Effect of Gap Size on the Dynamic of Micro Environments during the Daytime at *Castanopsis kawakamii* Natural Reserve Forest, Sanming City, China

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ABSTRACT

The temporal dynamics of micro-environments within gap size affect the species regeneration. This study aimed to determine the effects of gap size on the variation of micro-environments during the daytime. Nine sampling gaps at *Castanopsis kawakamii* Natural Reserve Forest, Sanming City, China were divided into three sizes (small, medium and large). The micro-environments viz. soil temperature at 0, 5 and 10 cm depth, air temperature, light intensity, and air relative humidity were recorded for the entire gap area in every 2 h interval from 8 am to 6 pm. The results showed time-dependent variations for these variables. In each gap size, the maximum light intensity was recorded from 10 am to 2 pm at the center of the gap, which was higher at the north and west directions than south and east directions, except for the north direction in large gap size. Light intensity has a significant positive correlation with soil temperature compared with that under canopy. Soil temperature responds differently according to the size of the gap that increased with time from morning to afternoon in large gap size with the highest during 12 to 2 pm which is different from small and medium gap sizes. Air temperature has a significant negative correlation with air relative humidity, both in gap sizes and under canopy. It could be concluded that gap size has a significant impact on the micro-environments and the variables in five directions were varied depending on the light intensity.

Keywords: Gap size/ Micro-environments/ Heterogeneity/ Light intensity/ Soil and air temperature
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1. INTRODUCTION

Forest gap is the areas in the forest created by old dying trees or trees struck by lightning or blown over by the wind or knocked down by other falling trees (Yamamoto, 2000). When a forest gap appears, it changes the micro-environment, especially the light intensity as well as air temperature, soil temperature, and soil moisture of the surrounding plants in the open area. Light bearing in mind the importance of gap and its influence on species diversity and community composition have attracted the attention of several researchers to investigate the dynamics of the gap (Abrams and Kubiske, 1990; Brokaw and Busing, 2000; Schumann et al., 2003; Ritter et al., 2005).

Gap results in heterogeneous environmental conditions within the gap areas. Brown (1993) studies about gap size and microclimate found that the relationship between gap size and microclimate is complex; however, the climate within the gap doesn't depend on gap size (Brown, 1993). Location and timing of gap created are the crucial factors influencing the microclimate and regeneration dynamic. According to the findings of Gray et al. (2002), solar radiation and soil temperature differ significantly among gap size and placement within the opening (Gray et al., 2002). Similarly, there is an increasing amount of evidence from tropical rainforest (Guyana) (Dam, 2001), in the temperate broadleaved deciduous forest (Latif and Blackburn, 2010), in *Pinus karaiensis* – dominated broadleaved mixed forest (Jing et al., 2012), *Castanopsis kawakamii* natural forest (He et al., 2012a) which are inconsistent and support the notion that gap size has significant impact on the micro-environments within the gap area.

C. kawakamii Hayata family Fagaceae is a rare species in southeast China that has been classified to be threatened by habitat loss (IUCN, 2016). This species is distributed in the southeast of

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China (South Fujian, Guangdong, Southeast Guangxi, South Jiangxi), Taiwan and north of Vitamin and can be found at an altitude below 1000 m.a.s.l. of broad-leaved evergreen forests. The *C. kawakamii* natural forest in Fujian province, which is the pure stand forest dominated by *C. kawakamii* had also been affected by the forest gap. Liu et al. (2006) studied the *C. kawakamii* population in both gap and canopy areas and their results showed that *C. kawakamii* was not gap-sensitive species; however, the population of the young tree was lack (Liu et al., 2006) . Nowadays, the population of *C. kawakamii* is reducing and the age structure of the population was not sustainable due to the decline of the population of seedling and sapling of *C. kawakamii*. The main causes are the lack of germination and seedling establishment and human disturbance (Liu et al., 2011). The most serious problem seems to be the low rate of seed germination. The percentage of seed germination in natural condition was below 30% (He et al., 2012b). Several studies have been conducted on this species to improve the image impacts of dynamic micro-environment resulted from the gap understood. Studies carried out to investigate the effects of forest gap on some microclimate variables in *C. kawakamii* natural forest gap have shown that the different gap size and gap location has different features of air-soil temperature, relative humidity, and soil water content accompanied by seasonal variability. A different condition in the microsite may influence the seed germination and seedling establishment of *C. kawakamii*. The required temperature for seed germination is 40-50 ºC (He et al., 2012b). However, the micro-environment variation data in the entire gap area in this study site is still incomplete. The previous study just determines along four axes. To understand the problem of *C. kawakamii* regeneration in the study site, the knowledge about variation of micro-environments in the entire gap areas is strongly required for the *C. kawakamii* species management and conservation of concern about the dynamic of micro-environment within the gap areas as well as the determination of the most suitable position for seed germination and establishment in the natural condition. Therefore, in this study, we aimed to: 1) determine the variation of micro-environments within the gap areas during the daytime, and then find the relationship between these factors; 2) investigate whether the gap size has an effect on micro-environments; and 3) determine the suitable position within the gap area for seed germination according to the requirement of seed germination temperature. The expected obtained results of this study might help to better understand the way to manage the *C. kawakamii* species regeneration.

2. METHODOLOGY

2.1 The study site

C. kawakamii Natural Reserve forest in Sanming city, Fujian province, China is located at N 26º07’-26º12’ and E 117º24’-117º29’ under a subtropical monsoon region, bordering with Wuyi and Daiyun Mountain in the northwest and southeast, respectively. The mean annual temperature is about 19.5 ºC (average of 40 years of data collected from the Sanming Meteorological bureau, China) and daily mean minimum temperature (in the winter season between December and January) is -5.5 ºC and maximum is 40 ºC. Annual rainfall is 1,500 mm in which 75% of rainfall occurs in the summer season between March and August. Annual average relative humidity is 79%, and mean velocity of the wind is 1.6 m/s. 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 is enriched in soil nutrition. More than 100 years ago, the name *C. kawakamii* was given by Graeme, an English botanist, who found this evergreen chinquapin. In 1994, Shuishen and Zhenting studied about the division of natural vegetation type in *C. kawakamii* Nature Reserve. They found that this forest has 1,010 species belonging to 434 genera and 145 families. The dominant species are as follow: 1) *C. kawakamii*, 2) *C. carlesii*, and 3) *C. fargesii*. (Shuishen and Zhenting, 1994). In this subtropical *C. kawakamii* Nature Reserve, there are evergreen broadleaved vegetations dominated by overmature *C. kawakamii* (the average age is over 100 years), *C. 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 found that the growth in the tree and the seedling populations has declined except 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).

2.2 Experiment area

We selected the forest gap by classifying the size of the gap into three sizes (small, medium and large) as shown in Figure 1. Measuring the gap size and gap area using fish eyes lens camera to take a photo at the center of each gap, We used the Adobe Illustrator CC 2014 computer software program

(Eastman kodak company, California, United State of America) to draw the line in the photo. Eighteen lines were drawn at 10º intervals through the image center of each gap. The length of each line was measured from the center of the image to the canopy edge (in pixels). The unit of length in pixels was converted to the centimeter. 1 cm=pixels/ 118.11 (this ratio id depends on the resolution of the photo) this method is according to (Hu and Zhu, 2009) and sampling plot in the understory. In each gap size, after measuring the width and length of a gap, a grid was used to cover all of the entire gap area (resolution 3 m x 3 m).

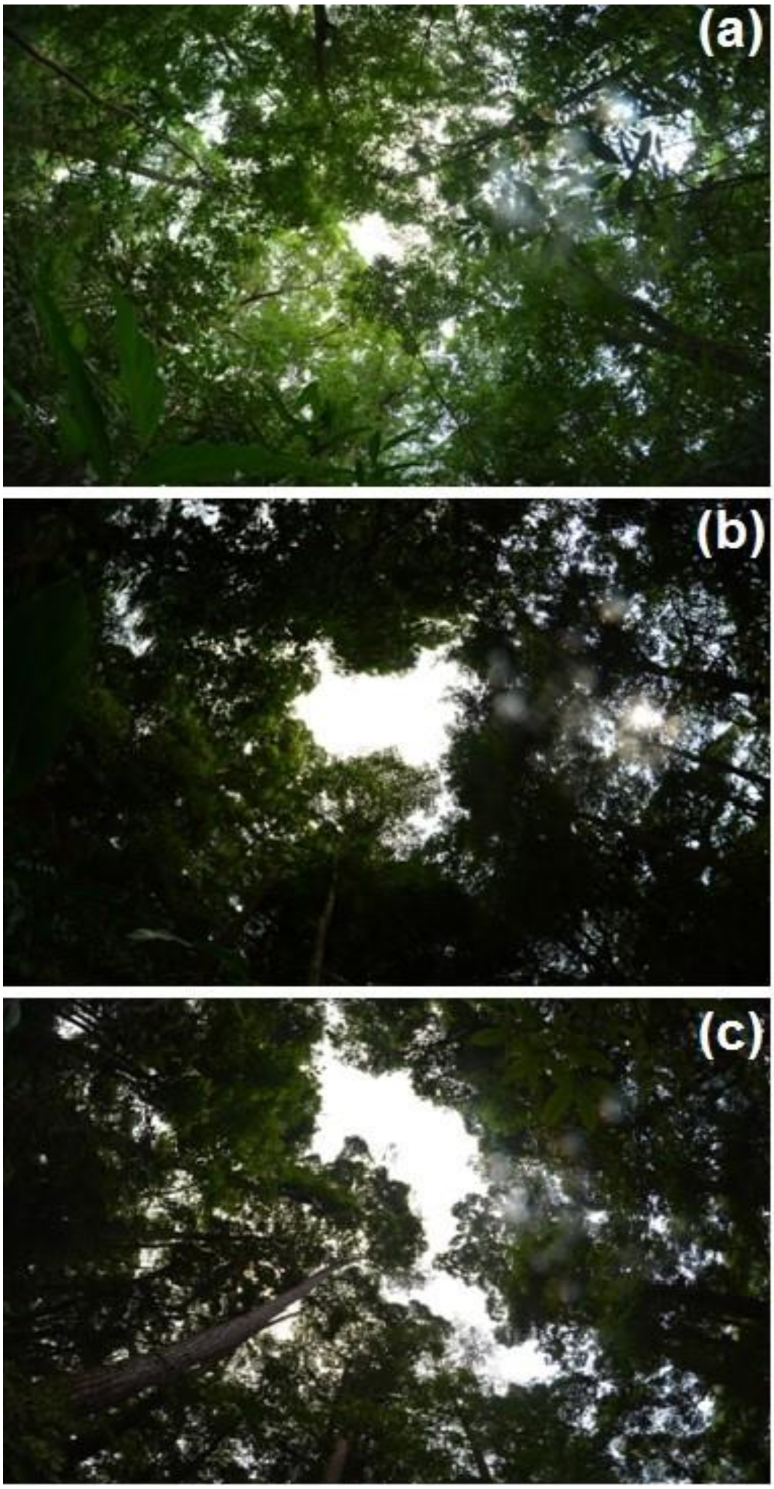

Figure 1. The photo of (a) small gap size; (b) medium gap size; and (c) large gap size

2.3 Environmental and soil measuring

In each sampling plot, we measured climatic factors such as air temperature (AT), air humidity (RH), and light intensity (LI). AT and RH were measured using TES-1360A handheld digital thermo-hygrometers. LI was measured using a light intensity meter. Soil temperatures at 0, 5 and 10 cm below the soil surface (ST0, ST5, and ST10) were measured using a 6300 needle soil thermometer. Soil water content (SWC) was measured using TZS-IIW soil moisture and temperature measuring instrument (length of the probe about 7 cm). All those factors were measured in 2 h interval from 8 am to 6 pm.

2.4 Statistical analysis

The average, maximum and minimum data values for all variables divided into five directions were calculated using Microsoft Excel 2007. The correlations were calculated using the Pearson correlation method (Steel and Torrie, 1980). All data were analyzed using the program SPSS 16.0. Figures were generated by using software Grapher version 8.1.388 (Golden software, Inc. Colorado, United State of America).

3. RESULTS AND DISCUSSION

3.1 Dynamics of micro-environments during daytime within gaps and the under canopy area

During the summer season: In small gap size, the values of the average ST0, ST5 and ST10 were lower in the morning and then gradually increased in the noon time particularly at the center of the gap, while the values were very high when compared with another direction shown in Figure 2. SWC in south, east and north exhibited the similar trend, dropping at 8 am and then rising up at 10 am and finally decreasing again at 2-4 pm. However, in the west and at the center, the peak of SWC was during 10 am-12 pm and then gradually decreased in the afternoon as shown in Figure 3. In the south and east directions, the peak of LI was recorded during 1-2 pm while in the north and the west directions, the peak of LI was during 2-4 pm. The highest value of LI occurs in the center of the gap (8,136.7 Lux) and it was during 1-2 pm. Average RH in every direction was the highest in the morning that decreased gradually in the afternoon unlike the average AT as shown in Figure 4.

As for the medium gap size, the average values of ST0, ST5 and ST10 were lower in the morning, followed by a gradual increase until the afternoon. The highest value was recorded at the center of the gap at 1-2 pm as shown in Figure 2. SWC in the south and the west directions has the same trend, the highest was during 10 am -12 pm while in the east direction, the highest was during 2-4 pm. The center of the gap had the highest SWC when compared with the other directions and it was in contrast with the north direction during 1-2 pm as shown in Figure 3. The maximum LI in the south, the north, the west, and at the center were observed during 10 am-12 pm while the east direction was observed during 1-2 pm. The highest average of LI in this gap size occurred in the west direction. The average RH in every direction was the highest in the morning and then decreases gradually in the afternoon that is opposite to the average AT. The lowest RH was recorded during 2-4 pm as shown in Figure 4.

Regarding the large gap size, the average values of ST0, ST5 and ST10 were lower in the morning, followed by a gradual increase until the afternoon. The highest value was recorded in the east direction of a gap at 4-6 pm as shown in Figure 2. The average SWC was low in the morning and reached the peak during 10 am-12 pm and then decreased gradually in the afternoon except in the east direction. The highest value was noticed during 2-4 pm as shown in Figure 3. The highest LI was during 1-2 pm, which was presented at the center of the gap. RH in every direction was the highest in the morning and then decreased gradually in the afternoon, unlike the average AT. The lowest of RH was during 2-4 pm as shown in Figure 4.

Under the canopy area, the soil temperature exhibited the similar trend in all three leaves and values No significant difference was found during the whole day as shown in Figure 2. SWC in the north and the east directions was the highest in the morning and then decreased in the afternoon. In the south direction and at the center, the highest SWC occurred during 4-6 pm while in the west, the SWC was not significantly different during the whole day as shown in Figure 3. LI reached the peak during 1-2 pm in the south, the west, and at the center. In the north direction, LI was the highest in the morning, decreased during 10 am-12 pm and then rose up again during 1-2 pm. RH value was high in the morning but declined in the afternoon in contrast with the AT as shown in Figure 4.

During the winter season: In the small gap size, the ST0 in the morning was lower than the ST10 but in the afternoon, the ST0 increased while the value of the ST10 did not so much change so in the afternoon the value of the ST0 was a little bit higher than the ST10 as shown in Figure 5. SWC in small gap size was stable all day as shown in Figure 6. Average RH was highest in the morning and then decreased gradually in the afternoon that is opposite to the average AT as shown in Figure 7.

As for the medium gap size, the average ST0, ST5 and ST10 had the same trend as shown in Figure 5. SWC in the small gap size was stable all day as shown in Figure 6. The south, the east and the west directions, the maximum average LI occurred during 1-2 pm and during 10 am -12 pm in the north and at the center. The highest average LI was in the north direction. The average RH was highest in the morning and then decreased gradually in the afternoon that is opposite to the average AT as shown in Figure 7.

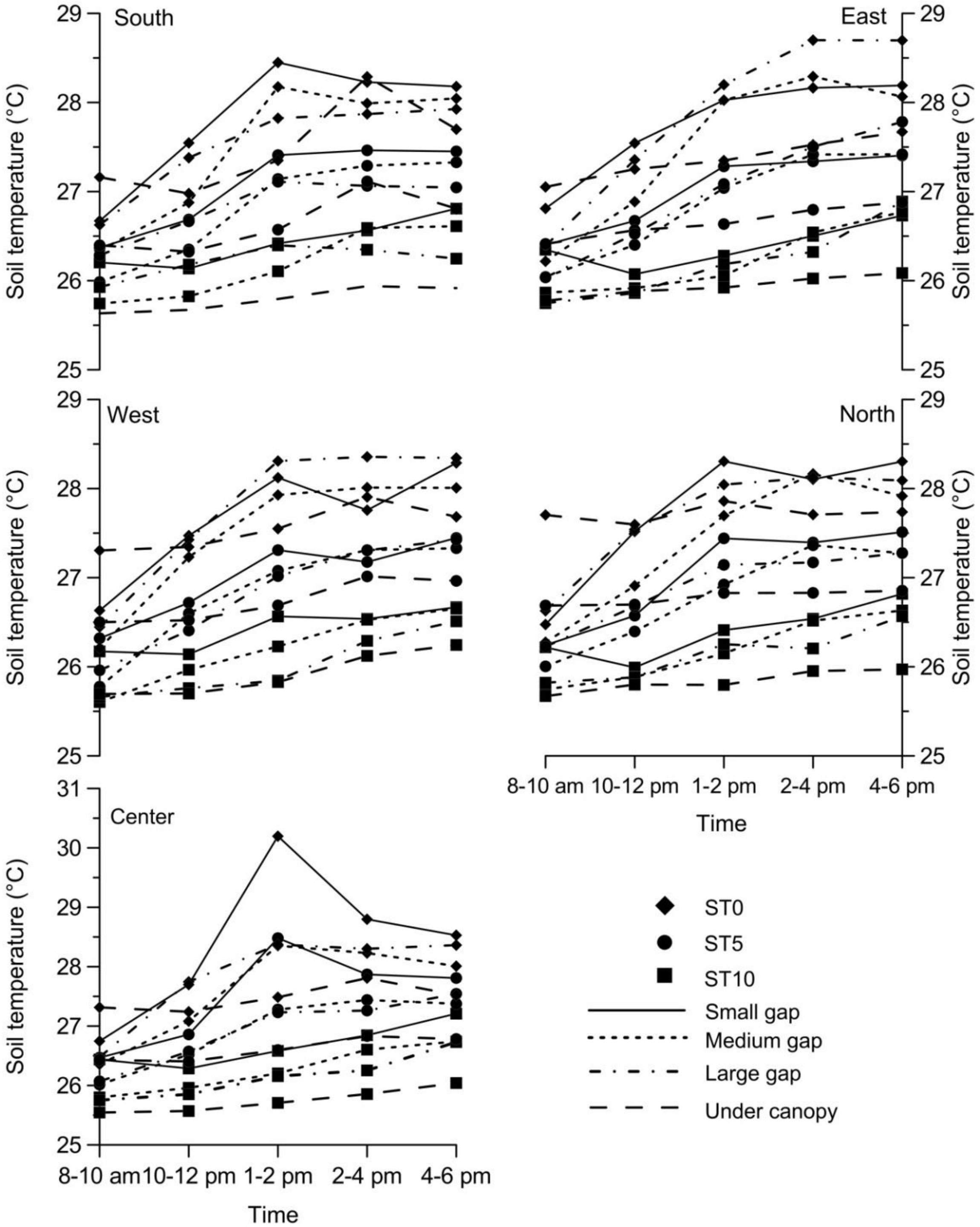

Figure 2. The average ST0, ST5 and ST10 of small, medium, large and under canopy area in the summer season

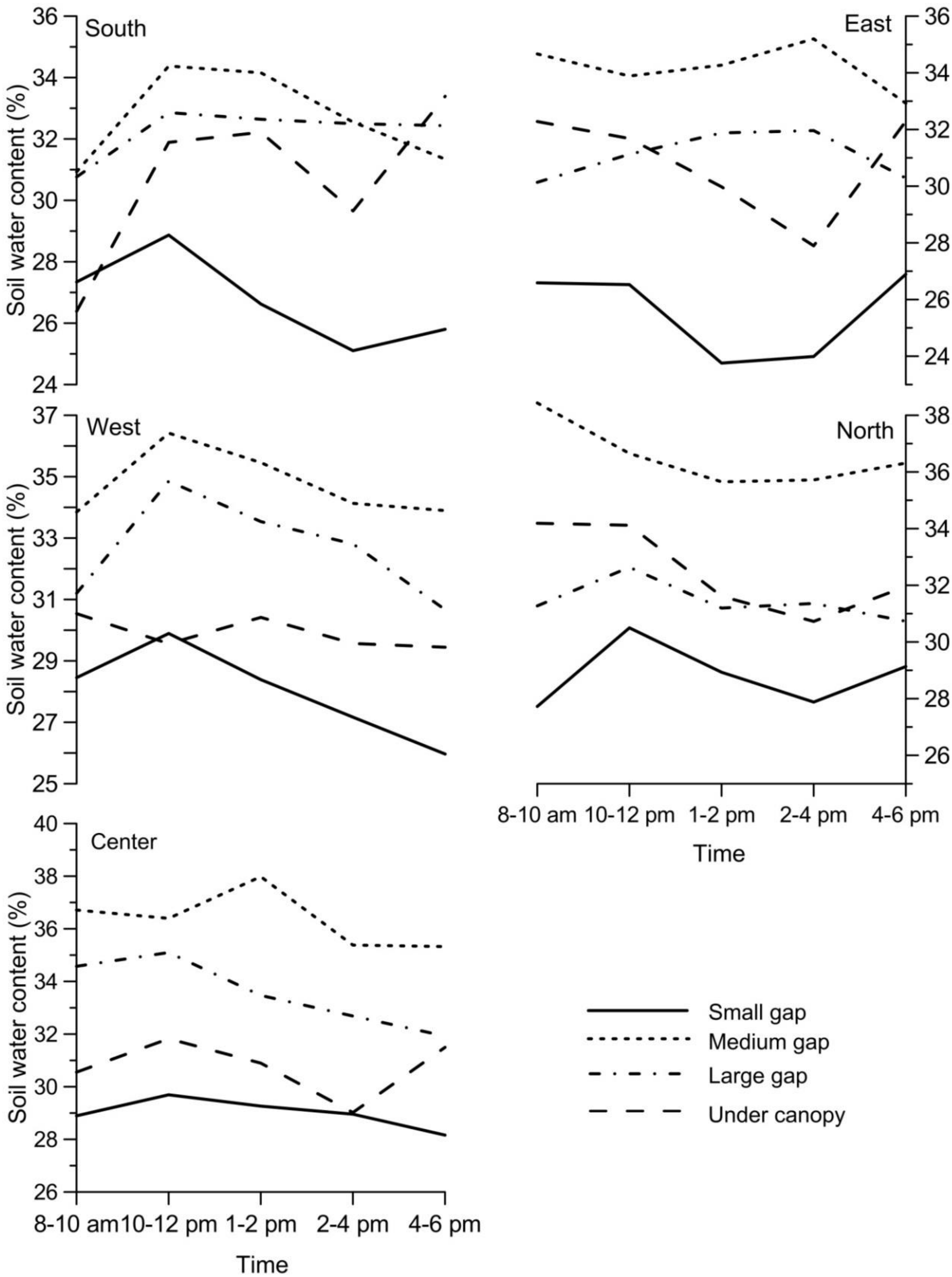

Figure 3. The average SWC of small, medium, large and under canopy area in the summer season

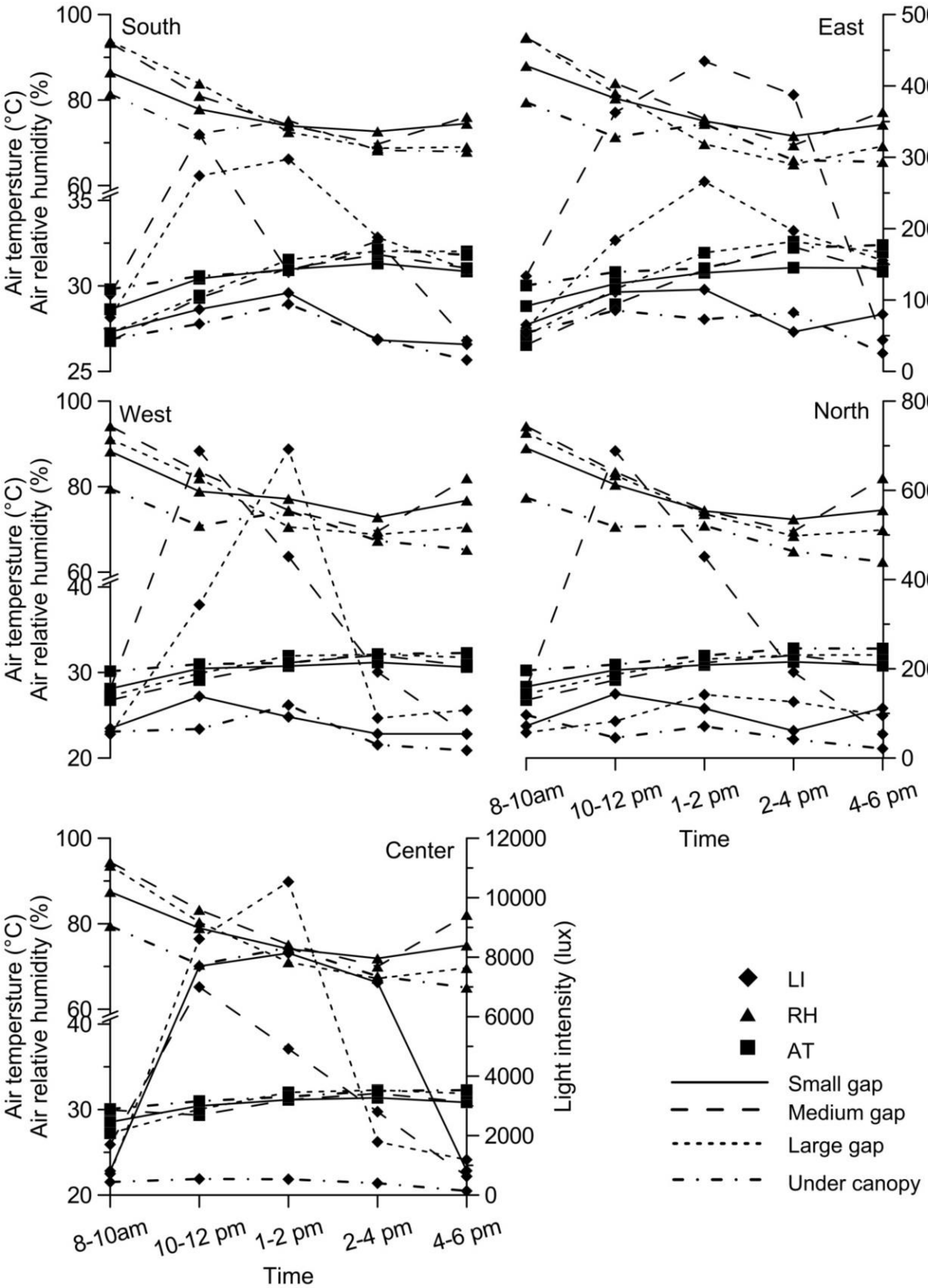

Figure 4. The average LI, AT and RH of small, medium, large and under canopy area in the summer season

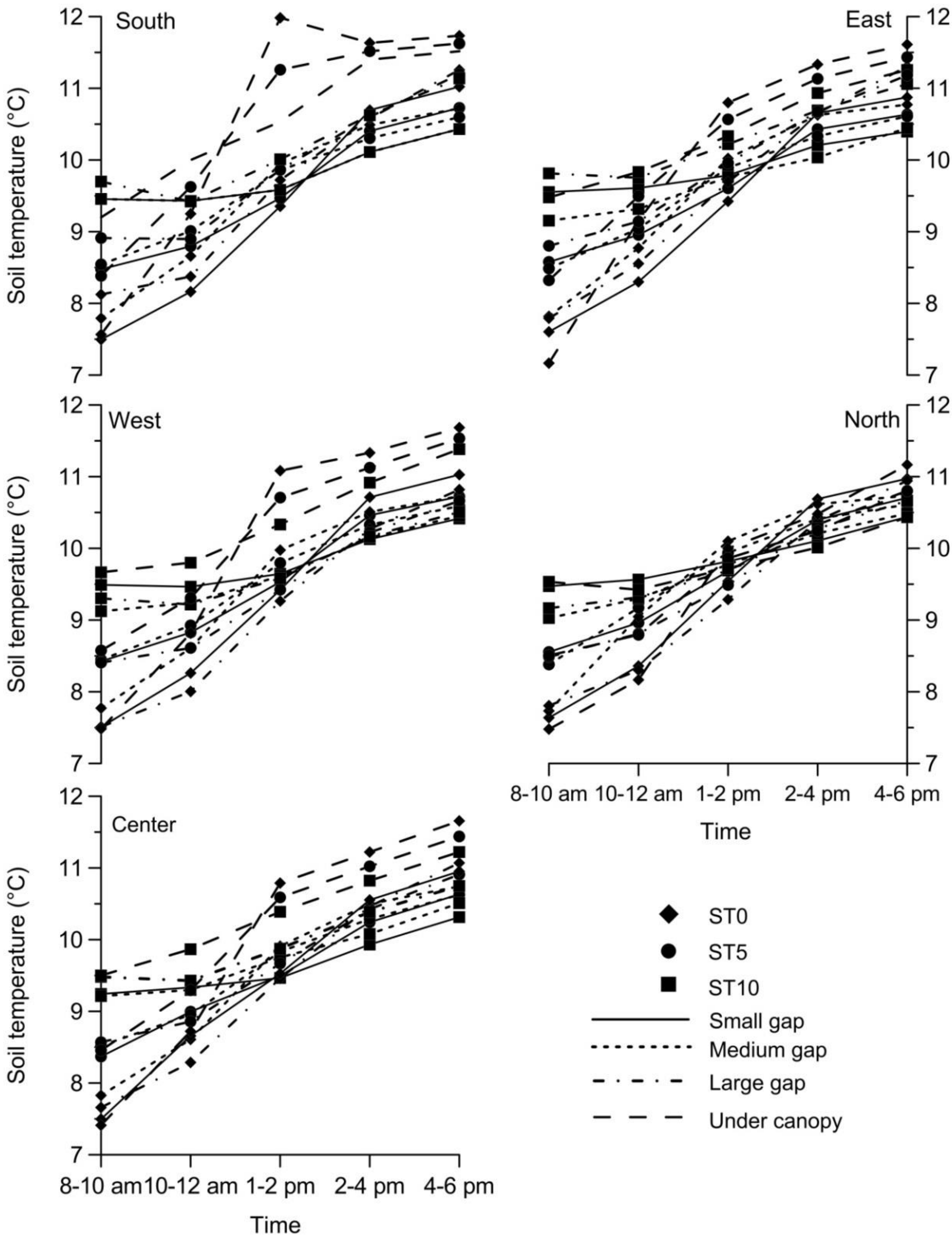

Figure 5. The average ST0, ST5 and ST10 of small, medium, large and under canopy area in the winter season

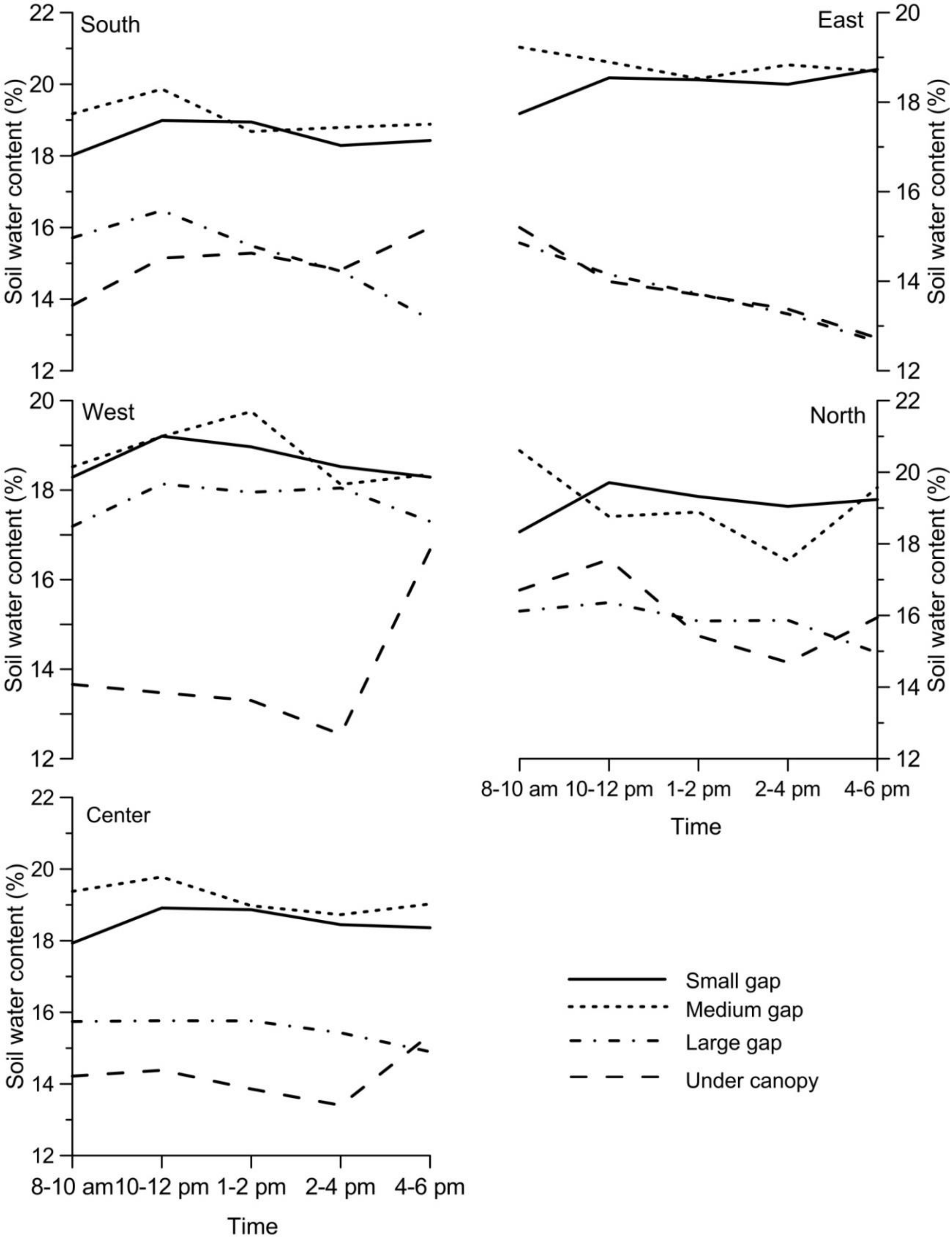

Figure 6. The average SWC of small, medium, large and under canopy area in the winter season

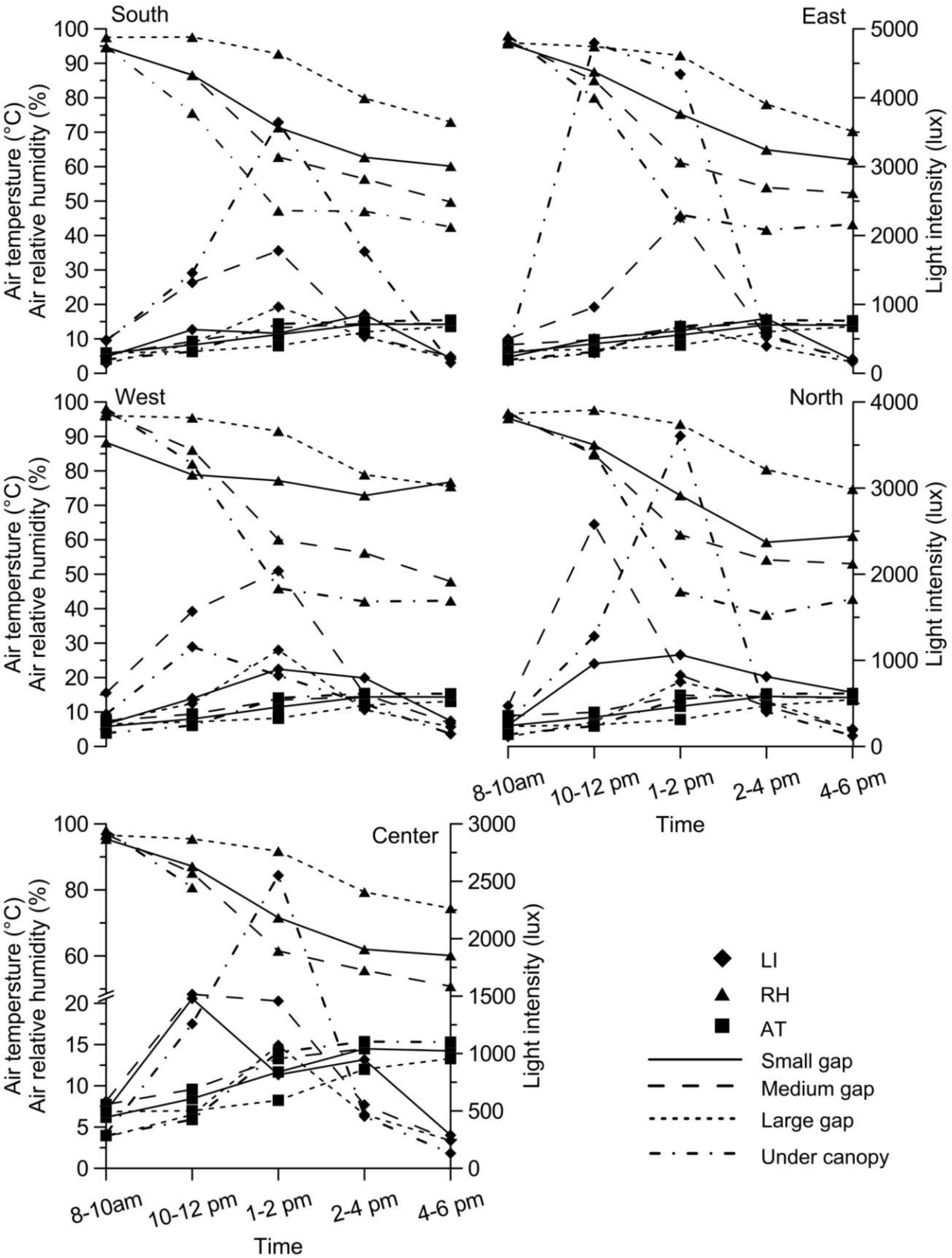

Figure 7. The average LI, AT and RH of small, medium, large and under canopy area in the winter season

Regarding the large gap size, the average ST0 in the morning was lower than the ST10 but in the afternoon, the ST0 increased while the value of the ST10 did not much change, so in the afternoon, the value of the ST0 was a little bit higher than the ST10 as shown in Figure 5. The SWC in the small gap size was high in the morning and then gradually decreased in the afternoon except in west direction is shown in Figure 6. The average LI in every direction was reached to the peak at 1-2 pm except in north direction was reach to the peak at 2-4 pm. The highest LI occurred at the center. Average RH was highest in the morning then decreases gradually in the afternoon oppositely with average AT is shown in Figure 7.

Under canopy area, the average ST0 was higher than the ST10 in the morning then both of them gradually increase in the afternoon but ST10 was increased more than ST0, so in the afternoon, the value of the ST10 was almost the same as the ST0 as shown in Figure 5. The value of the SWC was low in the morning and then increased in the afternoon except in the east direction, the high SWC occurred in the morning and then decreased in the afternoon as shown in Figure 6. LI reached the peak during 1-2 pm in the south the north and at the center. In the east and the west direction, the peak of LI was during 10 am-12 pm. The maximum LI occurred in the east direction. The RH in every direction had the same trend, high humidity occurred in the morning and then decreased in the afternoon that is opposite to the AT. The lowest AH was during 2-4 pm as shown in Figure 7.

3.2 The correlation of each environmental factor in two seasons

The relationships between the environmental factors and the soil variables were examined using the Pearson correlation method, and the correlation coefficients (*r*) in the summer season are shown in Table 1 and the winter season in Table 2.

Table 1. Correlation coefficients (*r*) for the relationships between environmental factors and soil variables in each size gap and under canopy area (summer season)

		ST0	ST5	ST10	SWC	LI	AT	RH	
Small (n=295)	ST0		.961**	.700**	-.268**	.149**	.126**	-.599**	Medium (n=660)
	ST5	.885**		.840**	-.280**	.122**	.123**	-.589**	
	ST10	.583**	.762**		-.140**	ns	.142**	-.498**	
	SWC	.125*	.179**	.158**		ns	ns	.074*	
	LI	.222**	.171**	.108*	ns		ns	-.069*	
	AT	.693**	.614**	.353**	.096*	.211**		-.122**	
	RH	-.634**	-.618**	-.364**	-.199**	ns	-.870**		
Large (n=930)	ST0		.894**	.244**	ns	ns	.349**	-.325**	Under canopy (n=180)
	ST5	.846**		.650**	ns	ns	.433**	-.437**	
	ST10	.433**	.784**		ns	ns	.342**	-.394**	
	SWC	ns	ns	ns		.312**	ns	ns	
	LI	.230**	.114**	ns	ns		-.143*	.166*	
	AT	.733**	.646**	.322**	.086**	.144**		-.867**	
	RH	-.477**	-.460**	-.249**	-.164**	-.078**	-.735**		

* Correlation is significant at the 0.05 level, ns is no significant.
** Correlation is significant at the 0.01 level.

The dynamic of micro-environments such as soil temperature, light intensity, air temperature, air relative humidity and soil water content were detected every 2 h from 8 am to 6 pm. These variables were found to be time-dependent, demonstrating enormous changes over time. The main factor that greatly affected the micro-environments was the light intensity which is congruent with Duan et al. (2013). The results showed that in every gap size, the light intensity peaked from 10 am to 2 pm according to the sun direction that is perpendicular to the forest ground (Duan et al., 2013). The highest light intensity was recorded at the center of the gap which is also previously reported by Tokiman (2005) and Gálhidy et al. (2006). The light intensity in the north and the west directions were higher than the south and the east directions except in the north direction of the large gap size. These results are related to the variation of light intensity in the Pinus koraiensis-dominated broad-leaved mixed forest (Duan et al., 2009). In addition, the study regarding the position within the gap and the level of light noted that the northern part of the small and the medium gaps has a higher level of light than that of the southern part (Berthiaume and Kneeshaw, 2009). The correlation coefficients showed that in the gap areas, light intensity has a significant correlation with soil, compared with the under canopy area, which has not shown a significant correlation between light intensity and soil. This indicated that in the gap area, light intensity has an effect on soil temperature.

Table 2. Correlation coefficients (*r*) for the relationships between environmental factors and soil variables in each size gap and under canopy area (winter season)

		ST0	ST5	ST10	SWC	LI	AT	RH	
Small (n=295)	ST0		.976**	.796**	-.136**	.153**	.581**	-.865**	Medium (n=660)
	ST5	.943**		.908**	-.177**	.097**	.550**	-.847**	
	ST10	.615**	.841**		-.234**	ns	.413**	-.694**	
	SWC	ns	-.149**	-.282**		ns	-.073*	.094**	
	LI	.149**	.123*	ns	ns		ns	ns	
	AT	.803**	.623**	.176**	ns	.108*		-.629**	
	RH	-.554**	-.357**	ns	ns	ns	-.897**		
Large (n=930)	ST0		.978**	.804**	-.250**	ns	.897**	-.877**	Under canopy (n=180)
	ST5	.958**		.910**	-.295**	ns	.845**	-.816**	
	ST10	.740**	.901**		-.345**	ns	.628**	-.586**	
	SWC	-.160**	-.210**	-.252**		ns	-.136*	.143*	
	LI	.174**	.146**	.079**	.148**		ns	ns	
	AT	.707**	.627**	.406**	-.066*	.092**		-.977**	
	RH	-.721**	-.615**	-.355**	.087**	-.142**	-.747**		

* Correlation is significant at the 0.05 level, ns is no significant.
** Correlation is significant at the 0.01 level.

The varied soil temperature of the three gap sizes during one day has a different trend depending on the size of the gap. The soil temperature in the large gap size increased from morning to afternoon, which differs from the small and the medium gap sizes with the highest value of soil temperature, presented during 12 to 2 pm. This is because the large gap size received the solar radiation longer than the small and the medium gap sizes as the large gap size has a more exposed area to the solar radiation (Gálhidy et al., 2006; Duan et al., 2013). The variation of the soil temperature in this study was related to the study about micro-environment that was conducted at the same site in the year 2011 (He et al., 2012a). Light intensity in gap areas has a significant correlation with soil temperature when compared with under canopy area. Soil temperature is the important factor for seed germination, especially for the *C. kawakamii* seed germination that required high temperature (40-50 ºC) for germination (He et al., 2012b). Air temperature has a negative significant correlation with the air relative humidity in the three gap sizes as well as under the canopy area. The variance of air temperature and relative humidity influenced by the light intensity as the results show the significant correlation between light intensity and air temperature. Air temperature in small and large gaps was influenced by light intensity, while the opposite applied for the light intensity in the medium gaps. This case might be because the effect of the wind on air temperature in the medium gaps was stronger than that of light intensity. In an open area like a gap, wind speed can decrease the air temperature by blowing away the hot air and replacing it with cooler air (Orzel, 2010). Moreover, the relationship between light intensity and air temperature and air relative humidity in gap areas were considered as opposites of that observed in under canopy areas, demonstrating that light intensity had a strong effect on micro-environments in the gaps. In this study, air temperature can be used as an indicator for soil temperature due to the significant correlation between them related to the study of air and soil temperature in the tropical forest (Tokiman, 2005; Ahmad and Rasul, 2008).

In the winter season, variable soil temperature behaved a little differently from the summer season, in which the value of soil temperature in all the three levels peaked at 4-5 pm. In the winter season, sunrise time was approximately 7 am and mostly, day was cloudy in the morning. In the study site, sunshine appeared approximately during 11 am-12 pm, so soil started to absorb the heat from the sun until sunset. Soil temperature in the winter season is not suitable for seed germination because of the low temperature. Soil water content had a negative significant correlation with soil temperature due to the dry season (winter season), the low soil temperature has more effect on percentages of water content in soil than a wet season (summer season) (Matejka et al., 2009). The variation of light intensity during one day in the winter season is similar to that the summer season. The highest light intensity was at the center of the gap. Light intensity in the north direction was higher than that of the south direction. The variance of air temperature and relative humidity were similar to the summer season.

The seasonal variation in values of these variables is reflected according to the different seasons. In summer, light intensity was higher in the summer than in the winter and this has an effect on soil temperature, air temperature, and air relative humidity. All those factors were higher in the summer season than in the winter season. Soil water content in the summer season was higher than in the winter season because rainfall in the summer season was higher than in the winter season (Zhou et al., 2014). The micro-environment has more variation in the summer season than in the winter season, considerated that the summer season is the optimal time for the species regeneration in this area.

The result of this study indicated that more variation of micro-environments was found in the forest gap than in the under canopy area, which can be beneficial to the species growth. The environmental heterogeneity within the gap areas leads to the species coexistence. Knowing about the variation of environments within the gap area can be applied to forest management. Gap areas, especially at the center and the north part of the gap which received the high solar radiation is the necessary for species regeneration. Moreover, the variation of environmental conditions in each season has importance in the species regeneration as well. This study enhances the knowledge about the micro-environments variation within gap areas in different seasons to protect and promote the rare species regeneration.

4. CONCLUSIONS

The variation of micro-environments within the gap area depends on time. Light intensity is the main factor, which affects other factors. The highest light intensity was presented in the large gap size particularly at the center of the gap. The north direction of the gap has higher light intensity when compared with the other direction. These factors have a significant correlation with one another, i.e., the air temperature has a significant correlation with soil temperature and air relative humidity. Moreover, light intensity has a significant correlation with soil temperature which was not found in the under canopy area in both seasons. The soil temperature is important to the seed germination and species regeneration, which indicates that gap area has the potential to promote seed germination and species regeneration.

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