

Microbial Respiration as Indicator of Soil Quality of Different Land Uses in Cienda, Gabas, Baybay City, Leyte

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ABSTRACT

Land use conversion affects soil ecosystem quality and balance, which can be reflected by microbial activities. This study was conducted to assess the effectiveness of microbial respiration as indicator of soil quality of different land uses, reforestation site, agricultural land and grassland, in Cienda, Gabas, Baybay City, Leyte. The amount of CO₂ evolved after one, three and seven days of incubation was used to determine microbial respiration rate of different land uses and across relief. Relationship between microbial respiration on pH, organic matter, total nitrogen, and moisture content at field capacity were also examined.

Results revealed that microbial respiration varies significantly among land uses with the highest rate observed in grassland while the lowest was in the reforestation site. Across relief, amount of CO₂ released was significantly higher in the lower slope compared to the upper and the middle. The process tends to be significantly influenced by soil organic matter and moisture content. Results suggest that there is an inverse relationship between microbial respiration and organic matter, and a direct relationship with moisture content. High soil respiration in the grassland and in the lower topographic relief implies that the soil organic matter is converted into inorganic forms which are available for uptake by plants. A significant interaction between land use types and relief was also observed in both organic matter and moisture content leading enhanced microbial respiration. Land use and relief showed no significant effect on total nitrogen and soil pH.

Keywords: microbial respiration, soil quality, land uses, organic matter, decomposition

INTRODUCTION

Microorganisms abound in the soil and are critical to ecosystem processes such as decomposition of organic residues and recycling of soil nutrients

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(Magdoff & Van Es 2001). Their population in the soil changes rapidly as soil organic matter (SOM) products are added, consumed, and recycled. Nonetheless, soil microorganisms exist in large numbers as long as there is carbon source for energy (Hoorman & Islam 2010). Being very sensitive to changes in soil conditions, microorganisms can reflect reliable outcomes and results to any soil quality changes even at a shorter period compared to any other parameters (Wolters & Schaefer 1994, Pankhurst et al 1997). Accordingly, the change in land use can alter both the rate and direction of natural processes (Turner et al 2001), including the soil equilibrium which could be disturbed easily.

Microbial respiration is vital in maintaining soil ecosystem. This oxidative process occurs within living cells, which releases chemical energy of organic molecules in a series of metabolic steps, involving the consumption of oxygen (O_2) and the liberation of carbon dioxide (CO_2) and water (H_2O). Among the various organisms in the soil, microbes play a fundamental part in the decomposition of organic matter which entails the highest possible source of CO_2 available for the soil (Pankhurst et al 1997). Through their acquisition of carbon and nutrients for growth, microbial biomass in soils constitutes an important sink and source of essential plant nutrients. Thus, microbial respiration is important for soil health and soil ecosystem sustainability. In order to determine the response of soil as an affected ecosystem, and to evaluate its condition, there is a need to understand and quantify the linkage between microbial response and change in soil processes such as decomposition and nitrogen mineralization.

Over time, many incidents of declining soil microbial respiration as well as soil health have been reported resulting from different human interventions including land use conversion. Many hypothesized that the rate of microbial respiration significantly varies from forestland to grassland to agricultural land (Anderson 2003), however, not much studies had been conducted to prove this claim. Determination of the impact of different land uses on the status of organic matter and nutrient availability on the tropical forests of Leyte was done by Asio et al (1998). Marohn (2006), on the other hand, studied the soil biological activities under different land uses in Leyte. However, the effectiveness of microbial respiration as indicator of soil quality of different land uses and in different topographic relief still needed to be assessed. Therefore, this study was conducted to determine the relationship between microbial respiration on soil organic matter, pH, nitrogen and moisture content at field capacity, and to determine if the rate of microbial respiration varies significantly among different land uses and topographic relief.

MATERIALS AND METHODS

Site Description

The study was conducted in the reforestation site, coconut land, and grassland areas in Cienda, Gabas, Baybay City, Leyte. The three land use types were selected because they are adjacent or least very near to each other, a factor in site selection aimed at minimizing heterogeneity of all other environmental factors affecting soil microbial respiration. The selection of land use was based on the usual trend in land use conversion especially in mountainous areas, that is, forest

agricultural land. Due to the absence of cropland in the area, coconut land was considered, which is also ecologically important considering that 3.52 million hectares or 26% of the total agricultural land of the Philippines is planted to coconut as of 2015 (PCA 2015).

The reforestation site in Cienda, approximately 10,000m², was established in 1996. It is dominated by dipterocarp and fruit tree species including bagtikan (*Parashorea malaanonan* [Blanco] Merrill), white lauan (*Shorea contorta* S. Vidal), bitanghol (*Calophyllum blancoi*), yakal saplungan (*Hopea plagata* [Blanco] Vidal), malakauayan (*Podocarpus* spp.), rambutan (*Nephelium lappaceum* L.), marang (*Artocarpus odoratissimus* Blanco) and lanzones (*Lansium domesticum* Correa), which were planted at an average distance of 2m x 1m. Adjacent to it is an agricultural land planted to coconut trees, with an approximate area of 10,000m², having undergrowth vegetation including grasses and bushes. Adjacent to the coconut land is grassland ecosystem, with an estimated area of 7,000m², dominated by creeping grasses such as *Paspalum* sp.

Soil Sample Collection and Preparation

In each land use, three sampling points were randomly selected in the upper, middle and foot slope of the areas with a total of nine sampling points per land use type. The upper, middle and lower topographic positions had an average elevation of 79, 77, and 75 m above sea level, respectively.

From each sampling point, one kilogram (kg) of bulk soil sample was collected from the topsoil (0-20cm) using a soil auger. One hundred grams (100g) of fresh soil samples were set aside; clods of soil were broken down but not sieved and roots were removed using forceps for the determination of microbial respiration (Marohn 2006). The remaining soil samples were air-dried and thoroughly mixed. After air-drying, soil clods and aggregates were pulverized with the use of a wooden mallet. Then, these were passed through a 0.425mm wire mesh sieve for the determination of soil pH, organic matter content, total nitrogen and moisture content at field capacity.

Soil Analysis

Soil pH was analyzed potentiometrically using a soil:water ratio of 1:2.5 (ISRIC 1998). Soil organic matter (SOM) was determined using the Walkley and Black wet combustion method (ISRIC 1998). Total nitrogen content of the soil was determined through micro Kjeldahl method (Jackson 1958). Moisture content at field capacity was determined by measuring fresh weight after soil saturation, and oven-dry weight of the soil (ISRIC 1998).

For microbial respiration, soil samples were prepared for incubation by weighing 100g of fresh soil sample collected from 0-20cm depth from the three land uses and across reliefs. These were then placed separately in properly labeled, sealed jars and were incubated at room temperature for one, three and seven days incubation period (Marohn 2006). In total, there were 28 jars used in this experiment: 27 for the soils from the three land uses and a control setup with no soil. Incubation was done by putting 15mL 1N NaOH on a beaker which was placed on top of the jars containing the soil. The jars were tightly sealed and after

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(in milligrams) after each incubation period was determined following the method of Alexander (1997) using the formula:

$$\text{Milligrams C or CO}_2 = (B-V) NE$$

where:

V= volume (mL) of acid to titrate the alkali in the CO₂ collectors from treatment to the end point

B= volume (mL) of acid to titrate the alkali in the CO₂ collectors from control (no soil) to the end point

N= normality of acid

E= equivalent weight, wherein if data are expressed in terms of carbon E=6, if expressed as CO₂, E=22.

Statistical Analysis

All data were tested for normality and homogeneity using PROC Univariate of Statistical Analysis System version 9.1 (SAS, 2003). PROC GLM (General Linear Model) procedure was initially performed to assess the significant effects of land uses, relief and their interactions on soil organic matter, pH, total nitrogen, soil moisture content at field capacity, and microbial respiration.

The final models for each response variables were analyzed but including only those significant main factors and interaction effects. Duncan Multiple Range Test (DMRT) and least square means (LSD) were carried out to compare treatment means and independent variables with significant variations at $p \leq 0.05$.

RESULTS AND DISCUSSION

General Characteristics of the Study Site

The study site lies within 10°43'33.9" to 10°43'44.2" North and 124°48'38.4" to 124°48'45.1" East. Soil in the area, based on Food and Agriculture Organization (FAO) classification, is dystric nitisol, and of volcanic origin (Marohn 2007) and falls to Type IV climatic category where the rainfall is almost evenly distributed throughout the year (www1.pagasa.dost.gov.ph). Soil climate has been classified as isohyperthermic, i.e. above 22°C, throughout the year with variation of less than 5°C in the 50cm depth (Asio 1996).

Soil Properties of Different Land Uses

Soil pH

Soils from different land uses and across reliefs are acidic. Between land uses, soil had pH values ranging from 5.10 ± 0.07 to 5.13 ± 0.07 (Figure 1A), which are insignificantly different ($p = 0.92$). Across reliefs, on the other hand, soil pH values are between 5.01 ± 0.07 to 5.24 ± 0.07 with the lowest value observed in the middle while the highest was in the upper relief (Figure 1B).

ANOVA shows that the difference between these values is nearly significant ($p=0.09$) although DMRT shows that this difference is significant at $p \leq 0.05$. Nevertheless, lower relief showed insignificant difference between upper and middle relief. Insignificant interaction ($p = 0.68$) between land use types and reliefs was also detected. The significant difference in soil pH between the upper and middle topographic positions may be attributed to the amount of litter present in the soil surface with the former having more leaf litters. The decomposition of such can alter soil pH. Increase in leaf litters may cause increase in soil pH as it enhances Mg^{2+} and Ca^{2+} input which can improve the buffering capacity of the soil that compensate the acidifying effect of acidic intermediates and humus compounds (Toth et al 2011). Results suggest that land use type may not have contributed enough to modify significantly the pH of the soil.

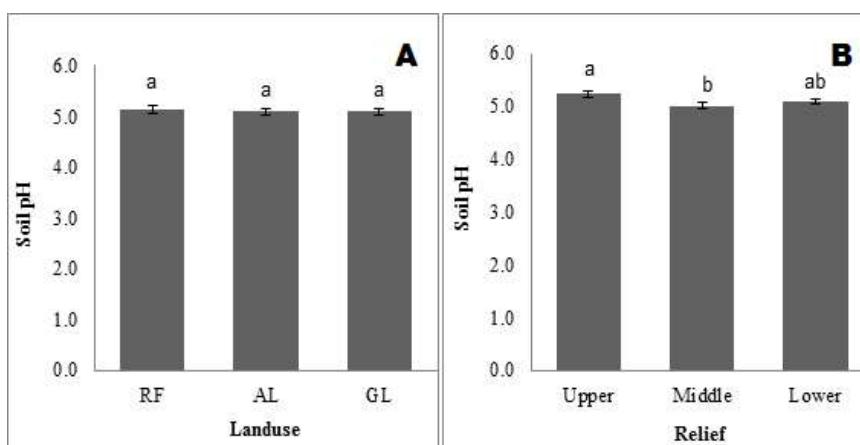


Figure 1. Soil pH of the different land uses (A) and at different reliefs (B) in Cienda, Gabas, Baybay City, Leyte. (Note: RF- Reforestation site; AL- Agricultural land; GL – Grassland. Different letter subscripts (a-b) of the same dependent variables among land use and relief are significantly different at $p \leq 0.05$, $n = 27$)

Soil Organic Matter

Results of soil organic matter content in different land use types revealed that the mean soil organic matter content was lowest ($2.18\% \pm 0.89$) in grassland while the highest ($3.44\% \pm 0.89$) was observed in the reforestation site (Figure 2A). These values are within the normal range for most mineral soils contain 2 to 10% organic matter (FAO 2005). Mean SOM values are found significantly different ($p = 0.00$) between land uses. The lowest SOM value in grassland among the three land uses could be explained by the fastest turnover rate of carbon in grassland ecosystem compared to the reforestation site and agricultural land. This implies increased decomposition, which could reduce the carbon available for growing plants and micro-organisms (Davidson & Janssens 2006) while increasing the inorganic nutrients for plant uptake. The faster decomposition in the grassland could be supported by the morphological characteristics of the dominant grasses in the study site which possess shiny and thinner leaves compared to the tree species in

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the reforestation site, and the coconut in the agricultural land. Morphological features of the grasses suggest thinner cuticle and wax layer on leaf surfaces which otherwise hinder the decomposition process since these substances are resistant to decomposition (Alexander 1977).

SOM across relief ranges from $2.50\% \pm 0.09$ to $2.89\% \pm 0.09$ (Figure 2B). ANOVA proves that relief has significant effect ($p = 0.01$) on organic matter. Specifically, the significant difference was found between the lower relief in comparison with the upper and middle relief. Nonetheless, there was no clear difference in OM between upper and middle slopes of the sites. A significant difference ($p = 0.05$) was also observed in the interaction between different land use types and different reliefs. The interaction was specifically observed between agricultural land and grassland in the lower slopes (Figure 3). This could probably be attributed by the similarity in some of the species composition in grassland and agricultural land. The grassland was dominated by *Paspalum* sp. while in the agricultural land, understory vegetations include the herbaceous and shrubby as well as grasses, especially *Paspalum*.

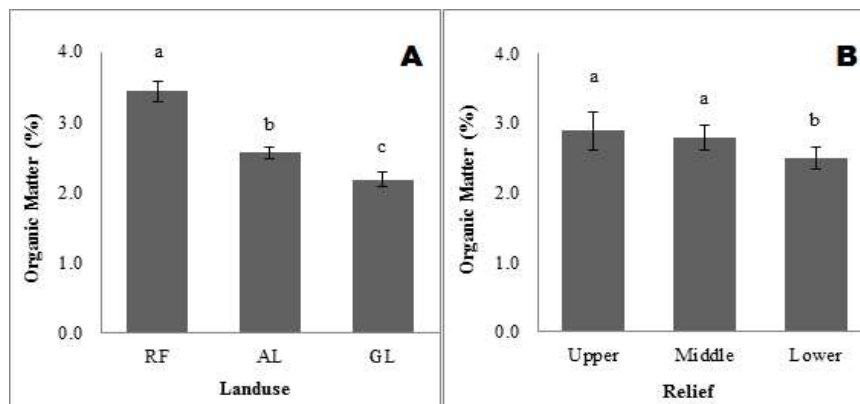


Figure 2. Soil organic matter of the different land uses (A) and at different reliefs (B) in Cienda, Gabas, Baybay City, Leyte. (Note: RF- Reforestation site; AL- Agricultural land; GL – Grassland. Different letter subscripts (a-b) of the same dependent variables among land use and relief are significantly different at $p \leq 0.05$, $n = 27$)

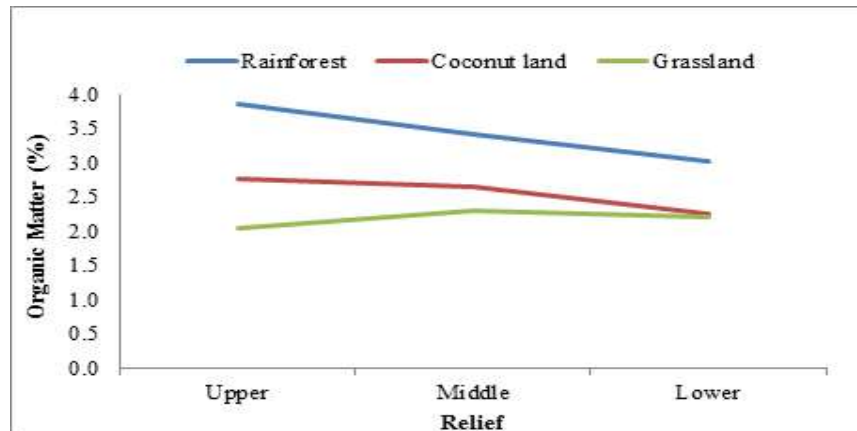


Figure 3. Two factor interaction effect of land use and relief on soil organic matter in Cienda, Gabas, Baybay City, Leyte

Total Nitrogen

Total nitrogen does not differ significantly ($p = 0.97$) between land use types and across reliefs. This is clearly because values show only very slight difference between land use types ranging from $0.34\% \pm 0.02$ in agricultural land to $0.34\% \pm 0.01$ in the reforestation site. Total nitrogen slightly varies across reliefs giving no significant difference ($p = 0.19$). Consequently, there is no significant interaction ($p = 0.87$) observed in total nitrogen between land use types and reliefs. These values support the study of Asio et al (1998) which reported that the total nitrogen of the topsoil in the reforestation sites in Baybay, Leyte ranges from 0.29 to 0.35%. They also stated that in the same area, lands planted to coconut, in association with bushes, have a total nitrogen of 0.28 to 0.59%. Marohn (2007) also reported around the same values of total nitrogen in the reforestation site in Leyte, Philippines, which are normal for old tropical soils.

Moisture content at field capacity

Across land use types, moisture content values range from $60.30\% \pm 1.57$ from reforestation site to $68.24\% \pm 1.57$ in agricultural land (Figure 4). Results revealed that soil moisture content of the reforestation site varied significantly ($p = 0.00$) with that of the agricultural land and grassland (Figure 4A). Results further show that there was no clear variation in moisture content between grassland and agricultural land. Likewise, as can be seen in Figure 4B, there was no significant difference ($p = 0.66$) in soil moisture content between reliefs with values ranging from $63.94\% \pm 1.57$ (upper) to $65.96\% \pm 1.57$ (middle). However, a significant difference ($p = 0.04$) was observed in the interaction between different land use types and different reliefs (Figure 5). This may be contributed by a similarity in soil texture, which is clayey, in the lower relief in the reforestation site and with that of the agricultural land and grassland, which moisture content across relief do not

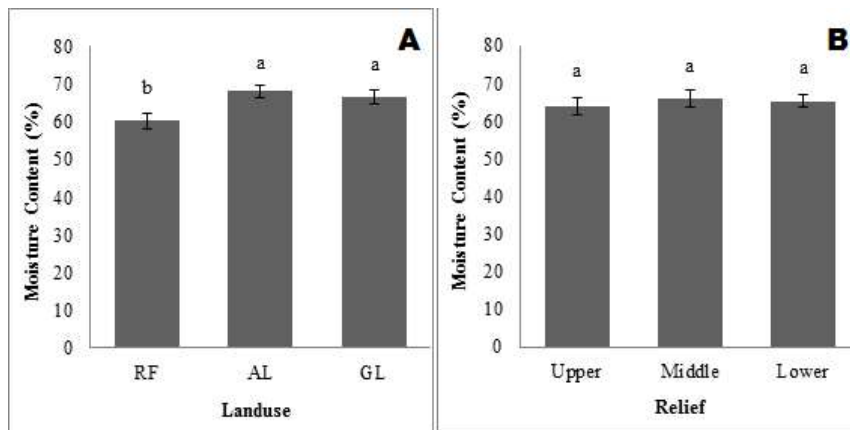


Figure 4. Soil moisture content at field capacity of the different land uses (A) at different reliefs (B) in Cienda, Gabas, Baybay City, Leyte. (Note: RF- Reforestation site; AL- Agricultural land; GL – Grassland. Different letter subscripts (a-b) of the same dependent variable among land use and relief are significantly different at $p \leq 0.05$, $n = 27$)

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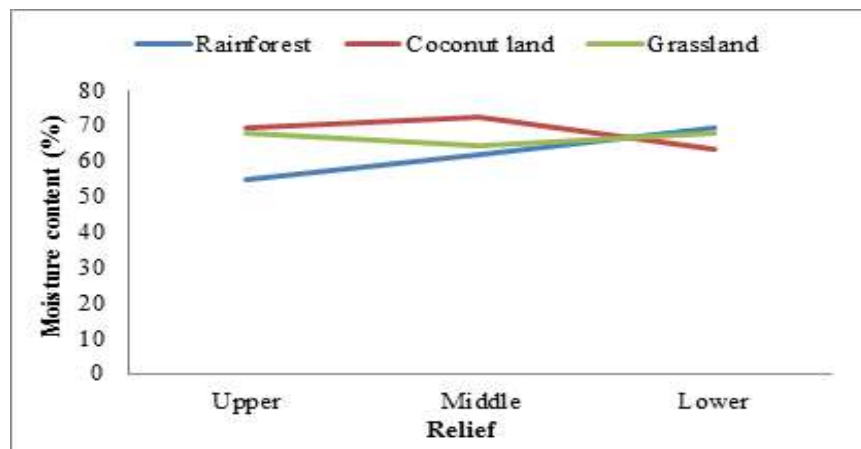


Figure 5. Two factor interaction effect of land use and relief on soil moisture content in Cienda, Gabas, Baybay City, Leyte

Soil texture affects water retention capacity of the soil. Clay tends to retain more moisture because of its density compared to sand and silt. Marohn (2007) reported that the Cienda reforestation site has a heavy clay soil texture. However, the significantly higher ($p=0.01$) moisture content at field capacity of the soil under the agricultural land may indicate higher percentage of clay compared to the reforestation site. Another possible reason could be the water holding-properties of OM (Hadi et al 2001) that changes moisture content at field condition.

Microbial Respiration of Different Land Uses

Results revealed that evolved CO_2 increased with increasing period of incubation. Data, however, suggest that the greatest production of CO_2 occurred during the first day of incubation. The increased CO_2 and the declining oxygen concentrations inside the sealed jars as the period of incubation increased could have possibly inhibited soil microbial activity (Batistel & Asio 2008). In addition, this indicates that the substrate level decreased which consequently reduced the microbial respiration to negligible rates (Chapin et al 2002). Moreover, results show that throughout the three incubation periods, grassland had the highest microbial respiration rate among the three land uses as reflected by the evolved CO_2 (91.32, 97.10, 100.50 mgCO_2) while the reforestation site had the lowest (51.62, 64.02, 68.97 mgCO_2) after one, three and seven days of incubation respectively (Figure 6). Throughout three incubation periods, a significant difference ($p = 0.00$) in microbial respiration between land uses was found.

Pearson correlation revealed that organic matter has a very strong negative correlation (-0.911) with soil microbial respiration. This suggests an inverse relationship between the two parameters implying that as microbial respiration increases organic matter decreases. This means that faster decomposition results in the formation of less stable humus and an increased liberation of CO_2 to the atmosphere, and a reduction in organic matter (Bot & Benitez 2005).

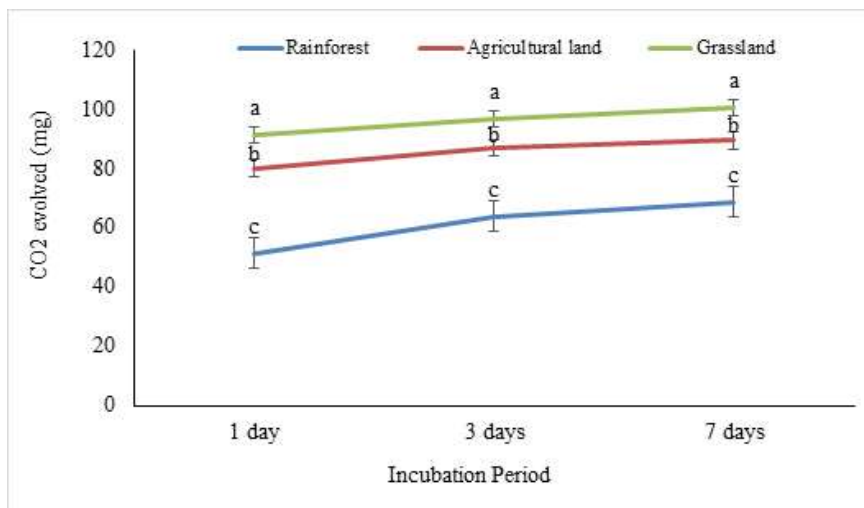


Figure 6. Microbial respiration in different land use types after incubation of soils from Cienda, Gabas, Baybay City, Leyte. (Note: Different letter subscripts (a-c) of the same dependent variable among land use are significantly different at $p \leq 0.05$, $n = 28$)

In addition, moisture content strongly influences microbial respiration with a correlation value of 0.537 which is highly significant at $\alpha=0.01$. This suggests that microbial activity is enhanced as moisture content increases. This explains the results of this study wherein microbial respiration rate was consistently highest (91.32 mgCO₂/day, 97.13 mgCO₂/3days, 100.56 mgCO₂/7days; standard error is ± 2.75) in grassland ecosystem. This conforms to the statement of Davidson and Janssens (2006) that grassland soil has high CO₂ evolution. Grassland is characterized by high moisture content at field capacity (66.62 \pm 1.57) and fast turnover rate of carbon (Davidson & Janssens 2006).

However, according to Curiel et al (2007), the most relevant factors affecting microbial respiration are temperature, soil moisture and carbon inputs. Although temperature was not measured on site, it is expected to be highest in grassland among the three land uses due to its nearly direct exposure to solar radiation relative to the two other land use types. Chapin et al (2002) stated that rising temperature causes an exponential increase in microbial respiration, speeding up the mineralization of organic carbon to CO₂. Under reforestation site, soil temperature is expected to be relatively lower due to presence of the tree canopy which intercepts solar energy. This environmental condition could decrease the decomposition process in the reforestation site resulting to the accumulation of organic matter on the forest floor thus, higher OM content on its topsoil.

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With respect to moisture content, moisture limitation can also reduce microbial activity and restrict microbial access to C substrates (Wood et al 2013). The decomposition rate of mineral soil generally declines at soil moistures less than 30 to 50% of dry mass (Haynes 1986), due to the reduction in thickness of moisture films on soil surfaces and therefore the rate of diffusion of substrates to microbes (Stark & Firestone 1995). However, decomposition is also reduced at high soil moisture contents (eg, greater than 100 to 150% of soil dry mass in mineral soils; Haynes 1986). Ideally, soil moisture enhances soil microbial respiration up to near field capacity, or when 60% of the pore space is filled with water (USDA-NRCS 2009). More than this, the ability of soil organisms to respire is negatively affected due to limiting oxygen availability. The moisture content obtained in different land uses falls on the values at which moisture content can facilitate microbial respiration. That is, in normal environment, grassland, having the highest moisture content, can still accommodate the highest possible microbial respiration and continuous decomposition of organic matter than the other land uses.

Across reliefs, microbial respiration also differs significantly after 1 day ($p = 0.01$), 3 days ($p = 0.01$) and 7 days ($p = 0.00$) incubation periods. This means that the amount of released CO_2 increases significantly with increasing incubation period. However, results showed that lower and middle reliefs have no clear differences, but differ significantly with upper relief (Figure 7). This may be attributed by the different microbial biomass present at each topographic position. The interaction between land use types and reliefs also showed no significant effect on microbial respiration.

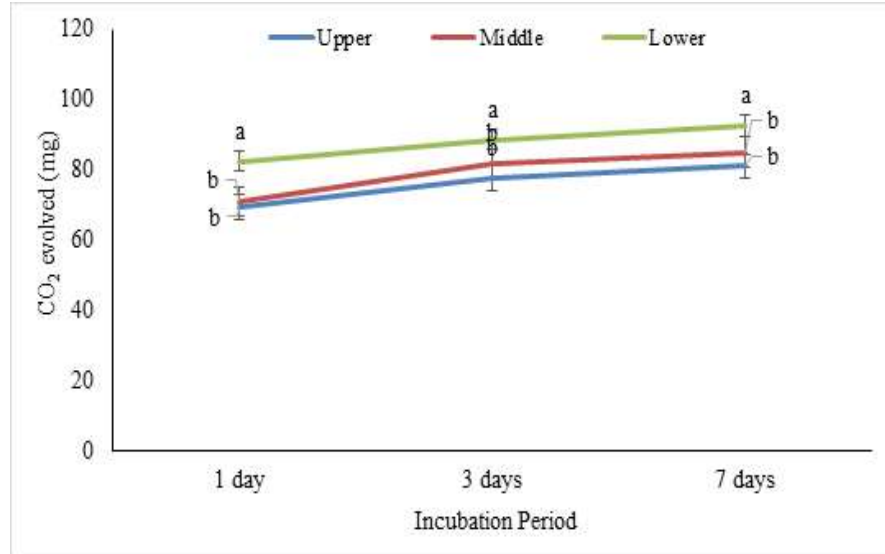


Figure 7. Microbial respiration at different topographic reliefs after incubation of soils from Cienda, Gabas, Baybay City, Leyte (Note: Different letter subscripts (a-b) of the same dependent variable among topographic relief are significantly different at $p \leq 0.05$, $n = 28$)

CONCLUSIONS

Among the soil properties tested, organic matter and moisture content significantly affects microbial respiration. Results suggest that soil organic matter decreases with increasing microbial respiration. Moisture content, on the other hand, enhances microbial respiration, however, up to near field capacity only. In addition, there is no clear difference in the effects of total nitrogen and soil pH on microbial respiration. Microbial respiration tends to vary significantly between land uses and across relief.

Among the three land uses, grassland has the highest microbial respiration rate while reforestation site has the lowest. There is no interaction between different land use types and across reliefs. Organic matter and moisture content are affected significantly by different land uses. Different relief also significantly affects organic matter. However, relief has no effect on moisture content. Results obtained show insignificant effect of different land uses and reliefs on total nitrogen and soil pH.

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