# Effect of Gap Size on Seasonal Variation of Soil Chemical Properties in Subtropical Forest, Southern China

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**ABSTRACT**

Gap area has an effect on the soil chemical properties. To find out whatever the effect of gap area on the soil chemical properties, gap area was divided into small, medium, and large gap sizes and under the canopy as control. To determine the soil chemical properties such as pH, organic matter (OM) (g/kg), total nitrogen (TN) %, total carbon (TC) %, C/N ratio, total phosphorus (TP) (g/kg), total potassium (TK) (g/kg), available phosphorus (AP) (mg/kg), available potassium (AK) (mg/kg), and hydrolysable nitrogen (HN) (mg/kg), the grid system (3×3 $m^2$) was applied for collecting the soil samples over the entire gap area at 20 cm depth. The results showed that most of the soil chemical properties varied significantly with respect to the gap sizes and the seasons. The summer season had greatly influenced all the chemical properties when compared with the winter season. However, the soil chemical properties exhibited irregular variation in different gap sizes. Moreover, a strong significant positive correlation among TN, TC, C/N, and OM was found. The highest soil OM in the large gap size indicated the high potential of nutrient supply for the plant growth. The results of this study provide useful information for the regeneration and conservation of *C. kawakamii*.

## 1. INTRODUCTION

Soil is considered as a complex entity defining the physical and chemical properties as well as biological processes occurring across spatial and temporal scales. Soil properties at a specific location integrate and reflect both past and present conditions (Rhoades, 1996). The soil serves as a medium for plant growth and nutrient supply. The amount of nutrients present in the soil has direct effect on plant growth. The lack of plant growth which is not related to the soil structure must be due to the deficiency of soil nutrients. Soil chemical properties are the indicter of soil quality. Foresters have always relied on understanding the soil chemical properties to assess the potential sites to promote the productivity of forests. Lately, the need for assessing soil properties has expanded because of growing public interest in determining the effect on managing the soil quality relative to the sustainability of forest ecosystem functions in addition to plant productivity (Schoenholtz et al., 2000). The spatial characteristics of soil properties are significantly influenced by several environmental factors such as climate, topography, parent materials, vegetation, and disturbances due to human activity (Tsui et al., 2004). However, some studies have proposed that soil properties are related to topographic positions in different forest ecosystems (Malo et al., 1974; Nizeyimana and Bicki, 1992; Stolt et al., 1993; Chen et al., 1997; Bohlen et al., 2001). A number of factors affect the stability of soil chemical properties (Bissonnais, 1996; Haynes and Naidu, 1998; Glaser et al., 2002). Forest gap alters the soil chemical properties which directly affect the plant growth in that gap area. An example, in a very recent experiment carried out in a *Cunninghamia lanceolata* stand in northern Guangdong Province, southern China has reflected the effect of canopy gap on soil properties. The researchers have found that the large gaps showed a significant increase in soil organic matter, N and P compared with the small gaps and the adjacent canopy-covered plots in the 0-10 cm soil. The differences in organic matter and nutrient levels found between the large and small gaps and the canopy-covered plots may be related to the changes in environmental conditions (Xu et al., 2016). Gray et al. (2002) have reported the effects of gap formation on solar radiation, soil and air temperature as well as soil moisture were studied in mature coniferous forests. Gap showed higher soil moisture than the control, which was the highest in intermediate gap size, and decreased during the growing season in single-tree gaps and on the north edges of large gaps. However, there was variation in moisture availability within individual gaps, primarily related to the variety of organic contents present (Gray et al., 2002). Gap has an effect on soil organic matter, total nitrogen, and total potassium which was higher in the gap area when compared with under-canopy, while $NH_4$-N, available phosphorus, available potassium, and total phosphorus were lower in gap areas than those in under-canopy (Zhang and Zhao, 2007). Gap size have also affected the soil chemical properties (electrical conductivity-EC, organic matter-OM, and nutrient content) at the Yuvacik watershed in Izmit (Turkey) (Özcan and Gökbulak, 2015). Thus, it is important to understand the interrelationship between gap size and environmental changes, and those that affects the regeneration processes for management techniques of nature-based forestry (Gálhidy et al., 2006).

The *Castanopsis kawakamii* natural forest in Fujian province is the pure stand forest, dominated by *C. kawakamii* and affected by forest gap. Nowadays, the population of *C. kawakamii* is reducing and the age structure of the population is not sustainable because of the decreasing population of seedling and sapling of *C. kawakamii*. The main cases are the lack of germination and seedling establishment and human disturbances (Liu et al., 2011). The results from studies about the effects of forest gap on some microclimate variables in *C. kawakamii* natural forest gap have shown that different gap sizes and locations have different features of air-soil temperature, relative humidity, and soil water content (He et al., 2012a). The knowledge about the effect of gap size on soil chemical properties is still limited. As aforementioned, gap alters the microenvironment within the gap; therefore, soil chemical properties might affect the gap formation, which impact the species growth. Thus, the aim of this study was to investigate the effect of gap size on the soil chemical properties in *C. kawakamii* forest to find whether the soil chemical properties were affected by the gap size. The results from this study have provided useful information for the regeneration and conservation of *C. kawakamii* at this study site.

## 2. METHODOLOGY

### 2.1 Site description

The *C. kawakamii* Natural Reserve forest in Sanming city, Fujian province, China was selected to be the study site (Figure 1). It is located at 26º 07’-26º12’N and 117°24’-117°29’E, which borders Wuyi Mountain on the Northwest and Daiyun Mountain on the southeast. The climate of this region is a middle subtropical monsoon. The mean annual temperature is about 19.5ºC (average of 40 years data collected from the Sanming Climatological bureau, China) and daily mean minimum is -5.5ºC, and maximum is 40ºC. The annual rainfall is 1,500 mm of which 75% occurs between March and August. Annual average relative humidity is 79%, and mean velocity of the wind is 1.6 m/s. The soil types under this climax natural forest vegetation are mainly dark red earth type, and one of red earth and purple soil is the second. The soil thickness is greater than 1.0 m, and the soil layer has abundant humus and enriched in soil nutrients. The *C. kawakamii* Nature Reserve is a subtropical evergreen broadleaved forest dominated by over mature *C. kawakamii* (average age over 100 years), *Castanopsis carlesii, Pinus massoniana* and *Schima superba,* which is the biggest and purest *C. kawakamii* natural forest (Liu et al., 2009). The structure and spatial pattern analysis of the *C. kawakamii* population in 2000 revealed that the population in tree and seedling were abandoned but not in young trees due to the human disruption. The lack of young tree population is the cause of the endangered status of the *C. kawakamii* (DaRong et al., 2000).

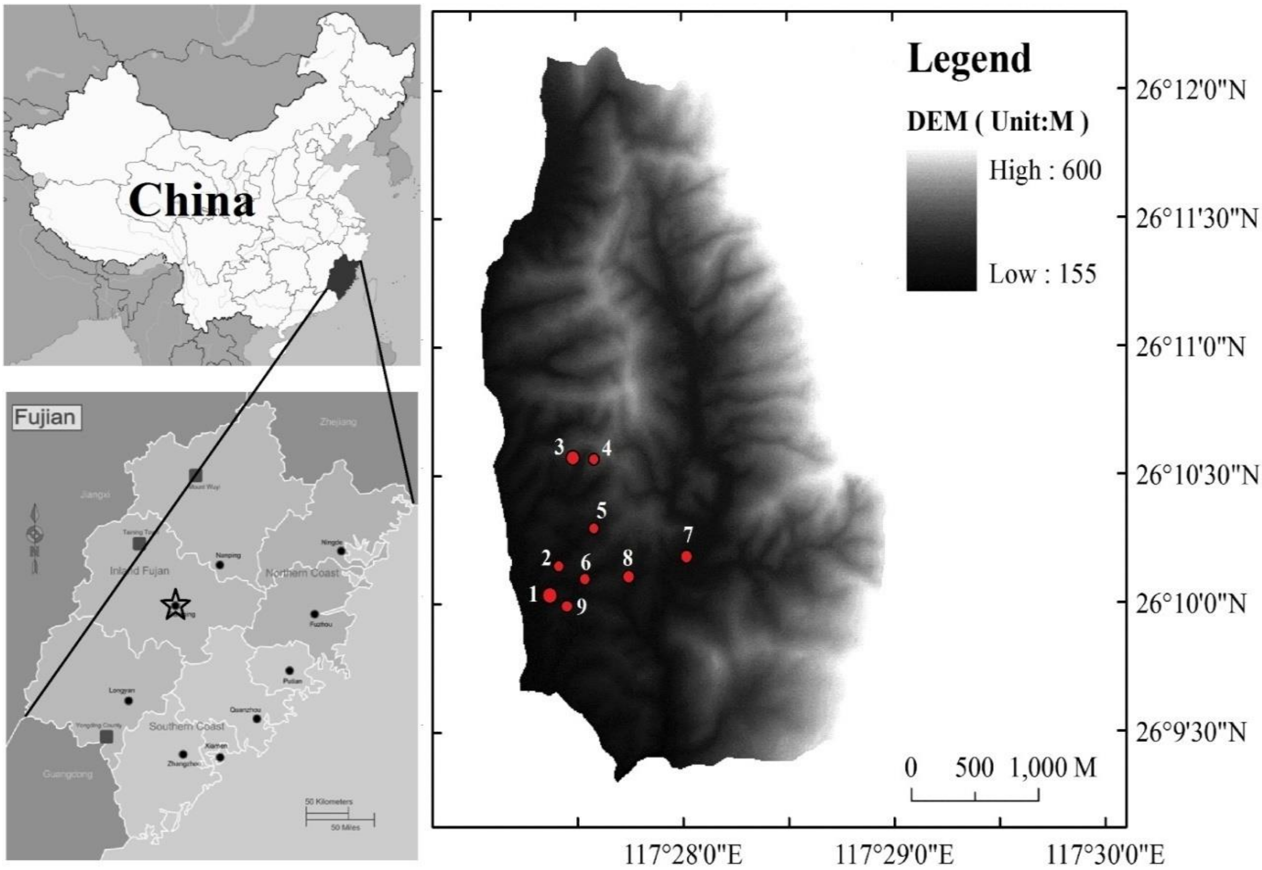


**Figure 1.** Location of the study area. The star denotes Sanming city location and the numbers one to nine denote the gap no. 1-9 location. This map is modified from (He et al., 2012b).

**2.2 Gap size classification and soil sample collection**

The two hemispherical photographs (THP) method was used to calculate the gap area (Hu and Zhu, 2009). A photo was taken at the center of each gap, using a fisheye lens camera. The photos were processed by computer software (Adobe Illustrator CC 2014, Eastman Kodak company, CA, USA) (Figure 2). The nine forest gap areas were measured. The largest area was 216.72 $m^2$ and the smallest area was 30.28 $m^2$. According to the ranging of gap area, we classified the nine forest gaps into small (30-50 $m^2$), medium (50-100 $m^2$) and large (> 150 $m^2$). The small gap size was created by branch fall, while the large and medium gap sizes were created by tree fall. Meanwhile, non-gap was selected as control group with the areas of 15×15 $m^2$. Sampling points were determined using a grid system (3×3 $m^2$) applied to the entire gap area and non-gap areas as well as shown in Figure 3. At every point, soil samples of approximately 1 kg were collected from 0-20 cm depth to determine the soil chemical properties such as pH, organic matter (OM), total nitrogen (TN), total carbon (TC), C/N ratio, total phosphorus (TP), total potassium (TK), available phosphorus (AP), available potassium (AK), and hydrolysable nitrogen (HN). These variables are the essential nutrients for plant growth and development. The soil samples were collected in the summer and the winter at the same point. In total, there were 413 soil samples.

**2.3 Soil chemical analysis**

Soil reaction or soil acidity (pH) was determined by 1:1 soil suspensions with a pH meter (Jackosn, 1973). The organic matter content (OM) was determined by Rapid Titration Method (Walkley and Black, 1934). Hydrolysable nitrogen was calculated as the sum of ammonium nitrogen ($NH_4$-N) and nitrate nitrogen ($NO_3$-N). Available phosphorous was extracted using 0.5 mol/L $NaHCO_3$ solutions and determined by Mo-Sb calorimetry method. Available potassium was extracted with ammonium acetate and measured by flame atomic absorption spectrometry. Total nitrogen, carbon and C/N ratios were measured using the CN machine model vario Max CN Element Analyzer. The value expressed in %N and %C. The total phosphorous and potassium was calculated first by digesting the soil using the $H_2SO_4$-$HClO_4$ method and then measuring the level as described in available potassium and phosphorous. All samples for this study were analyzed in triplicate (Burt, 2009).


**Figure 2.** The gap photo taken by fish eye lens camera (a). The measurement of length in pixels by Adobe Illustrator CC 2014 computer software program (b).

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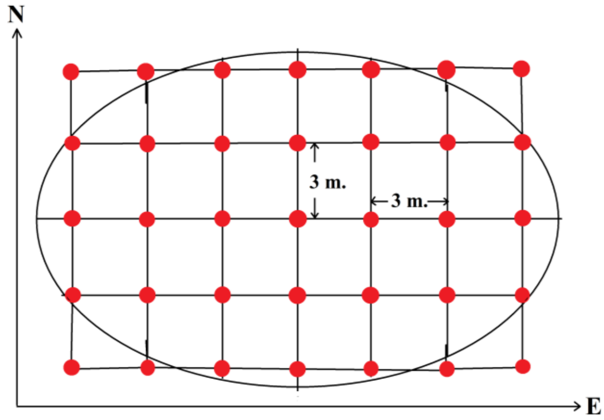


**Figure 3.** Grid system (3×3 $m^2$) in each forest gap and non-gap area for the investigation of soil chemical properties. The oval denotes the gap area and the red dots denote the soil sampled points.

### 2.4 Statistical Analysis

The average, maximum and minimum data values for all variables were calculated using Microsoft Excel 2013. In each gap size, soil variables data were average in each gap size except for the soil pH of which the medium value was calculated. The data for one-way analysis of variance (ANOVA) was the average from the three small gap sizes, the three medium gap sizes and the three large gap sizes as well as the non-gap. A one-way ANOVA was used to analyze the difference among the three gap sizes and the multiple comparisons were analyzed by the Tukey's post-hoc test ($p<0.05$). Paired-samples t-test was used to analyze the difference of soil variables in the summer and the winter. These analyses were calculated using the program SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

## 3. RESULTS

### 3.1 The effect of gap size on the soil chemical properties in the summer and the winter

A one-way ANOVA was calculated on the effect of gap size to the value of the soil variables. The results are shown in Table 1.

During the summer season: the effect of gap size on the soil chemical properties showed that every soil chemical property was significantly different among the three groups of gap size and non-gap area. The multiple comparison analysis by the Tukey's post-hoc test ($p<0.05$) on the soil chemical properties during the summer season is shown in Figure 4. Seven out of ten chemical properties (TP, HN, OM, TK, TC, TN, C/N) had the highest values that appeared in the large gap size, while the highest of AP was noted in the small gap size, the highest of AK was recorded in the non-gap areas and the highest of soil pH was observed in the medium gap size. The significant pattern of differences between TN and C/N ratios was similar.

**Table 1.** The results of a one-way ANOVA conducted on the effect of gap size on the value of the soil variables in the summer and the winter.

| Soil variable | Summer | | Winter | |
|---|---|---|---|---|
| | F value | P value | F value | P value |
| pH | 10.479 | 0.000* | 2.219 | 0.099 |
| Organic matter (g/kg) | 7.955 | 0.000* | 10.867 | 0.000* |
| Total phosphorous (g/kg) | 38.145 | 0.000* | 2.781 | 0.052 |
| Total potassium (g/kg) | 14.553 | 0.000* | 8.006 | 0.000* |
| Available phosphorous (mg/g) | 4.034 | 0.013* | 1.963 | 0.133 |
| Available potassium (mg/g) | 4.574 | 0.007* | 2.439 | 0.076 |
| Hydrolysable nitrogen (mg/kg) | 5.923 | 0.002* | 4.409 | 0.008* |
| Total nitrogen, TN (%) | 3.083 | 0.036* | 6.983 | 0.001* |
| Total carbon, TC (%) | 7.818 | 0.000* | 8.662 | 0.000* |
| C/N ratio | 9.074 | 0.000* | 5.410 | 0.003* |

* The mean difference is significant at the 0.05 level.

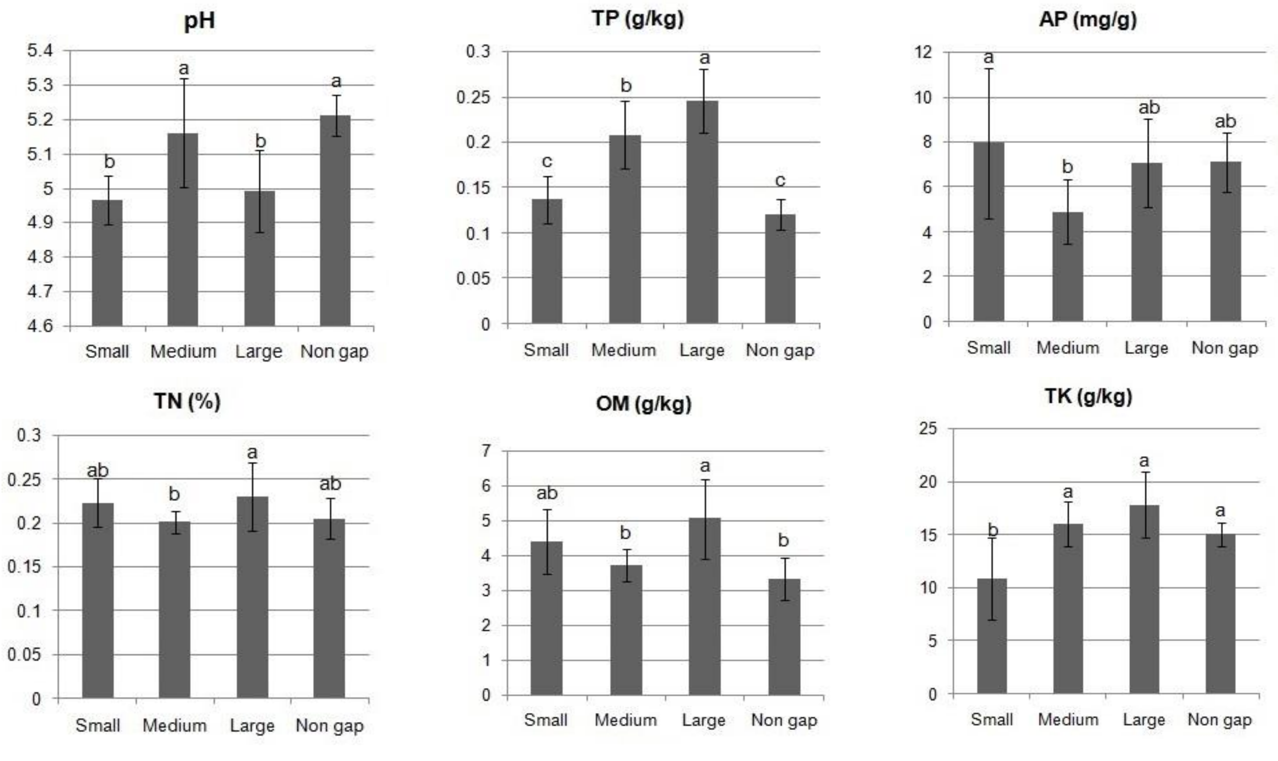


**Figure 4.** Bar graph and statistical analysis of soil chemical properties in each gap size and non-gap area during the summer season (one-way ANOVA, Tukey's post-hoc test, $p<0.05$); error bars show the standard deviation value; different letters over the bars indicate the statistically significant results.

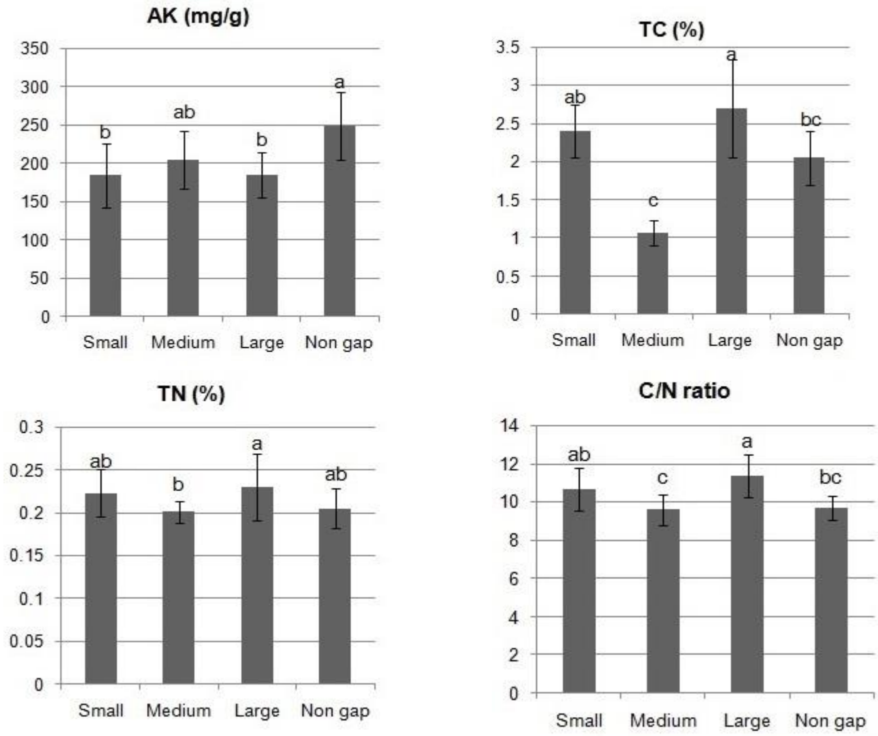


**Figure 4.** Bar graph and statistical analysis of soil chemical properties in each gap size and non-gap area during the summer season (one-way ANOVA, Tukey's post-hoc test, $p<0.05$); error bars show the standard deviation value; different letters over the bars indicate the statistically significant results. (cont.)

During the winter season: It was found that soil pH, TP, AP, and AK had no significantly difference among the three groups of gap size and non-gap area while OM, TP, HN, TN, TC and C/N had a statistically significant difference among the three groups of gap and non-gap area. The multiple comparison analysis by the Tukey's post-hoc test ($p<0.05$) of soil chemical properties during the winter season is shown in Figure 5.

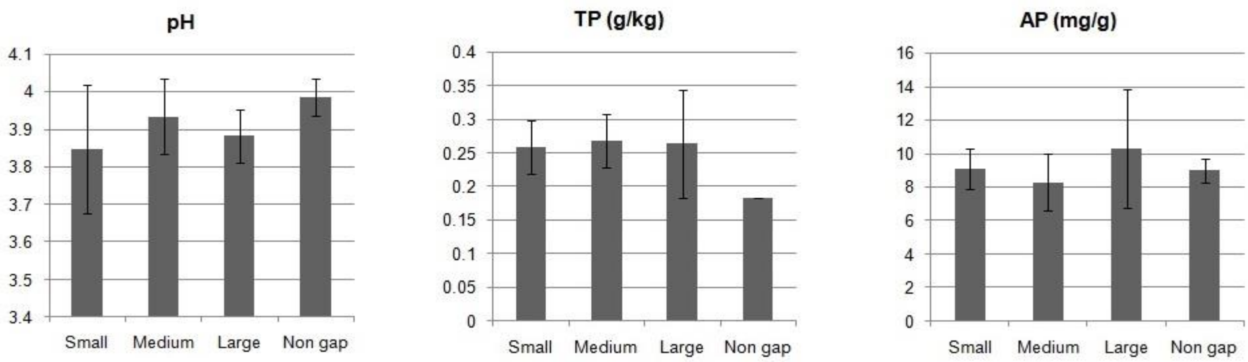


**Figure 5.** Bar graph and statistical analysis of soil chemical properties in each gap size and non-gap area during the winter season (one-way ANOVA, Tukey's post-hoc test, $p<0.05$); error bars show the standard deviation value; different letters over bars indicate statistically significant results.

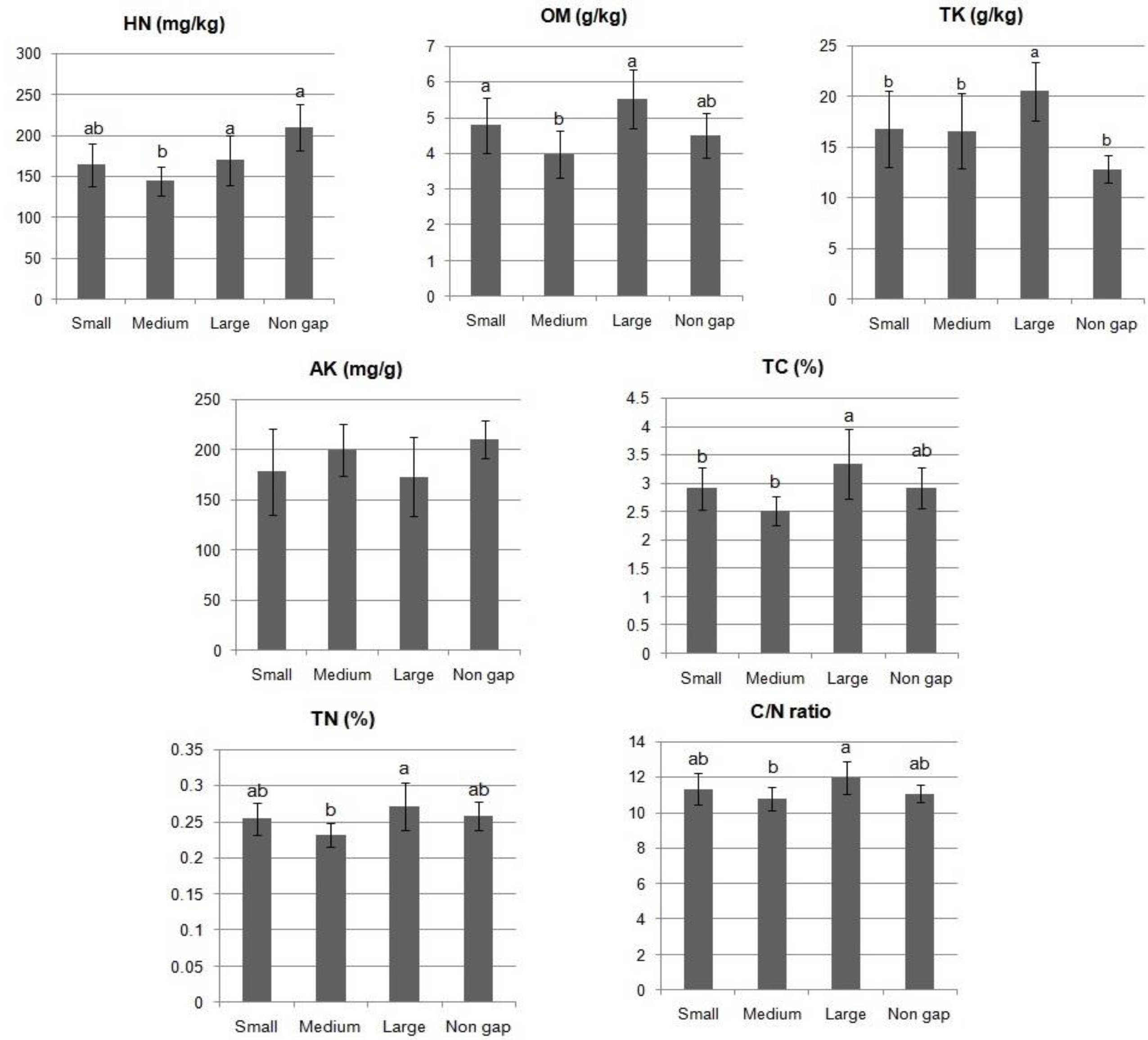


**Figure 5.** Bar graph and statistical analysis of soil chemical properties in each gap size and non-gap area during the winter season (one-way ANOVA, Tukey's post-hoc test, $p<0.05$); error bars show the standard deviation value; different letters over bars indicate statistically significant results. (cont.)

### 3.2 The soil chemical properties in the summer and the winter

The results from paired samples t-test analysis of soil chemical properties between summer and winter are shown in Figure 6. It was found that soil pH, TC, TN and C/N ratios were significantly different between the summer and the winter in all gap sizes and the non-gap area. While soil TP and OM had significant difference only in the small gap size and the non-gap area, soil AP in the small gap size and soil TK in the medium gap size had no significant difference. Moreover, soil HN in the small and large gap sizes and soil AK in the non-gap area were significantly different between the two seasons.

## 4. DISCUSSION

During the summer season, all the tested soil chemical properties were significantly different among the gap sizes and non-gap area. However, during the winter season only OM, TK, HN, TN, TC and C/N ratios differed significantly among the gaps and the non-gap area. The results of this study showed that the gap size had profoundly influenced the soil chemical properties but in a non-regular pattern with respect to gap size.

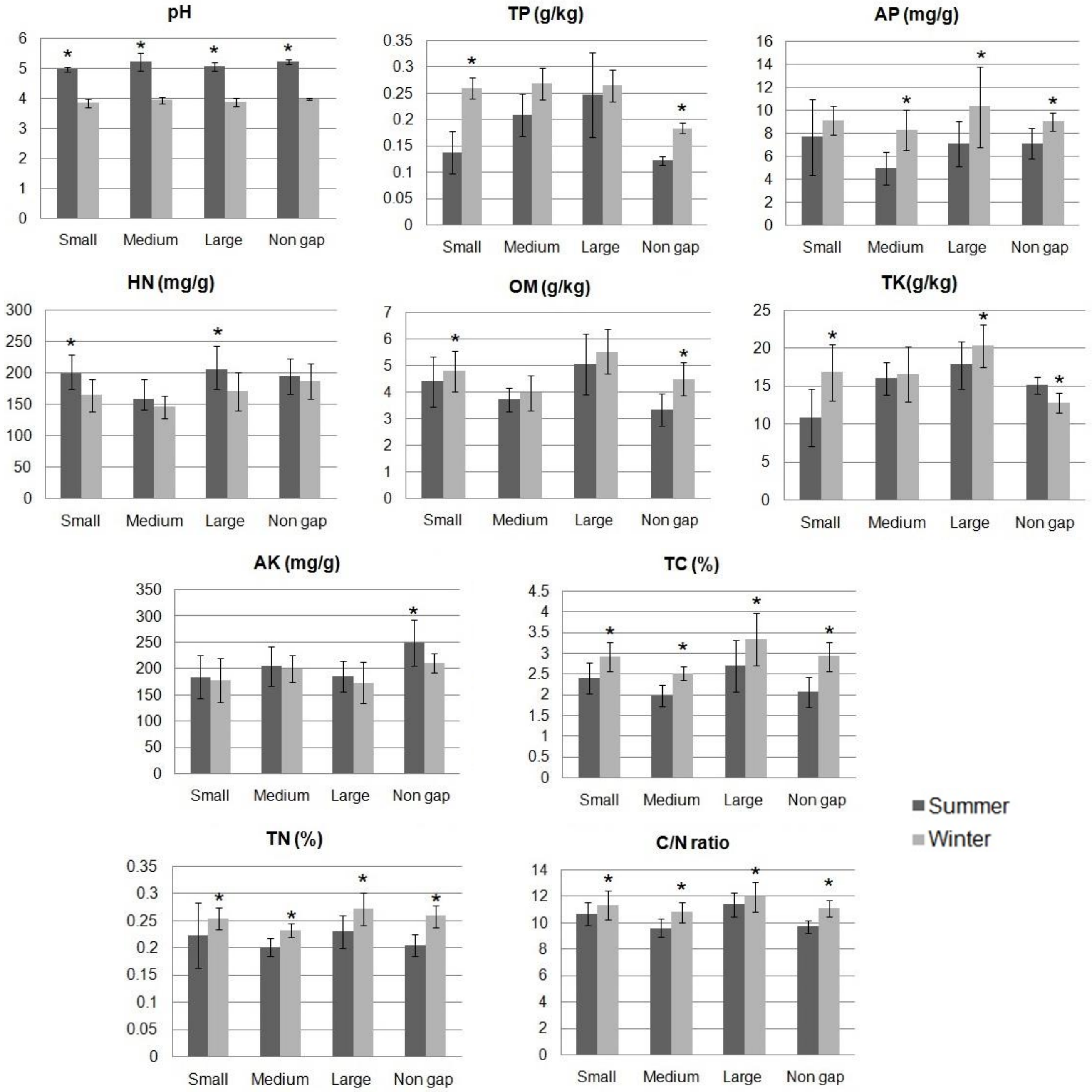


**Figure 6.** The graphs demonstrate the differences in mean soil chemical properties, between the summer and the winter, using paired samples t-test. Statistically significant differences ($p<0.05$) are denoted using asterisk ($^{*}$).

Soil pH in the small gap size was significantly lower when compared with the medium gap size. The values of soil pH in the small gap size were very strongly acidic while in the medium, the large gap size and the non-gap area were strongly acidic. According to the report of soil survey in China, the soil groups of this study area is the mixture of yellow and red earth, the soil pH value is less than 5.5, which means that the soil type is strongly acid-base (Hseung, 1980). The lower pH in the small gap size might be related to the level of gap disturbance, given that the small gap size was disturbed by branch fall while the medium and large gap sizes were disturbed by tree fall (Buajan et al., 2017). The soil pH in this study was a little higher than the value of soil pH in the same area that was previously determined in 2010 (He et al., 2015). The soil pH changes over time due to the weathering and managements (Pagani and Mallarino, 2011). Likewise, the effect of gap size on soil pH of the present study was not always congruent with those of the previous studies. Some studies have reported that soil pH was higher in the large gap size (Kooch et al., 2010; Haghverdi et al., 2012). On the contrary, some other studies have reported that soil pH was higher in the small gap size (Arunachalam and Arunachalam, 2000; Muscolo et al., 2010). However, the effect of gap size on soil pH was in the same pattern but in opposite direction with soil OM. According to our results, soil pH in every gap size and the non-gap area has a negative significant correlation with soil OM. The soil pH in this study was measured from the hydrogen ions ($H^+$) that was in connection with the organic ions, which means the accumulation of organic matter can lead to the soil acidification (Ritchie and Dolling, 1985). Moreover, soil pH also affects the HN, TN, TC, and the availability of plant nutrients. Most of the plant nutrients such as nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium are available at soil pH ranging from 6.5-7.5 while iron, manganese, boron, copper, and zinc are available at soil pH ranging from 5-6.5 (NRCS USDA, 2007).

Gap size did influence the OM, TN, TC, and C/N ratios. These factors were the lowest in the medium gap size and the highest in the large gap size. Similar findings have been reported from the subtropical humid forest of north-east India (Arunachalam and Arunachalam, 2000) and from the beech forest in northern Iran (Vajari, 2015), where the authors have shown that gap size has an effect on organic carbon and total nitrogen. Organic matter is the main source of nutrient for the plant growth, which decomposed from the decomposition of organic material by the microbial activity in soil (Grigal and Vance, 2000). The highest organic matter in large gap size indicated that soil in the large gap size has a higher potential to permit the plant growth than the other gap sizes. These results are related to the study from the Calabria pine stand forest, stating that average gap size of 380 $m^2$ has the greatest amount of organic matter compared with another size (Muscolo et al., 2007). Moreover, the differences of OM, TN, and TC among the gap sizes in this study had the similar trend with their contents in the order of large gap > small gap > medium gap. This order was also consistent with the study at the natural *Pinus koraiensis* mixed forest, Xiaoxing'an Mountains of Northeast China (Wen-biao et al., 2013).

The effect of gap size on TP and TK were in the same patterns where the value of TP and TK increased with the gap size. This result does not coincide with the studies reporting that the P value was the highest in the medium gap size (Özcan and Gökbulak, 2015) and the TK was the highest in the small gap size (He et al., 2015).

AP and AK have the greatest value in the small gap size. As we know that P and K are the essential elements for the plant growth. The available P in $PO_4^{-3}$ form uptake by the plants. A number of base cations resulted from litter decomposition can increase with increasing gap size, however, due to the leaching losses it can also decreased in more open areas (Scharenbroch and Bockheim, 2007). Similar results from the mixed beech - Hornbeam Forest of Iran have reported the reducing of available P and K in the larger area (Kooch et al., 2010; Haghverdi et al., 2012). The available P has a positive significantly correlation with HN. A research has reported that N concentration can explain about 70% of available P concentration due to the 15% N is constitutional in the structure of phosphates. The amount of N can improve the creation of phosphates (Olander and Vitousek, 2000; Treseder and Vitousek, 2001; Liu et al., 2014).

In addition, the numbers of soil chemical properties tested during the summer season were more significantly different among gap sizes and non-gap area than the winter season. Furthermore, it was revealed that the soil pH, TC, TN, and C/N ratios were significantly different in all gap sizes and the non-gap area during the two seasons, which indicated their seasonal sensitivity. Soil pH, HN, and AK were higher in the summer when compared with the winter, while the average values of soil OM, TP, TK AP, TN, TC, and C/N ratios in the winter were higher than those in the summer. The soil pH and OM are related with the studies of seasonal variation of soil chemical properties in natural forest in India, which reported that soil pH was the highest in the summer and soil OM was the highest in the winter (Salim et al., 2015). The lower OM in the summer might be due to the high temperature speeding up the degradation of organic matter (Vanhala et al., 2008; Conant et al., 2011).

The lower of soil OM might affect the other soil nutrients due to the soil OM being the main source of these soil nutrients. Summer is the growing season; therefore, the nutrient uptake by the plant was higher than that in the winter, this might be the reason why the value of soil OM, TP, TK AP, TN, TC, and C/N ratios in the summer were less than those in the winter. The lower soil pH during the winter season might be due to the effect of organic acid compounds in the organic matter, which can acidify the soil, depending on the plant form which the organic matter is derived (Ritchie and Dolling, 1985; Kononova, 2013). Moreover, the value of soil HN and AK during the winter were lower than that in the summer, this might be due to the chemical weathering effect on the soil properties (Olojugba and Fatubarin, 2015).

## 5. CONCLUSIONS

Most of the soil chemical properties varied according to the gap sizes and seasonal variability. The gap size affected the soil chemical properties, with the higher significant effect appeared during the summer as compared to the winter. The results of this study have shown that the gap size may affect the soil chemical properties in a non-regular pattern. Most of the highest values were reported in the large gap size both in summer and winter. We found a strong significant correlation between TN, TC, C/N ratio and soil OM. The highest soil OM in large gap size indicated the high potential of nutrient supply for the plant growth of soil in the large gap size. Besides, the soil OM has a negative significant correlation with the soil pH. However, the range of soil pH in this study area is strongly acidic which might affect the availability of nutrient uptake by the plants. For the regeneration and conservation of *C. kawakamii*, the medium and large gap sizes that have higher soil nutrients than those in the small gap size should be considered. This could be beneficial to the *C. kawakamii* growth.

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