbon (WSC) are applied as parameters. It was found that organic soil management increases all those fractions and therefore those parameters are suggested as an indicator of soil/land management changes (Lou et al., 2011). In addition, those organic carbon fractions are a rapid response to any physical and chemical soil changes and therefore they are suggested as indicators of soil quality (Zhang et al., 2006; Wang et al., 2012).

The labile fraction of N and C acts as N and C sources for microorganisms and several plants that are able to directly absorb these labile fractions (Burton et al., 2007). The labile fraction which is generated from organic matter has a significant effect on the residue of soil organic matter. The quantitative change of that fraction is the initial indicator to predict the effect of land use and land management.

Soil organic matter where the soil organisms live is a crucial supplier of energy and nutrients for soil microorganisms. Instead of soil organic matter, microbial biomass is also very important in maintaining soil organic status through its action as a source and sink of nutrient availability. Organic farming where plenty of organic matter is applied shows the best amount of microbial biomass compared to those obtained from intensive farming with no organic matter application (Amaral and Abelho, 2016). The labile fraction of organic matters is the result of decomposition and mineralization processes of organic matter where these processes are very

affected by the quality of organic matter, pH, moisture content and temperature of soils, as well as altitude (Handayanto et al., 1997; Griffin and Honeycutt, 2000; Cookson et al., 2002; Samuel et al., 2002; Bonito et al., 2003; Kyveryga et al., 2004; Agehara and Warncke, 2005; Fritschi et al., 2005). In dry areas, the process of mineralization is very influenced by soil temperature and soil moisture content. In areas with high soil temperature and moisture content, therefore, the mineralization process runs quickly and conversely to the wetlands. The mineralization rate is going to influence the amount of labile fraction within soils. Altitude also influences the rate of mineralization, and in general, in high altitude places/areas, the mineralization process goes slowly because of low temperature. However, the information on the dynamic of labile fraction of soil organic matter in dry areas with dry climates has been very limited. The objective of the study, therefore, was to assess the changes of a labile fraction of soil organic matter along natural altitudinal dry lands with dry climates in Sumba Timur Region of East Nusa Tenggara, Indonesia.

Materials and Methods

Soil sampling and analysis

The sampling activities were conducted at Sumba Timur District of Nusa Tenggara Timur Province in May 2015 when the rains have nearly stopped. A total of 22 soil samples were obtained from agriculture lands grown by groundnut crops spread in seven villages at four Sub District where these sites were in the altitude between 25 m – 900 m above sea level (asl). The detailed amount of samples and locations of sampling was listed in Table 1. The soil chemical analysis consisted of soil pH, total N, organic C, and labile fraction analysis that consisted of water-soluble fraction, microbial biomass C, and particulate organic matter (POM). The samples were obtained from 0-20 cm soil depth, where 5 subsamples were obtained in each site, thoroughly mixed, and 1000 g of mixed soils were obtained and kept in a plastic bag. The analysis was run at Plant and Soil Analytical Laboratory of Indonesia Legumes and Tuber Crops Research Institute (ILETRI). Water extractable organic C and water extractable N were determined from soil solution prepared from 4 g of dry soil which was added with 40 mL deionised water and shake for 10 minutes in a mechanical shaker. Samples were then centrifuged for 5 minutes at 3500 rpm, filtered through Whatman paper and analyzed for water extractable organic C and water extractable N (Haney et al., 2012). Particulate Organic Carbon (POC) was determined

according to Figueiredo et al. (2010). The amount of 20 g air-dried soil samples after having 2 mm sieving were placed in a plastic bottle (volume of 250 mL) and 70 mL of sodium hexametaphosphate was added at a concentration of 5.0 g/L. The mixture was shaken for 15 h in a horizontal shaker. After this process, the entire content of the vial was placed in a 53 µm sieve and washed with a weak

jet of distilled water. The material retained on the sieve was dried at 50°C, and it was defined as total particulate organic matter (>53 µm). After drying, the sample was ground in a porcelain mortar and passed completely through a 0.149 mm sieve, weighed and analyzed for their C and N contents, representing the particulate organic C (POC) and N in particulate organic matter.

Table 1. The names of sampling sites and number of samples in each site, Sumba Timur District

Sub District	Village	Amount of sampling locations	Altitude (m above sea level)
Kanatang	Hamba Praeng	5	244-255
	Haharu	2	18-87
Pandawai	Rambang Aru	3	18-87
	Hambuung	2	100-125
	Palaka Hembu	3	14-25
Matawai La Pawu	Leindeha	2	526-555
	Tanarara	5	800-900

Soil microbial biomass C and N were measured by fumigation extraction using ethanol-free chloroform as a fumigant and followed by extraction with potassium sulphate (K₂SO₄). Extracts of fumigated and un-fumigated soils were analyzed for extractable organic C, and N. Microbial C and N were calculated as the difference in the particular nutrient between fumigated and un-fumigated extracts and corrected for unrecovered biomass using k factors of 0.35 for microbial C and 0.54 for microbial N (Nottingham et al., 2015).

Statistical analysis

Analysis of variance was used to find out the significant effect of altitudes on the observed parameters. Once there was a significant effect, a Duncan Multiple Range Test (DMRT) at 5% probability was applied to compare among the means. This statistical analysis was processed using Mstat-C program. Linear regression and correlation, as well as graphical presentation, were performed using Microsoft Excel Program.

Results and Discussion

Total nitrogen, organic carbon, and C:N ratio

The study showed that altitudes influenced the amount of nitrogen in the soil. Starting from low altitude up to 700 m above sea level (asl), the amount of soil nitrogen was almost similar. However, when it moved to the places higher than 700 m asl, soil nitrogen reduced from 0.18 % to 0.10%. Conversely, the concentration of organic C and ratio of C:N in the soil increased by increasing

the altitudes (Table 2). At the altitude <200 m asl, the concentration of organic C was 3.01%, and this number increased to 3.48% at >700 m asl altitude. In term of C:N ratio, the number increased from 16.72 to 24.85 by increasing the altitude from <200 m to >700 m asl (Table 2). Total nitrogen negatively correlated to organic C. It means that the higher the concentration of organic C, the lower was the total N content in the soil. The availability of nitrogen in the soil was very affected by mineralization process of organic matter where this process was dictated by many factors such as quality of organic matter, soil pH, soil humidity, soil temperature, and altitudes (Samuel et al., 2002; Handayanto et al., 1997; Agehara and Warncke, 2005; Griffin and Honeycutt, 2000; Cookson et al., 2002; Bonito et al., 2003; Kyveryga et al., 2004; Fritsch et al., 2005). The C:N ratio expressed the quality of organic matter, and the critical point of nitrogen mineralization was obtained when the C:N ratio was 20 (Prescott et al., 2000). The mineralization of organic matter occurred when the ratio was lower than 20, but when the ratio was higher than 20 there was an immobilization process (Abera et al., 2012). The results of the observation pointed out that at 0-700 m asl altitudes, the C:N ratio was lower than 20, and at the altitudes of higher than 700 m asl the C:N ratio was higher than 20. It can be interpreted here that at 0-700 m altitudes, the nitrogen mineralization process ran well while at altitudes >700 m asl there was nitrogen immobilization by soil microorganisms. The mineralization of organic materials was also related to soil humidity, temperature and altitudes.

At higher altitude places, there was higher rainfalls and lower temperatures. This condition retarded the decomposition and mineralization process of organic materials and resulted in reducing the amount of N and conversely increasing C organic in the soil. Decreasing soil temperature and

increasing humidity were two factors responsible for reducing the decomposition rate that resulted in the accumulation of soil organic materials. In addition, reducing soil temperature was also reducing the nitrogen mineralization rate (Kirschbaum, 1995).

Table 2. The effect of altitudes on soil chemical characters in Sumba Timur, NTT 2015

Altitude (m asl)	pH	Total N (%)	Organic C (%)	C:N ratio	Organic matter (%)
0 - 200	7.5 a	0.18 a	3.01 b	16.72 c	5.20 b
200 - 700	6.8 ab	0.17 a	3.11 a	18.19 b	5.39 b
>700	6.3 b	0.14 b	3.48 a	24.85 a	6.02 a

The changes of labile fraction organic C and N at several altitudes

Labile fraction organic C increased by increasing altitudes. At <200 m altitude, the concentration of water-soluble carbon was 19.8 mg/kg; this amount increased to 20.2 and 23.5 mg/kg with increasing altitude to between 200-700 m and >700 m asl, respectively (Figure 1). The microbial biomass carbon (MBC) and particulate organic carbon indicated the same trends. It indicated that MBC increased by 92% with increasing altitude from 200 m to 700 m asl. In term of particulate C concentration, its concentration consecutively increased from 15.8 to 21.3 and 35.1 mg/kg by increasing altitude from <200 m through to 200-700 m and further to >700 m asl. In other words, the concentration of POM increased as many as 121% by increasing the altitude from 200 m to 700 m asl. The increase in labile fraction was the result of the increase of soil organic matter content as labile fraction carbon was the component of soil organic matter. Zhang et al. (2010) stated the concentration of labile fraction carbon very depended on soil organic matter content, and labile fraction C was a good indicator to predict the changing of soil organic matter in terms of the carbon cycle. Wang et al. (2012), Pabst et al. (2013), Zhang et al. (2010) and Chang et al. (2016) concluded that labile fraction C in the soils was reduced by lowering the altitudes. Zhang et al. (2010) found that the concentration of MBC and POM were affected by altitude, where their concentrations at 1996 m asl were higher than those at 1350 m, and those at 135 m were higher than those at 740 m asl. Labile fraction C is an active fraction as a component of soil organic matter and can change quickly. This fraction was a sensitive indicator of environmental changes. Instead of providing energy to plants and microorganisms, the labile fraction also played an

active role in the biochemical transformation process in the soils (Zhang et al., 2006). The concentration of labile fraction in the soil was very affected by temperature, humidity, altitude, and quality of organic matter (Zhou et al., 2015; Gutierrez-Giron et al., 2015) as well as soil management and cropping pattern (Wijanarko and Purwanto, 2017).

The result of labile fraction nitrogen analysis (water-soluble N and microbial biomass N) showed that the higher the altitude was, the lower was the concentration of water-soluble N and microbial biomass N. At the altitude of lower than 200 m asl, the concentration of water-soluble N was 22 mg/kg. This amount lowered to 20.2 and 14 mg/kg by increasing the altitude to 200-700 m and >700 m asl, respectively (Figure 2). The concentration of microbial biomass N was 34 mg/kg at altitude <200 m asl, and this concentration reduced to 30.2 mg/kg at altitude 200-700 m, and further reduced to 24 mg/kg at an altitude of 700 m asl. It can be mentioned that there was a significant reduction (29%) of MBC N concentration by increasing altitude from <200 m to altitude of 700 m asl. The mineralization process was more active in the altitude of lower than 200 m compared to that when it occurred at the altitude higher than 700 m asl. This can be observed from the C:N ratio at those two different altitudes. At the altitude <200 m asl, the C:N ratio was 16.7. This figure shows that there was a mineralization process of organic matter. While at altitude >700 m asl the C:N ratio was 24.8 and this shows the presence of immobilization process by microorganisms. Li et al. (2011) stated that organic matter with high N content and low C:N ratio can accelerate the process of mineralization compared to that with low N content and high C:N ratio as a result of increasing the activity of microorganisms which depend on the quality of organic matter and N availability

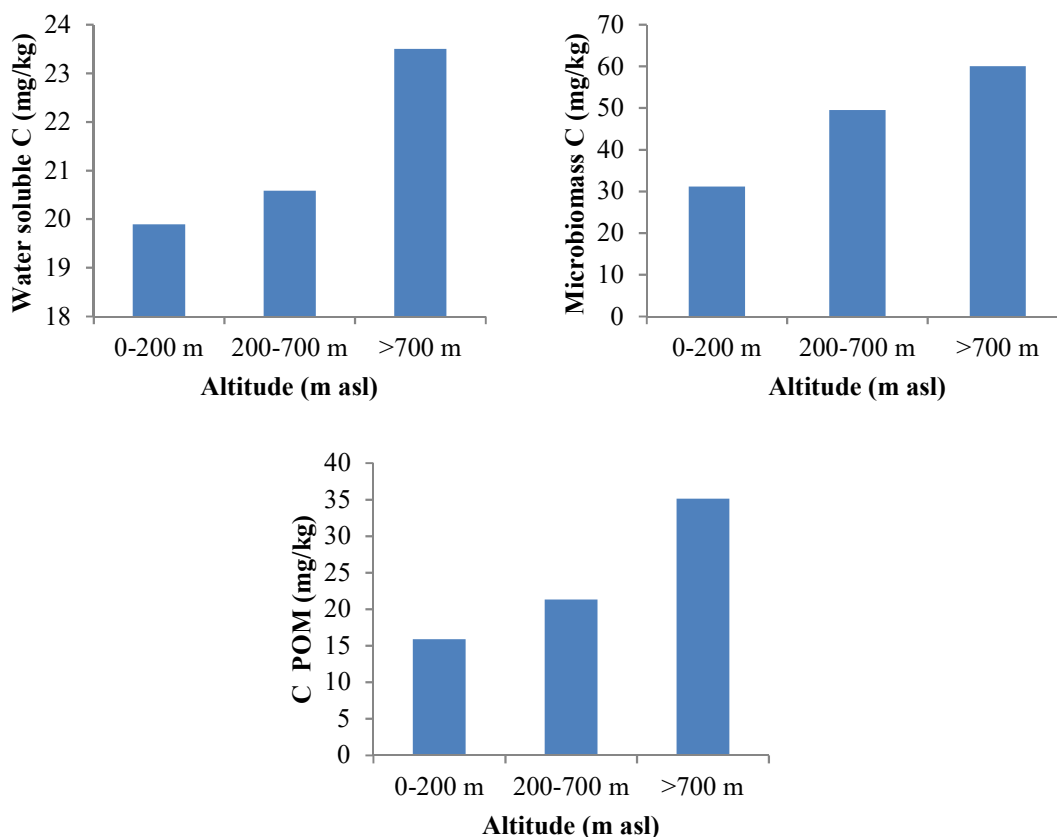


Figure 1. The concentration of labile fraction carbon (water-soluble C, microbial biomass C and particulate organic matter (POM)) at several altitudes

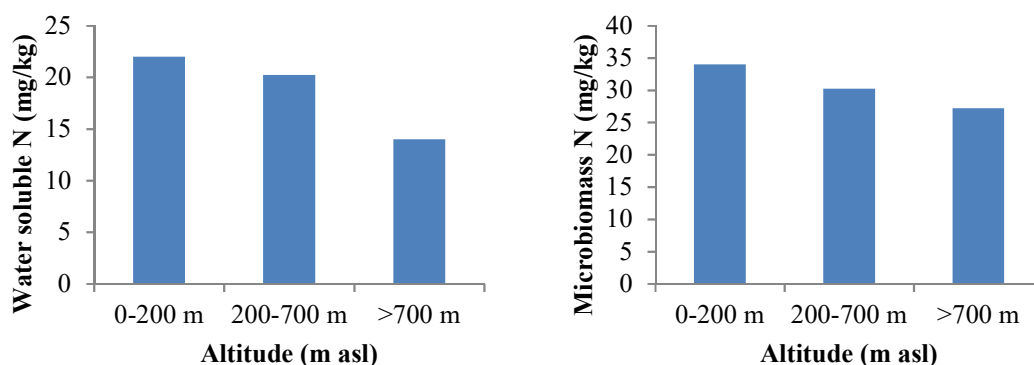


Figure 2. The concentration of labile fraction N (water-soluble N and particulate) at several altitudes

The comparison of labile fraction C and soil organic carbon

The comparison of soil organic C and labile fraction C was used to find out the amount of soil organic C that changed into labile fraction C. This

phenomenon also showed that the change from soil organic C to labile fraction C could easily happen (Zhang et al., 2010). This process was very influenced both by internal and external factors of organic matter. It can be explained here that the internal factor was the quality of organic matter

that generally is related to C:N ratio, while the external factor was soil temperature, moisture content, pH, as well as microorganisms and altitude. The current study indicated that at altitude >700 m asl, the ratio water-soluble C/organic C, MBC/organic C, and labile fraction C/organic C were higher than those at altitude <700 m asl.

The ratio of water-soluble C, MBC, Particulate organic C and total labile fraction C to soil organic matter was very small, i.e. less than 1% (Table 3). This result was in accordance with Zhang et al. (2010) who pointed out that the comparison of particulate C to soil organic matter was in the range between 0.3-1.7%. While Wang et al. (2012) obtained the ratios of 0.21-2.28%, 0.46-7.14%, and 0.13-1.77% for particulate C/organic C; MBC/organic C, and labile fraction C/organic C, respectively. The ratio of labile fraction/organic C at altitude >700 m asl was higher compared to that at altitude <700 m asl. This showed that at altitude >700 m asl, the concentration of active carbon pool was higher compared to that in altitude <700 m asl. High labile

organic C (LOC) was a sensitive indicator for soil quality and soil fertility compared to soil organic C. Xu et al. (2006) declared that there was a positive correlation between LOC concentration and crop yield, but there was no correlation between soil organic C (SOC) content and crop yield.

The ratio MBC/SOC at altitude >700 m asl was also higher compared to that ratio at the altitude <700 m asl. The high MBC/SOC value pointed out that (1) the conversion of soil organic matter into MBC was efficient, and (2) the indication for a high rate of biological activity. Experiments conducted by Siles and Margesin (2016) and Siles et al. (2017) showed there was an increase on soil organic content and followed by the increase of population and activity of microorganisms, which these two later components were influenced by organic matter substrate. Whenever the organic matter contained material that was easily decomposed, the microbial activity would like to increase and resulted in rapid changes of organic matter that can be seen by increasing polysaccharides and N soil contents.

Table 3. The ratio of labile fraction C and soil organic C

Altitude (m asl)	Water-soluble C/organic C	MBC/organic C	Particulate C/organic C	Labile fraction/organic C
0-200	0.066	0.10	0.05	0.22
200-700	0.066	0.16	0.07	0.29
>700	0.068	0.17	0.10	0.34

Conclusions

Altitude influenced total N availability and soil organic C. The higher the altitude, the lower was the N concentration. Conversely, the higher the altitude, the higher was the concentration of organic C and C: N ratio. Labile fraction C increased by increasing the altitudes. The labile fraction N (water-soluble N and microbial biomass N) was reduced by increasing the altitudes. The ratio of labile fraction C/organic C at altitude >700 m asl was higher. This showed that the concentration of the active carbon pool was higher compared to that at altitude <700 m asl. The ratio of MBC/SOC at altitude >700 m asl was high. This high value showed an efficient on the conversion of soil organic matter into MBC and played as an indicator for biological activity rate.

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