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Original Article

# Effects of Drought Levels on Soil Microbial Respiration and Biomass in Correspondence with Land use Types

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**Abstract:** Quang Nam province located in the middle of Vietnam, has suffered an increasing drought for many years, this threatens the crop production. Drought severity seems to be added in by land use change from forest to horticultural land but the interactions among drought, land use change and soil biological properties remain elusive in this area. Therefore, the research aimed to evaluate drought occurence in Quang Nam and also the effect of land use change on soil respiration and microbial biomass. Three hypotheses were proposed as i) Drought tends to be more severe in future in Quang Nam but behaves differently between plain and mountainous areas; ii) Microbial respiration reduces with increasing drought severity but depending on land use types; and iii) Water stress (60% to 30% water holding capacity - WHC) induces reduction of microbial biomass which remains no changes as soil moisture reduces from 30% to 10% WHC. Forest land decreased by 8.34% from 2003 to 2013 but increased by up to 5.86% in 2018 compared to 2013. Drought severity level has decreased slightly during 2003 - 2019 but more concentrated in the coastal plain than mountainous area, mainly occurred in the dry season from February to July. Basal respiration (BR) decreased a half as soil moisture declined from 60% to 30% WHC and remained unchange given the soil moisture decreased to 10% WHC. The dramatic decrease of BR demonstrated a shock of microbial community to altered environment condition. The similarity of BR between two soil types

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implied more important role of drought impacts than land use conversion. The decrease of soil moisture resulted in the reduction in nutrient diffusion that cause difficulties for microorganisms to approach available nutrients in soil and negatively affecting microbial biomass synthesis. Higher microbial biomass nitrogen (MBN) in forest than pineapple might suggest that forest soil would be of advantage to sustain soil fertility and microbial activities than crop land in resistence to drought impacts. Briefly, interdisciplinary approach is critical in assessment of climate change impacts on C and N cycles in correspondence to land use changes.

*Keywords:* WHC, drought severity, microbial respiration, climate change, microbial biomass.

## 1. Introduction

Climate change is a natural process but it is boosted by anthropogenic activities [1]. Rapid increase in atmospheric $CO_2$ concentrations over the last few centuries leads to a series of unpredictable weather events. Severe drought is one of the consequences of climate change, which is projected to increase unprecedentedly in prone areas [2]. The world temperature is supposed to increase over 1.5 to 2.0 ºC in the period of 2081 – 2100 [3]. Each increase of atmospheric temperature results in 7% increase of atmospheric moisture holding capacity [4] triggering more condensed precipiation, and hence, prolonged dry season over a year. In drought sensitive areas, such as the Mediterranean, North-Eastern Asia, West Asia, many regions of South America and the majority of Africa [2], global warming exacerbates drought severity by accelerating evaporation, enhancing shortage of soil moisture. Globally, land use change occurs extensively in response to the high demand for expanded cropland as a result of the population growth, and the reduction of soil moisture and quality. During 1990 - 2005, 13 million hectares of forest were destroyed per year [5] to convert forest land to cropland, which reduces soil C sequestration and a rapid biomass C loss, releasing up to 180 - 200 Pg (pentagrams) C emissions in the last two centuries [6].

The coupling between land use change and drought induces impacts on the biochemical properties of soil. Increasing frequency and intensity of drought is predicted to reduce the functions of microorganisms, which is essential to ecosystem sustainability [7]. Moreover, the structure of the soil microorganisms is greatly influenced by the change of land use, land cover, and agricultural activities. Those factors impact soil organic matter (SOM) and regulate the microbial structure appropriately [8, 9]. Thus, land use change releases influences on soil microbial biomass and C use efficiency [10]. Terrestrial plants are the main sources of SOM which retains moisture in different soil horizons. However, during 20 years (1980 - 2000), more than 80% of newly cultivated land came from the intact and disturbed forests [11]. Land conversion from forest to cultivated land reduces SOM content, leading to a decline in soil moisture content and lowering resistance and resilience capacity of the terrestrial ecosystem to drought impacts [12]. This land use change also triggers potential drought events as the soil is over-exploited for intensive agricultural production, which causes exhaustion in soil nutrients, bio-imbalance and hence soil WHC.

In tropical dry land ecosystems, studies in land use change under drought are still restricted as compared with the total coverage of wet ecosystems around the world [6], especially in Vietnam. During the period 1999 - 2018, Vietnam ranks 6th among 10 countries most affected by the extreme weather events according to the table of Long-term Climate Risk Indices (CRI) [13]. The increase of drought frequency in some regions of Vietnam causes negative impacts on the production activities of local people. Quang Nam province located in the South Central region of Vietnam with diverse terrain conditions and harsh climate, is severely impacted by drought due to its high sensitivity to the El Niño–Southern Oscillation (ENSO) [14]. According to H. T. L. Huong [15], the prolonged drought is projected to damage 33% winter-spring rice productivity and 49% summer-autumn rice productivity by the end of $21^{st}$ century. In addition, there are over 3,000 hectares of rice that cannot be sown due to aridity, along with 5,000 hectares of crops lacking irrigation water and nearly 5,000 people suffering from water shortages in the midland and mountainous districts of Quang Nam. From the beginning of the summer-autumn season in 2019, the weather was abnormal characterized with long-lasting hot and sunny days. The storage capacity in many irrigation and hydropower reservoirs is only about 20 – 60% of the designed capacity, lower than the average of many years [16].

Therefore, this interdisciplinary study was conducted in dry season in Quang Nam, to elucidate the relationship between abiotic factor (soil moisture) and biotic factors (microbial biomass and respiration) in two different land use types, namely forest and pineapple land. Accordingly, two moisture conditions of drought as 30% and 10% WHC were set up for two land use types to compare with normal condition of 60% WHC in each land use. By coupling GIS technique and soil biochemical analysis, the study will provide stakeholders in Quang Nam with the scientific basis for setting up the climate change adaptation strategy while maintaining soil health. The study proposed three hypotheses as i) Drought tends to be more severe in future in Quang Nam but behaves differently between plain and mountainous areas; ii) Microbial respiration reduces with increasing drought severity but depending on land use types; and iii) Under water stressed condition, microbial biomass dramatically reduces from 60% to 30% WHC then sustains its stable status due to microbial adaptation as soil moisture goes to 10% WHC.

## 2. Materials and Methods

### *2.1. Data Collection*

i) Meteorological data: To assess the drought conditions of Quang Nam province, daily meteorological data of mountainous and coastal plain meteorological stations from 2000 to 2019 were collected from Vietnam Institute of Meteorology, Hydrology and Climate Change (IMHEN), including average air temperature, maximum air temperature, minimum air temperature, average air humidity, number of sunshine hours, amount of evaporation, rainfall, wind direction and wind speed;

ii) Remote sensing data: The MODIS image data used in this study is the MODIS Land Cover Type Product (MCD12Q1). Since 2001, MCD12Q1 has provided the annual map of global land cover at 500 meters spatial resolution with six different land cover legends. Classification of the International Geosphere-Biosphere Programme (IGBP) Type 1 land cover scheme was chosen with 17 land cover classes (0 - 16) which includes 11 natural vegetation classes, 3 developed and mosaicked land classes and three non-vegetated land classes [17]. Information about all of the data layers, including Quality Control is shown in Table 1. The image MODIS was extracted to create land use and land cover maps in Quang Nam province from classifications of spectro-temporal features derived from data collected in 2003, 2008, 2013, 2018 by QGIS 3.4.6 software.

### *2.2. Drought Indicators*

The drought extension over time was determined by rainfall as follows [18].

- Drought occurs when the amount of rainfall per month is less (equal) than 30 mm. Drought frequency per month was caculated as:

$$P = \frac{m}{n} \qquad (1)$$

Where, m is drought frequency observed in one month; n is frequency of rainfall observed in one month.

- To describe the general situation of drought in the areas and their evolutions over time, the drought indices [19] of months and years was used:

$$K_m = \frac{Pm}{Rm} \qquad (2)$$

Where, $K_m$ is drought indices of month (year), $P_m$ is evaporation amount of month (year) according to Piche; $R_m$ is monthly (annual) rainfall.

The values of K indices were classified as following $K < 0.5$: Very wet, $0.5 \leq K < 1$: Wet, $1 \leq K < 2$: Slightly dry, $2 \leq K < 4$: Dry, $K > 4$: Too dry.


Figure 1. Soil materials were collected from topsoil of forest and converted pineapple plantation.

*2.3. Soil Sampling and Processing*

Soil was sampled from topsoil (0 - 30 cm) of pineapple plantation and neighboring forest in Dai Son commune, Dai Loc district, Quang Nam province ($15^0$ 49’35” N, $107^0$51’28’’ E), where drought happens annually (Figure 1). Forest has been converted into pineapple plantation for 3 years. The soil samples were collected at the beginning of the dry season (3rd January 2020).

The soil samples were preserved in laboratory under 5 $^oC$ and sieved through 2 mm mesh to remove plant litter, roots and gravels larger than 2 mm of dimension. A subsample was separated to measure soil bulk density, soil texture, $pH_{H2O}$, total organic C, total N and total P.

*2.4. Measurement of Water Holding Capacity*

WHC was determined according to modified methods [20]. An aliquot of 30 g soil was placed in a 100 $cm^3$ cylinder. The cylinder was kept on 20 cm sand layer within a big container, which was then saturated with water for at least 24 hours. After that, water was drained out of the big container for 24 hours. Finally, soil in the cylinder was dried in an oven overnight at 105 $^oC$. WHC was calculated as below:

$$WHC(\%)=\frac{(\text{Water saturated soil weight} - \text{Soil dry weight})*100}{\text{Dry weight}} \quad (3)$$

*2.5. Effect of Drought on Soil Microbial Respiration, Soil Microbial Biomass Carbon and Nitrogen*

*2.5.1. Soil Microbial Respiration*

An aliquot of 300 g of sieved soil (oven-dry equivalent) of each land use type was separately weighed in a plastic box (15x10x5 cm) and the soil moisture was adjusted to 60% WHC using sterilized water. The experiment contained 3 treatments of soil moisture (60% WHC, 30% WHC, and 10% WHC).

The boxes were divided into 5 sets: Set 1 contained soil (60% WHC) at the initial experiment stage, set 2 contained soil (30% WHC) and set 3 (60% WHC) was control soil for set 2, set 4 contained soil of 10% WHC and set 5 (60% WHC) was control soil for set 4 (Figure 2). All the soil containers were pre-incubated at 28 $^oC$ for one week to achieve the microbial growth stabilization and equilibrium the activity of soil microbe before starting the experiment. During the pre-incubation, soil weight was gravimetrically checked to maintain an equal soil moisture of 60% WHC for all boxes. Soil from set 1 was taken right after the pre-incubation as the soil moisture was at 60% WHC. Soil in set 2 was let dry to 30% WHC and sampled simultaneously with soil from set 3 (60% WHC) as its control. Soil in set 4 was kept drying to 10% WHC and continued being sampled with soil from set 5 (60% WHC) as it's control.

Microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), and basal respiration (BR) were measured for each set of soil container at respective moisture. Each treatment was setup with 4 replicates.

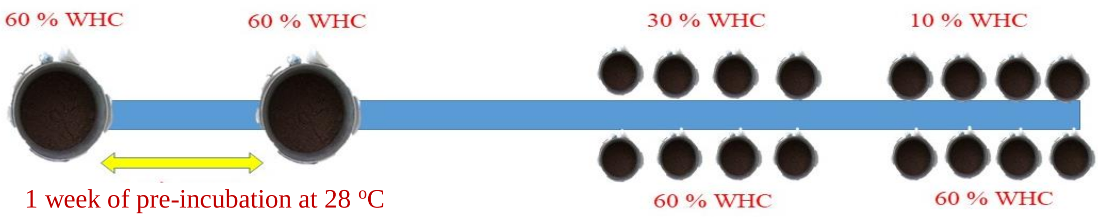



Figure 2. Experiment designs of drought (30% and 10% WHC) and control (60% WHC) which included 5 sets of containers.

To measure the soil microbial respiration, an aliquot of 50 g soil subsample from this soil moisture experiment was incubated in Mason jars at a fixed temperature and ambient air pressure. A small vial containing 10 mL 1N NaOH was placed in the jar to trap $CO_2$. The vial was replaced after 6 hours, 18 hours, 24 hours, and 48 hours to measure the trapped $CO_2$ respired by active microorganisms using titration with 0.1N HCl against the phenolphthalein endpoint [23]. $CO_2$ trapped was the net emissions of $CO_2$ for soil, which was calculated as follows:

$$CO_2 \text{ trapped (mg } kg^{-1}) = \frac{(V_{NaOH}(\text{mL}) \times 1 \ (\text{mol}.l^{-1}) - V_{HCl}\ (\text{mL}) \times 0.1(\text{mol}.l^{-1})) \times 44\ (\text{g}.mol^{-1})}{2 \times \text{dry weight of bulk sample (kg)}}$$

The microbial BR was calculated by dividing sum of trapped $CO_2$ by 48 hours ($mg.kg^{-1}.h^{-1}$) [20].

*2.5.2. Microbial Biomass Carbon and Nitrogen*

Microbial biomass was defined one day after sampling soil at respective moisture using the chloroform fumigation extraction [22, 23]. Briefly, an aliquot of 5 g soil was fumigated with $CHCl_3$ for 24 hours (FT) and total organic C and N was extracted with 20 mL 0.5 M $K_2SO_4$ to define total microbial biomass, while another 5 g soil was immediately extracted with 20 mL 0.5 M $K_2SO_4$ without fumigation (NFT) to measure the dissolved organic C and N. MBC and MBN were calculated by differences between fumigated and non-fumigated samples with a conversion factor of 0.45 for MBC [22] and 0.54 for MBN [22].

*2.6. Statistical Analysis*

Data were analyzed using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA). Independent sample t-test was conducted to test the differences between the two land use types and between two different drought levels. Effects of soil WHC treatments on average values of soil respiration during constant moisture period were tested using one-way analysis of variance (ANOVA). In order to understand the effect of soil biochemical properties (explanatory variables) on soil microbial biomass (response variables), Pearson's correlation analysis was used. Significance for all statistical analyses was accepted at the level of $p < 0.05$.

## 3. Results

*3.1. Land use and Land Cover Change*

The interpretation of the MODIS satellite image (MCD12Q1) from 2003 to 2018 (Figure 3) showed that the forest area was largest, account for 60.27±1.77% total area. The agricultural area accounted for 5.89±0.23% and concentrated on the coastal plain.

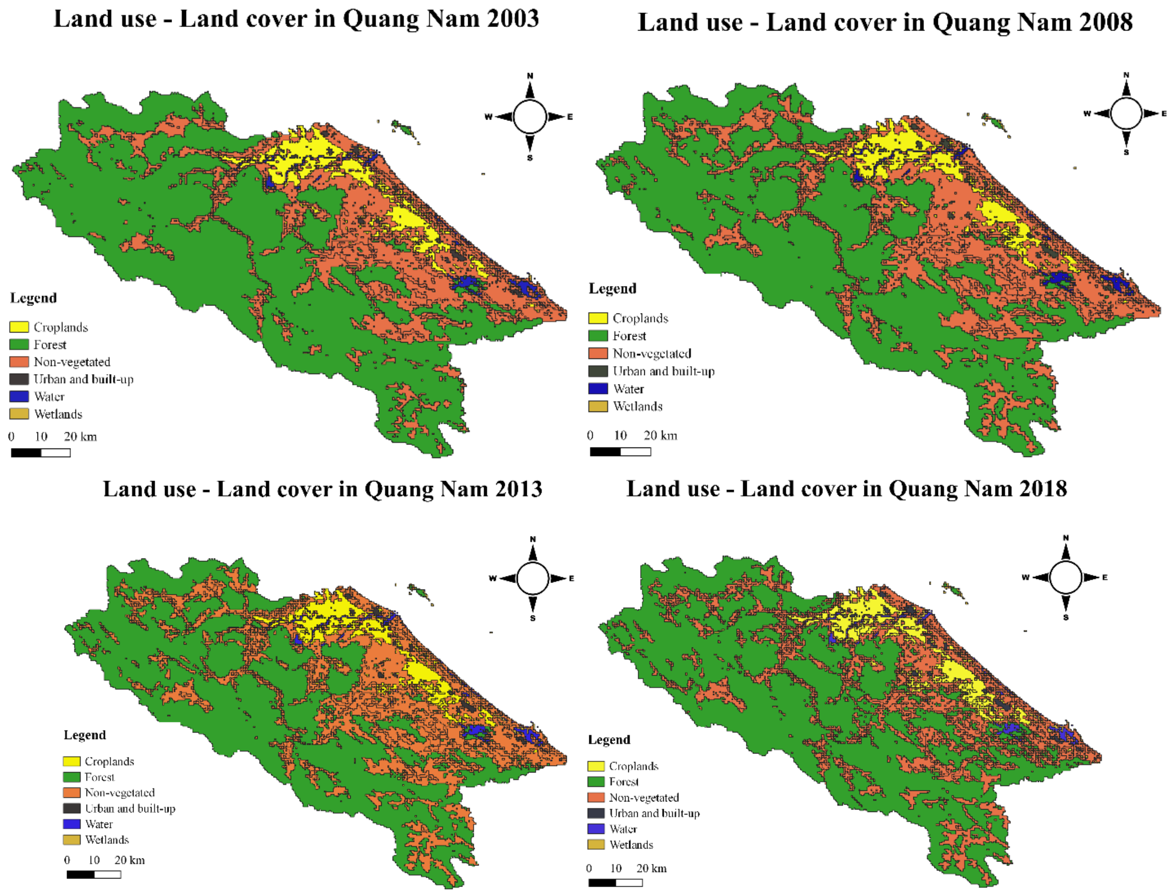



Figure 3. Land cover maps in Quang Nam demonstrated the change of land use from 2003 to 2018.

The change of land use area occurred in most of land use types (Figure 4). The crop land area increased slightly from 2003 - 2018, about 0.83% of the total agricultural area. The forest area decreased about 8.34% from 2003 - 2013, then increased by up to 5.86% in 2018 as compared to 2013. By contrast, bare land area increased by 7.93% from 2003 - 2013 but decreased by 6.65% during 2013 - 2018.

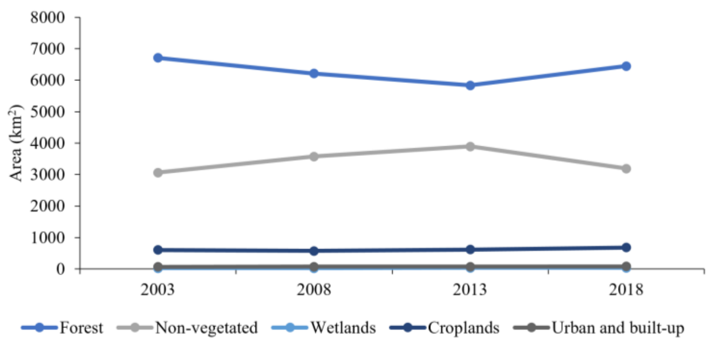



Figure 4. The total area of each land use type and land cover in Quang Nam from 2003 - 2018.

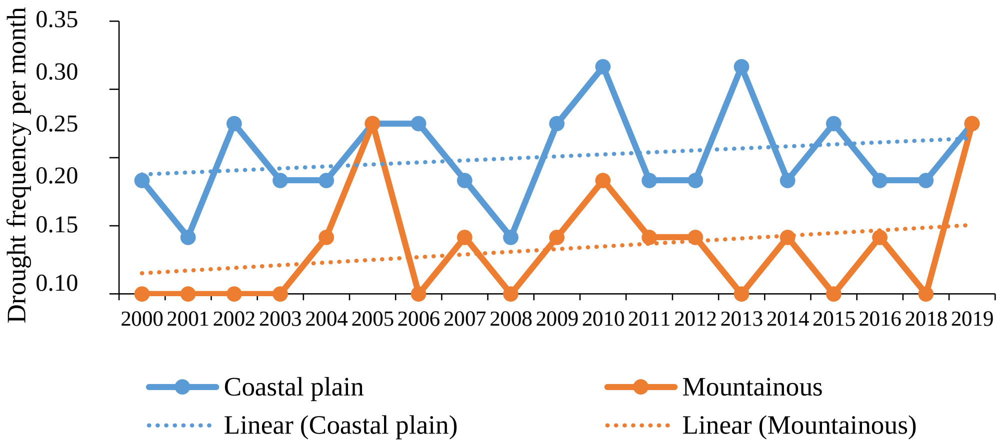



Figure 5. Drought frequency month during 2000 – 2019.

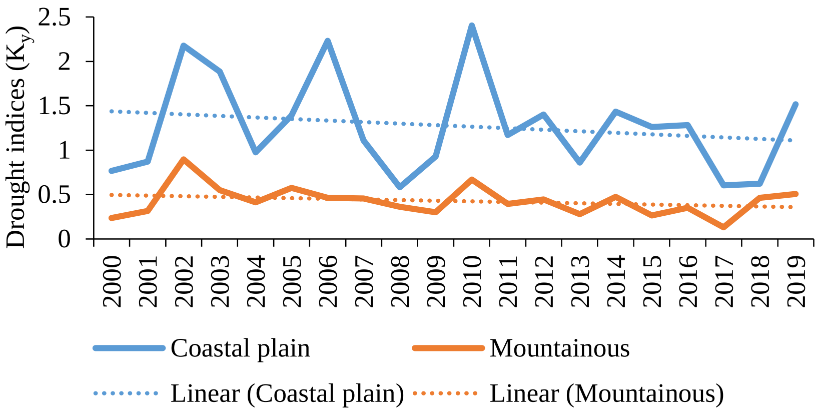


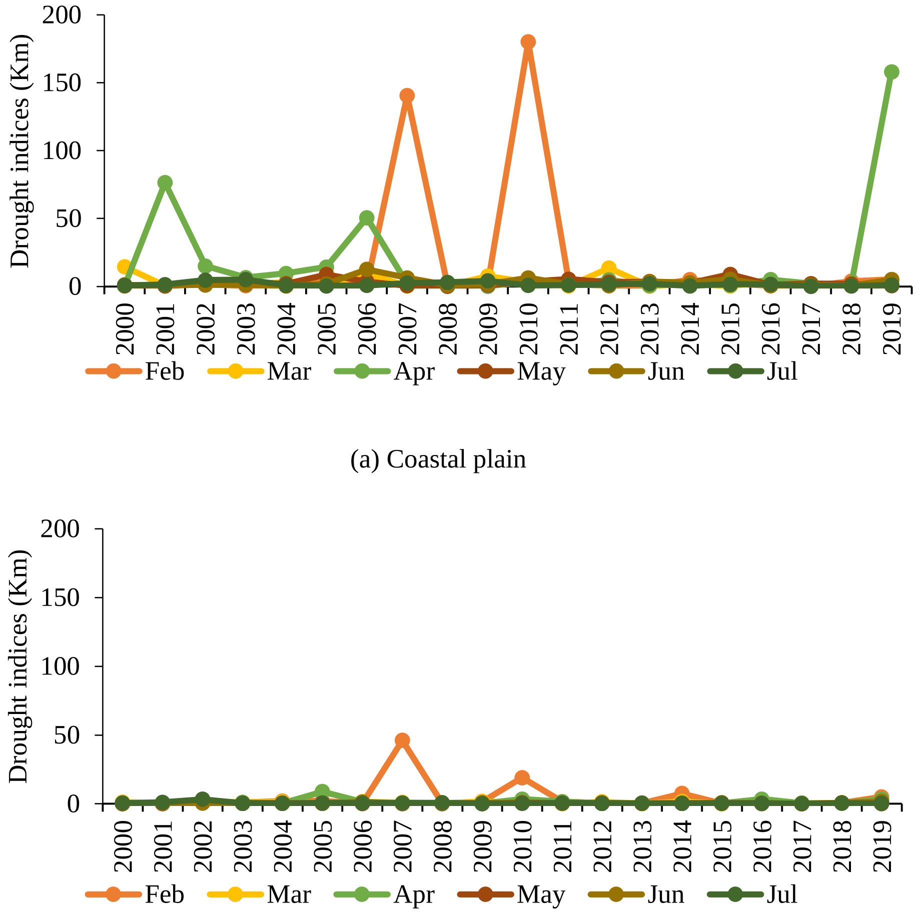

Figure 6. K indices of dry season of a year during 2000 – 2019.

*3.2. Drought Progress Characteristic*

The drought frequency was calculated based on observation of rainfall at two monitoring stations (Tam Ky and Tra My) which demonstrated a similar trend during 2000 - 2019 in mountainous area and coastal plain. The number of months with frequent drought tended to increase (Figure 5) with the highest frequency occurring in coastal plain from 2010 - 2013. Drought took place at equal frequency in 2005 and 2019.

The K indices of dry season of a year ($K_y$) were used to assess the severity levels of drought and the drought year means the year has drought indices equal to or higher than 1 unit. Accordingly, drought severity level decreased slightly during 2003 - 2019 but more concentrated in the coastal plain than mountainous area (Figure 6). The drought years of coastal plain appeared 12 times (out of 19 years of observation) and being most severe in 2010 as indicated with the highest $K_y$ (2.4). In the mountainous area, the $K_y$ fluctuated from 0 to 1 unit. This result showed that the mountainous area did not occur drought. It was different from reality. So those K indices of dry months ($K_m$) were used to assess the severity levels of the drought of months in the dry season (from February to July) based on rainfall and evaporation of each month from February to July (Figure 7) during the period 2000 – 2019 in both areas.

$K_m$ indices of dry months showed that severe drought also appeared in the mountainous area mainly from February to April, which was the same as the coastal plain. Wherein the highest $K_m$ in February showed that this month was the most severe drought month of the year in mountainous and coastal plain areas, corresponding 46.08 (2007) and 180.25 (2010). Moreover, the $K_m$ were the same as the $K_y$, the drought level in the coastal plain was severer than in the mountainous area.




(a) Coastal plain

(b) Mountainous

Figure 7. K indices of dry months (from February to July) during 2000 – 2019.

Table 1. Soil characteristcis of two different study sites

| Parameters | Pineapple soil | Forest soil |
|---|---|---|
| Bulk density (g/cm$^3$) | 1.3 | 1.3 |
| $pH_{H2O}$ | 6.6 | 5.7 |
| Organic carbon (%) | 1.04 | 0.81 |
| $N_{Total}$ | 0.15 | 0.12 |
| $P_{Total}$ | 0.80 | 0.87 |

*3.3. Soil Properties*

Soil properties of the studied sites were presented in Table 1. Generally, soil pH was ranged from light acidity to medium and there was no significant difference about soil properties between two different study sites.

*3.4. Microbial Activities*

- *Microbial BR:* The soil BR was strongly impacted by moisture. The soil BR was three times higher in the control soil at 60 % WHC than water stressed condition regardless of 30% or 10% WHC ($p<0.01$) (Figure 8). Significant differences ($p<0.05$) of BR between land use types were found at 60% WHC and 30% WHC.

- *MBC and MBN:* MBC at initial stage was significant lower than two control treatments ($p<0.05$) despite their similar soil moisture of 60% WHC (Figure 9). Under water stressed condition, MBC of pineapple and forest soil decreased at least three times compared to its respective control moisture conditions. Interestingly, MBC at 10% WHC was significantly higher than one at 30 % WHC. Land use types demonstrated significant effects on MBC at 60% WHC and 30% WHC.

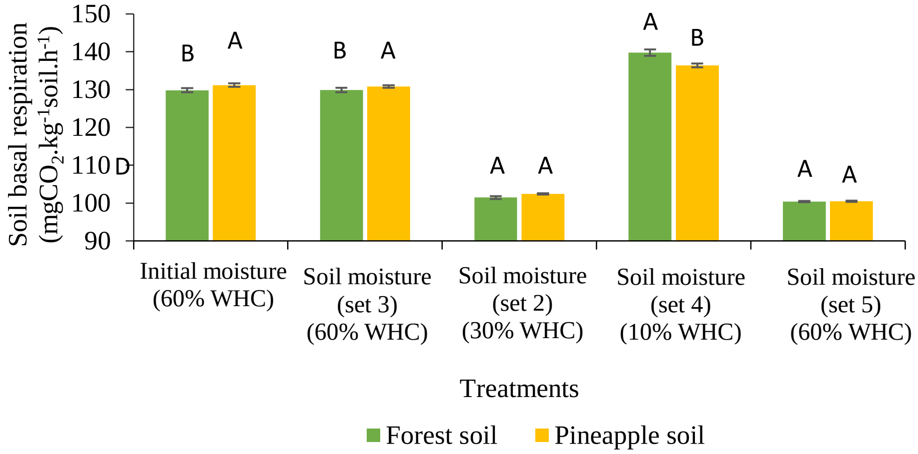



Figure 8. The microbial BR in different land use types at different water stressed levels (Letters showed the significant differences between land use types).

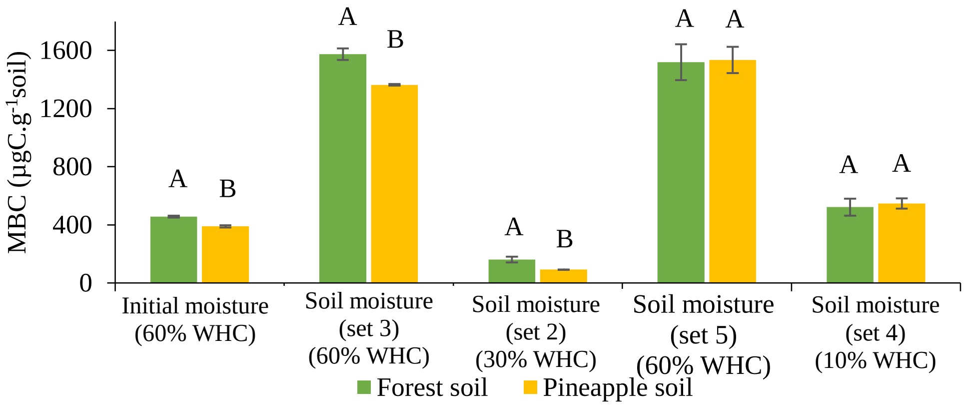



Figure 9. MBC of forest soil and pineapple soil
(Letters showed the significant differences between two land-use types).

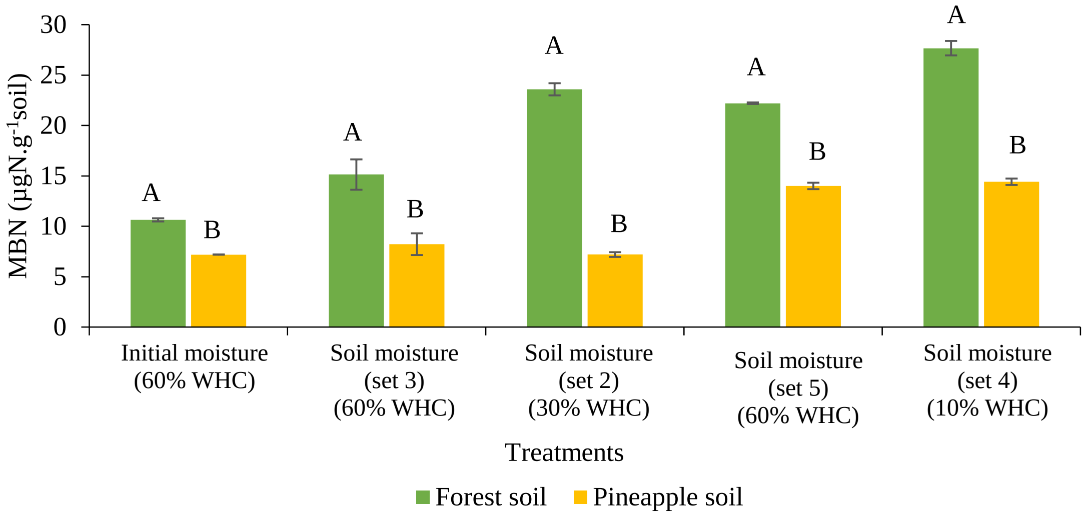



Figure 10. MBN of forest soil and pineapple soil
(Letters showed the significant differences between two land-use types).

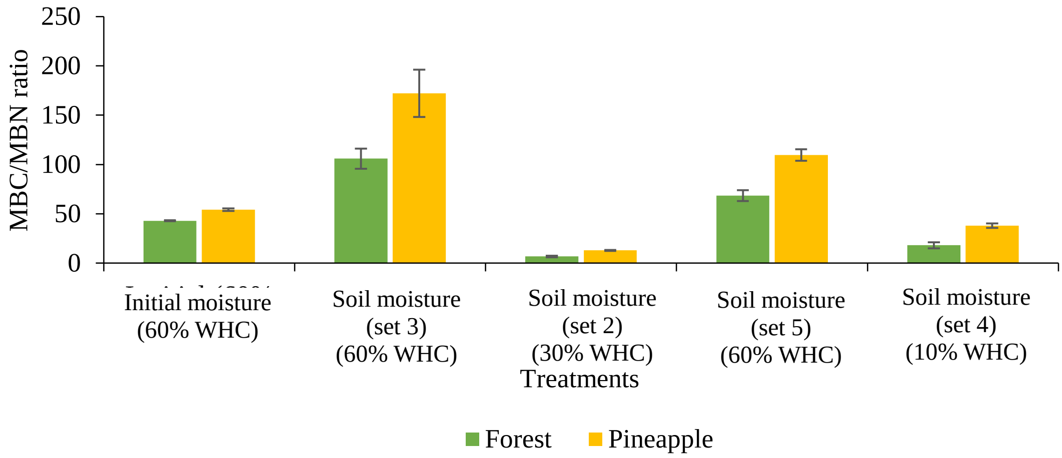



Figure 11. MBC/MBN ratio of two soil types at different soil moistures.

MBN was significantly higher in forest soil than pineapple soil (p<0.01). Drought induced the increase of MBN in comparison with optimum condition (60% WHC).

MBC/MBN ratios was significantly higher in pineapple soil than forest soil (p<0.05) (Figure 11). Drought dramatically reduced MBC/MBN ratio but more reduction was found at 30% WHC compared to 10% WHC.

## 4. Discussion

### *4.1. Land use Change and Drought Prediction*

The figures showed the result of the MODIS image interpretation of the land use types distribution and land use change over the years in Quang Nam, especially forest land and cropland. Through interviews with local leaders, combined with field survey methodology, the results indicated that the area of paddy land was converted because drought occurred usually in the riparian area. This area had the characteristics as located at the foothills and foot of the mountains and far away from irrigation areas. The drought indices combined with climate factors, such as rainfall, evaporation, temperature, and sunshine hours, demonstrated that drought in Quang Nam province tends to be more complicated in future. Severe drought appeared more frequently in February and April, which was an important time of crop growth in spring season, thus greatly affecting the agricultural production in Quang Nam, especially paddy rice. As a result, drought was the reason for rice land being converted to other land use type from 2003 - 2018 with the purpose to adapt to the drought complex in agriculture production.

*4.2. Soil Microbial Activities*

In general, soil moisture, pH, total organic C and total N were significantly different between the two land use types. We supposed that this difference was derived from the distinct land cover by different species. In contrast to our expectation, lower soil pH in pineapple soil than in forest soil was likely the result of fertilizer addition to pineapples, especially N fertilizer. Indeed, the addition of $NH_4$-N fertilizer causes soil acidification, because the nitrification of $NH_4^+$ increases $H^+$ ions in the soil [24]. Moreover, the leaching of bases from the soil profile due to pineapple cultivation on slope may contribute to the loss of alkalis elements, lowering soil pH [25].

Under the impact of drought, reduction of microbial activity leads to the decrease of N-cycling as well as C cycling processes [26] and respiration [28, 29]. Soil moisture is also a major factor controlling microbial biomass [29]. Microbial respiration decreased a half as soil moisture declined from 60% to 30% WHC and kept stable given the soil moisture decreased to 10% WHC. The dramatic decrease of microbial respiration demonstrated a shock of microbial community to altered environment condition. In fact, soil drying causes microorganisms stressed [30]. However, the sustainability of microbial respiration as soil moisture declined from 30% to 10% WHC could be explained by the adaptation of microbial community after the shock. This adapation possibly derived from the fact that microorganisms exert polysaccharide and protein to make exopolysaccharides and other polymer to support microbial resistance to drought impacts [31]. The similarity of microbial respiration between two soil types implied more important role of drought impacts than land use conversion.

In the same pattern with microbial respiration, MBC was also found two to three times less under water stressed condition than optimal moisture. The decrease of soil moisture resulted in the reduction in nutrient diffusion that cause difficulties for microorganisms to approach available nutrients in soil and negatively affecting microbial biomass synthesis [32]. The water stress may trigger microorganisms to enter a dormant physiological state [33] and/or cells of sensitive microorganisms die [30]. The significant increase of MBC at 10% WHC in correspondense to 30% WHC was in contrast to our hypothesis supposing more reduction of MBC accompanied with more reduction of soil moisture. Another reason could lead to this result is that perhaps at 10% WHC, the more favorable condition about moisture for soil microbes than 30% to decompose soil organic matter, then more nutrients like N, P, K, S,... compounds were mineralized, thus bringing the higher MBC. However, this increase of MBC once supported our discussion above on the adaptation of microbial community to drought condition. In other words, microbial communities not only adapt to drought condition, the adaptive community also started their growth leading to increase in MBC despite moisture decreases. Given the similar soil moisture content, the increase of MBC in the control of 30% and 10% WHC compared to initial stage could be resulted from pre-incubation time that is not enough for microorganisms to recover after soil sieving and processing.

Ecosystem type and land management play important role in the distinct effects of drought on N mineralization and nitrification [34-37]. Likewise, our finding showed a significant difference of MBN between two land use types which was in contrast to MBC. Higher MBN in forest than pineapple might suggest that forest soil would be of advantage to sustain soil fertility and microbial activities than crop land in resistence to drought impacts. Another reason could be proposed is that no disturbance for soil microorganisms found in forest soil than in agricultural soil. Drought condition boosted accumulation of N in biomass in forest soil but not in pineapple soil. In contrast, Fuchslueger et al., (2019) [38] and Schimel (2018) [26] supposed a reduction of N concentrations in microbial biomass and N-cycling. The increase of MBN in forest soil under drought in our findings is attributed to N conservative strategies of microbial communities by producing N containing osmolyte compounds [30].

To support our overall discussion on a possible shift of microbial community due to drought and a difference in microbial dorminance depending on soil management, we calculated MBC/MBN ratio. Higher ratio implied the predominance of fungi over bacteria in the microbial population [39]. Higher MBC/MBN ratio ($p<0.05$) in pineapple soil suggested higher proportion of fungus in microbial community than those in forest soil. On the contrary, drought dramatically reduced MBC/MBN ratio ($p<0.01$) may imply a strategy of microorganisms by shaping microbial composition to overcome harsh environmental condition.

## 5. Conclusions

The study suggests that under the impact of drought and land use change in Quang Nam in the period of 2003 - 2018, not only do the soil chemical properties change but also drought reduced the activity of soil microorganisms. The low value of C/N ratio in forest soil and pineapple soil indicated a high rate potential of SOM decomposition. However, when drought occurred, the MBC and soil respiration of both land use types decrease significantly compared with soil at respective soil moisture. By contrast, the MBN values of both land use types under the impact of drought increased. Moreover, the conversion of land use to pineapple cultivation has caused soil pH, C/N ratios and MBN to change.

## Acknowledgement

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