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The Spatial Variability of Soil Physical Properties of Different Sized-gap in a Subtropical Forest, China

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Abstract

Gap areas create heterogeneity in the spatial environment, which is important to plant regeneration and diversity. Soil physical properties (SPP) are factors that affect plant growth. This study aims to assess the spatial variability of SPP in different gap sizes and to determine the effect of gap size on SPP. We used geostatistical analysis to illustrate the spatial patterns of SPP variability within 9 gaps, classified into three sizes (small, medium, and large) and under the canopy at the *Castanopsis kawakamii* natural reserve forest, the soil samples were collected entire gap area at 20 cm depth with the grid system (resolution: 3 m × 3 m). The following SPPs were determined using soil cores: soil bulk density (SBD), soil water mass content (SWMC), soil volumetric moisture content (SVMC), maximum moisture capacity (MMC), capillary water capacity (CWC), minimum water-holding capacity (MWHC), soil capillary porosity (SCP), and soil total porosity (STP). We found that every SPP, except SCP and STP, significantly differed with gap size. Gap sizes generally improved the SPPs, especially in the small and large gaps, indicating that the soil there was more suitable for plant growth than the soil under the canopy. The highest spatial variability of SPPs was observed in the large gaps. Gap size affected SPP and its spatial variability. The results from this study will be useful for work on forest gap regeneration and conservation, especially around the study site.

Keywords: Gap size; Spatial variability; Soil physical properties; Sub-tropical forest; China

Introduction

Soil is a natural medium, which developed on the Earth's surface and acts as the habitat for countless organisms. It consists of organic matter, minerals, gasses, liquids, and innumerable living things [1]. It is of importance for agriculture and forestry and is one of the two key factors influencing plant growth, with the other being climate. Plants need soil throughout their life cycle, from germination to maturation; this is

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especially true for wild plants because in agriculture other media can be used [2]. Forest soil provides the space for roots to develop. It holds the water in which micronutrients are ionized, turning into a form that is available to plants. Soil also holds air pockets that prevent waterlogging. All of these soil characteristics are influenced and can be determined by soil physical properties.

Soil physical properties include density, permeability, and porosity. These parameters play an important role in water and nutrient extraction by the plant root. A limit to plant growth can be imposed by the nutrient supply, or the soil characteristics such as texture or structure, salinity, acidity, waterlogging, and compaction. The characteristic of soil can be described by soil bulk density which is the ratio of mass to volume and can also indicate its compaction [3]. Highly compacted soil will have a high bulk density value [4]. Bulk density is also related to soil permeability and porosity, which also affect plant growth. The permeability of soil refers to the movement of water through the soil pore space, which is reduced by compaction [5]. The last parameter is porosity, which refers to the space between soil particles. More pore space allows for more water and gas in the soil, which is both necessary for plant growth. Pore size was shown to have a positive effect on root development [6]. Lack of water in soil diminishes nutrient uptake by plants [7]. On the other hand, extreme amounts of water in the soil affect root respiration. Clark et al (2003) reviewed how root development was influenced by compact soil and found that it decreases elongation rate [8]. The soil compaction also affects root cell expansion [9] and the rate of cell flux which is the number of cells per unit time moving past a reference point a fixed distance behind the root tip [10]. Soil that combines optimum levels of the three physical properties described (soil density, permeability, and compaction) is most suitable for plant growth [11–13].

Canopy gaps are open areas caused by felled trees or branches. The appearance and disappearance of such gaps drive the forest dynamic, as they provide a link between forest disturbance and succession. Without gaps, biodiversity is generally quite low, inter-species competition does not happen because a few species tend to dominate the area, and the forest structure has only one layer because the regeneration of new seedlings does not happen. Canopy gaps are therefore very important for maintaining the forest ecosystem [14]. Gap areas promote the density of species' recruit [15]. Many researchers have reported that forest gap areas alter the microenvironment such as soil physiochemical properties and climate, which directly affects the plants [16]. Duan et al (2009) noted the heterogeneity of soil properties within forest gaps [17]. Additionally, our previous studies have shown that gap size affects the soil chemical properties [18]. Both sizes and developmental stages of forest gaps improved soil properties when compared to the soil properties of areas under the canopy. In particular, small gap size improves soil moisture and porosity composition, compared to medium and large gap size. The early and later stages of the gaps, improve soil moisture and porosity composition [19]. With these regards, we hypothesized different-sized gaps may affect soil physical properties. However, the spatial variability of soil physical properties within a gap and the effect of gap size remain unclear. Thus, spatial variability of soil physical properties was also investigated using geostatistical analysis. Specifically, this study aims to investigate the spatial variability of soil physical properties in different-sized gaps to shed light on this issue. Our results can be applied to species management, regeneration, and conservation within gap areas.

Materials and methods

1) Site descriptions

The study area was located (26º07′–26º12′N, 117°24′–117°29′E) at the sup-tropical forest in Sanming City, Fujian Province, China (Figure 1 (a) and (b)). The *Castanopsis kawakamii* Natural Reserve forest is the part of this forest which, on the northwest bordering is the Wuyi Mountain and on the southeast bordering is the Daiyun Mountain. The climate zone of this region is the middle subtropical monsoon. The average annual temperature is about 19.5°C; the daily mean lowest temperature is -5.5°C, while the highest temperature is 40°C. Total rainfall per year is about 1,500 mm (data was averaged of 40 years (1972–2012) collected by the Sanming Climatological Bureau, China). Humus and soil nutrients are concentrated in the top 1 m layer of the soil [20].

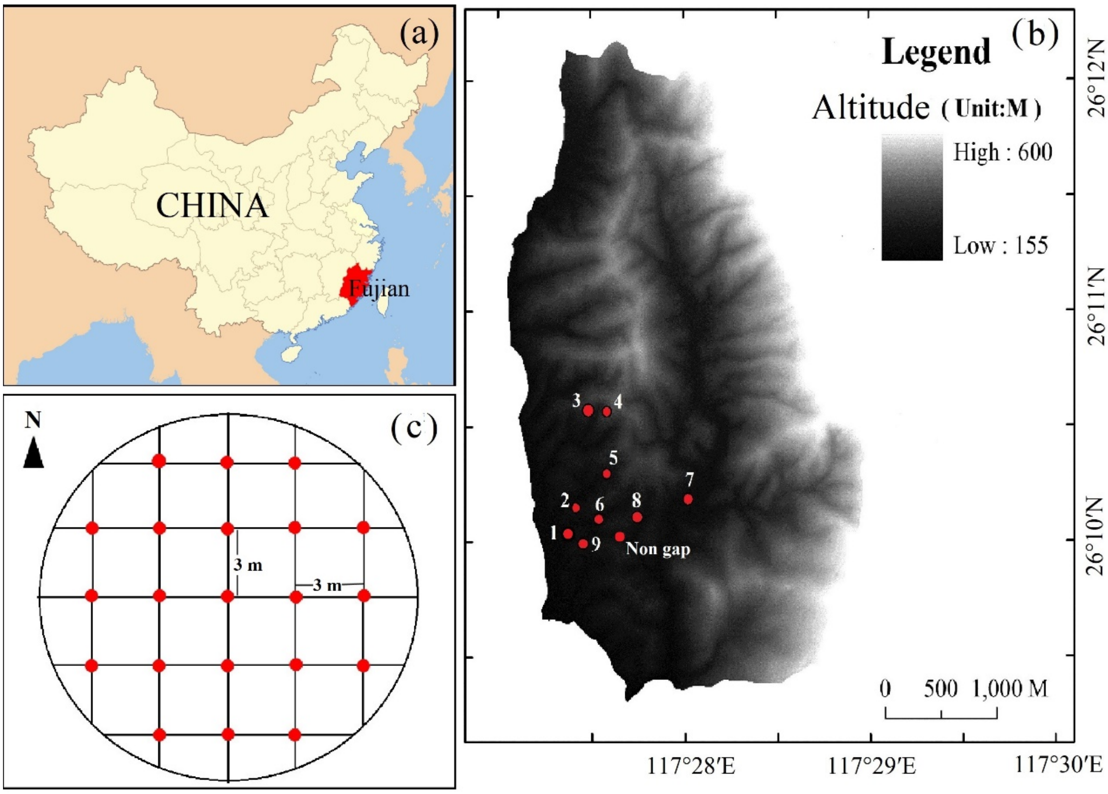

Figure 1 (a) Map of China shows the location of Fujian province, (b) location of the study area at *Castanopsis kawakamii* Natural Reserve forest, Sanming City, Fujian Province, and the numbers one to nine denote the gap no. 1–9 location, This map is modified from [21], (c) schematic of the grid system (3×3 m^2) in each forest gap and non-gap areas for the investigation of soil physical properties. The cycle indicates the gap area and the red dots denote the soil sampled points.

2) Gap size classification and soil sample collection

The method for calculating the gap area was the two hemispherical photographs (THP) method. A photo was taken at the centre of each gap by using fish-eye lens camera. The photos were processed by computer software (Adobe Illustrator CC 2014, Eastman Kodak company, CA, USA) and the equations for calculating the gap size are shown in Hu and Zhu, 2009 publication [22]. The areas of nine forest gaps ranged from 30.28 to 216.72 m^2. The nine forest gaps were categorized into small, gap no. 1, 5 and 6 (30–50 m^2) medium, gap no. 3, 7 and 8 (50–100 m^2), and large gaps, gap no. 2, 4 and 9 (> 100 m^2), according to the ranging of gap area.

The topographical factors (slope, altitude and slope direction) and features of each gap (gap maker and gap stage) are reported in our prevised study [23]. The under-canopy areas were selected and the plots of 15 m × 15 m size were established. A grid system (3 m × 3 m) was applied to the entire gap and under canopy areas to determine the soil sampling points as shown in Figure 1 (c). At each point, soil samples at 0–20 cm depth were collected using a soil core volume of 94.2 cm^3 (diameter and length of soil core were 6 cm and 5 cm, respectively). Soil physical properties including soil bulk density (SBD) (g cm^{-3}), soil water mass content (SWMC) (g kg^{-1}), soil volumetric moisture content (SVMC) (g kg^{-1}), maximum moisture capacity (MMC) (g kg^{-1}), capillary water capacity (CWC) (g kg^{-1}), minimum water-holding capacity (MWHC) (g kg^{-1}), soil capillary porosity (SCP) (%), and soil total porosity (STP) (%) were determined on the basis of the forest soil analysis method [24] following Eq. 1–8.

3) Geostatistical methods and statistical analysis

The spatial heterogeneity of soil physical properties in each gap was analyzed by the Kriging spatial interpolation analysis method using the program GS+ Geo Statistics for Environmental Sciences (version 7, Gamma Design Software, Plainwell, MI, USA). Maps of the soil properties were produced with the GS+ software, with a block size of 2 m × 2 m. We calculated the value of soil physical properties by using a semivariogram model, which is an autocorrelation used to predict the value of an unsampled point. The statistic function was calculated using following Eq. 9 [26].

$$SBD = m_1 / V \quad \text{(Eq. 1)}$$

$$SWMC = (m_2 – m_1) / m_1 \times 1000 \quad \text{(Eq. 2)}$$

$$SVMC = SWMC \times SBD / \text{density of water} \quad \text{(Eq. 3)}$$

$$MMC = (m_3 – m_1) / m_1 \times 1000 \quad \text{(Eq. 4)}$$

$$CWC = (m_4 – m_1) / m_1 \times 1000 \quad \text{(Eq. 5)}$$

$$MWHC = (m_5 – m_1) / m_1 \times 1000 \quad \text{(Eq. 6)}$$

$$SCP = 0.1 \times CWC \times SBD / \text{Water density} \quad \text{(Eq. 7)}$$

$$STP = NCP + CP \quad \text{(Eq. 8)}$$

Where, m_1 is the mass of dry soil after drying (g), V is the volume of the soil core (cm^3), m_2 is the quantity of fresh soil (g), m_3 is the soil quantity after infiltrating for 12 h (g), m_4 is the soil quantity after sand drying m_3 for 2 h (g), and m_5 is the soil quantity after sand drying m_3 for 72 h (g). NCP is Non-capillary porosity (%) and CP is capillary porosity (%). The soil organic matter content (SOM) was determined by Walkley and Black rapid titration method [25]. The soil sample was collected in the summer season (June 2014). The total soil samples from every gap sizes and non-gap areas are 413 samples. The average soil sample of a small, medium, large gap size and non-gap area are 19.67, 44, 63, and 36 m^2, respectively.

$$r(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(Xi + h) - Z(xi)] \quad \text{(Eq. 9)}$$

Where, *r(h)* = semivariance for interval distance class *h, Z(xi)* = measured sample value at point I, $Z(x_i+h)$ = measured sample value at point i plus *h,* N*(h)* = total number of sample couples for the log interval *h*.

A semivariogram consists of three basic parameters that describe the spatial structure: nugget, sill, and rang. Nugget (C_o) is the local variation occurring at scales finer than the sampling interval, such as sampling error, fine-scale spatial variability, and measurement error. Sill (C_o+C) is the maximum value that the variogram reaches after the initial increase. It depicts the total variance of the process. The rang (*A*) is the distance at which the variogram reaches the sill and beyond which the process is no longer spatially dependent [26]. The ratio of nugget to sill can be used to identify the spatial dependence of data. Three distinct classes of the soil variable following: a ratio less than 0.25 indicates strong spatial dependence, if ratio between 0.25−0.75 means moderate spatial dependence, and if ratio more than 0.75 indicates weak spatial dependence [26].

Because the sample size was lower than 2,000, Shapiro-Wilks test (S-W test) was used to test the normativity of each soil physical property. For these tests, a significance level of 0.05 was used. The CV (coefficient of variation) was used to explore the variation of soil physical properties in each gap and under the canopy. The degree of spatial dependence was determined using the ratio of the nugget to the total variogram.

A one-way analysis of variance (ANOVA) was used to determine the differences in the mean of soil physical properties among three different gap sizes and non-gap areas. The difference comparison was investigated using multiple comparisons by the Tukey post-hoc test method. The analyses were conducted using SPSS (version 16, SPSS for Windows, SPSS Inc., Chicago, USA).

Results

1) Descriptive statistics of soil physical properties in each gap size and under the canopy

The classical statistics method was used to understand the characteristic of soil properties. Based on the CV (coefficient of variation) value, we categorized the classes of variability as follows: 1) 0%−10% indicates low variability, 2) 10%−100% indicates moderate variability 3) more than 100% indicates high variability [27].

The CV value of SBD in most of the gaps was more than 10%, which indicates that this variable had moderate variability in these gaps while the CV value for gap 8 was low. In the large gaps, the variability of SBD was higher than in the medium-sized and small gaps, indicating that area affects the variability of SBD. However, the average values of SBD in every gap and every area under the canopy were less than 1.5 g cm^{-3}, which is suitable for root growth [4]. The SWMC of gap 1 had low variability, while other gaps and areas under the canopy had moderate variability. The OM, SVMC, MMC, CWC, MHWC, and SCP of every gap as well as the areas under the canopy had moderate variability. The STP of gaps 6 and 8 had low variability, while the other gaps had moderate variability.

2) Spatial variability of soil physical properties of each gap and under the canopy

SWMC was strongly spatially dependent in gaps 1 and 8, moderately spatially dependent in gap 7 and under the canopy, and weakly spatially dependent in the other gaps. The spatial variability of MMC was strongly spatially dependent in the canopy areas, gap 3, and gap 5. It was moderately spatially dependent in gap

8; and it was weakly spatially dependent in the other gaps. The spatial variability of CWC was strongly spatially dependent in gap 3 and the canopy areas, and weakly spatially dependent in the other gaps. The spatial variability of MWHC was strongly spatially dependent in gap 5 and under the canopy, moderately spatially dependent in gaps 1 and 7, and weakly spatially dependent in the other gaps. The spatial variability of SCP was strongly spatially dependent in the canopy area and the gaps 3 and 6, moderately spatially dependent in gap 8, and weakly spatially dependent in the other gaps. The spatial variability of STP was strongly spatially dependent in the canopy area and the gaps 3 and 5; it was weakly spatially dependent in the other gaps.

Maps of the soil physical properties within the gap 1 represent small gap, gap 3 represent medium gap, gap 2 represent large gaps and under the canopy are shown in Figure 2−5. The maps show the pattern of the distribution of each soil physical property in gaps and under the canopy. We found similar patterns of MMC, CWC, and MWHC in all gaps and under the canopy. This pattern might be related to the strong significant correlation between these parameters (Table 1). A similar pattern was also found in SCP and STP in each gap and under the canopy. Besides the pattern of distribution of SBD in small gaps, we found its pattern being different from the other properties, potentially due to the absence of a significant correlation between them (Table 1). This different pattern was also found in SVMC and MMC in the small gaps.

Table 1 Correlation coefficients (*r*) for the relationships between the amount of organic matter and soil physical properties in each gap size and under the canopy

		OM	**SBD**	**SWMC**	**SVMC**	**MMC**	**CWC**	**MWHC**	**SCP**	**STP**	
Small gap size	OM		ns	.237**	.174*	.224**	.246**	.226**	.205*	.186*	Medium gap size
	SBD	ns		-.605**	ns	-.755**	-.694**	-.601**	-.201*	-.323**	
	SWMC	ns	-.455**		.835**	.880**	.838**	.843**	.648**	.797**	
	SVMC	ns	.433**	.595**		.576**	.564**	.638**	.678**	.782**	
	MMC	ns	-.808**	.531**	ns		.894**	.850**	.617**	.851**	
	CWC	.312*	-.727**	.654**	ns	.897**		.797**	.832**	.750**	
	MWHC	ns	-.462**	.714**	.300*	.653**	.708**		.598**	.760**	
	SCP	Ns	ns	.402**	.485**	.370**	.607**	.493**		.758**	
	STP	Ns	ns	.362**	ns	.733**	.673**	.583**	.757**		
Large gap size	OM		ns	ns	ns	ns	.336*	ns	ns	ns	Under canopy area
	SBD	-.286**		-.553**	ns	-.704**	-.676**	-.507**	-.392*	-.415*	
	SWMC	ns	-.621**		.911**	.760**	.799**	.870**	.750**	.708**	
	SVMC	ns	ns	.680**		.548**	.610**	.769**	.701**	.636**	
	MMC	.219**	-.739**	.644**	ns		.979**	.765**	.890**	.930**	
	CWC	.179*	-.701**	.778**	.332**	.817**		.790**	.934**	.920**	
	MWHC	ns	-.537**	.724**	.401**	.687**	.847**		.765**	.740**	
	SCP	ns	.165*	.390**	.670**	.280**	.561**	.523**		.964**	
	STP	ns	ns	.358**	.422**	.701**	.505**	.468**	.663**		

Remark: ** Correlation is significant at the 0.01 level; *at the 0.05 level; ns is no significant; OM = organic matter; SBD = soil bulk density; SWMC = soil water mass content; SVMC = soil volumetric moisture content; MMC = maximum moisture capacity; CWC = capillary water capacity; MWHC = minimum water-holding capacity; SCP = soil capillary porosity; STP = soil total porosity.

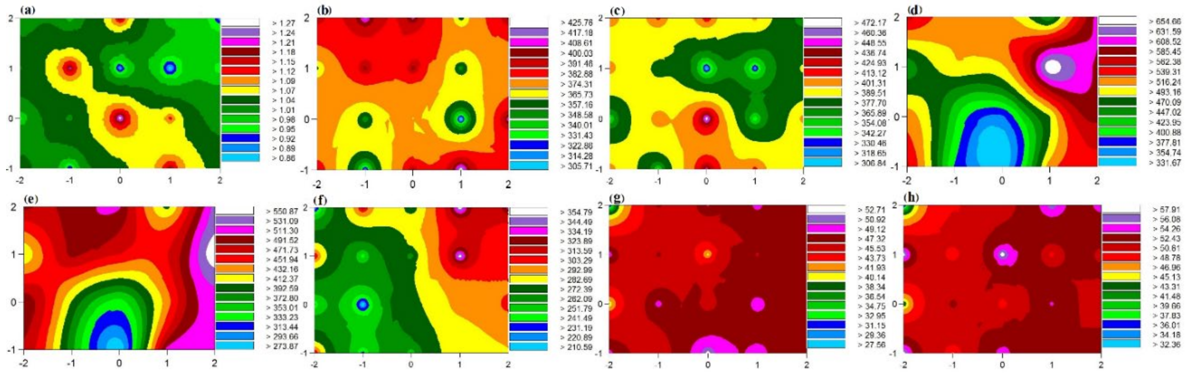

Figure 2 Map of spatial heterogeneity of soil physical properties in the small gap size during the summer season generated from program GS+ Geo Statistics for the Environmental Sciences. The different colour shows the rang of values as show on the right of each figure; (a) SBD (g cm^{-3}); (b) SWMC (g kg^{-1}); (c) SVMC (g kg^{-1}); (d) MMC (g kg^{-1}); (e) CWC (g kg^{-1}); (f) MWHC (g kg^{-1}); (g) SCP (%); (h) STP (%).

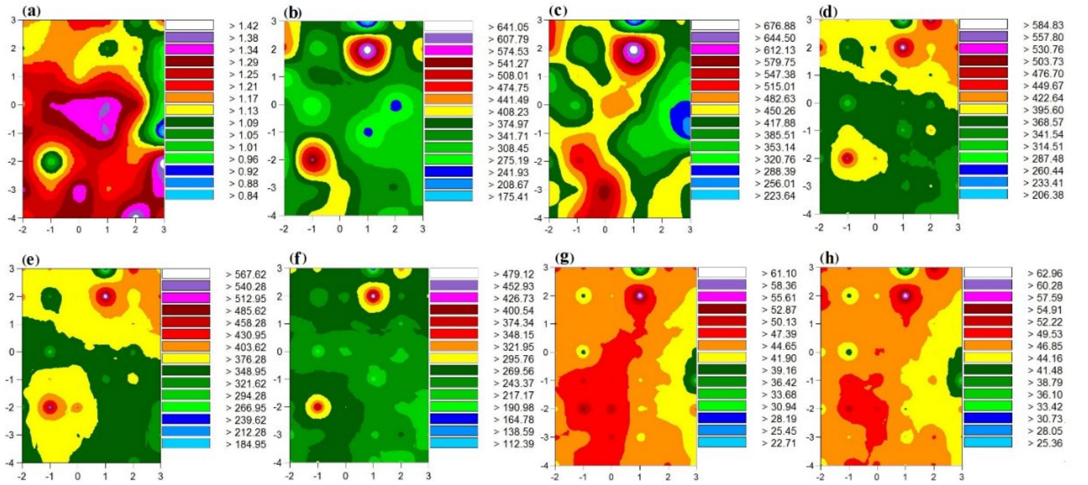

Figure 3 Map of spatial heterogeneity of soil physical properties in the medium gap size during the summer season generated from program GS+ Geo Statistics for the Environmental Sciences. The different colour shows the rang of values as show on the right of each figure; (a) SBD (g cm^{-3}); (b) SWMC (g kg^{-1}); (c) SVMC (g kg^{-1}); (d) MMC (g kg^{-1}); (e) CWC (g kg^{-1}); (f) MWHC (g kg^{-1}); (g) SCP (%); (h) STP (%).

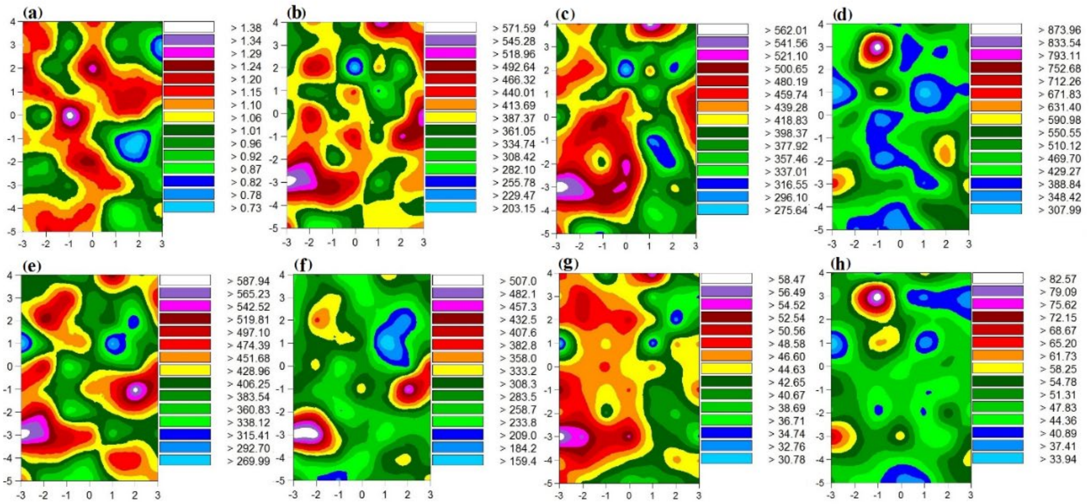

Figure 4 Map of spatial heterogeneity of soil physical properties in the large gap size during the summer season generated from program GS+ Geo Statistics for the Environmental Sciences. The different colour shows the rang of values as show on the right of each figure; (a) SBD (g cm^{-3}); (b) SWMC (g kg^{-1}); (c) SVMC (g kg^{-1}); (d) MMC (g kg^{-1}); (e) CWC (g kg^{-1}); (f) MWHC (g kg^{-1}); (g) SCP (%); (h) STP (%).

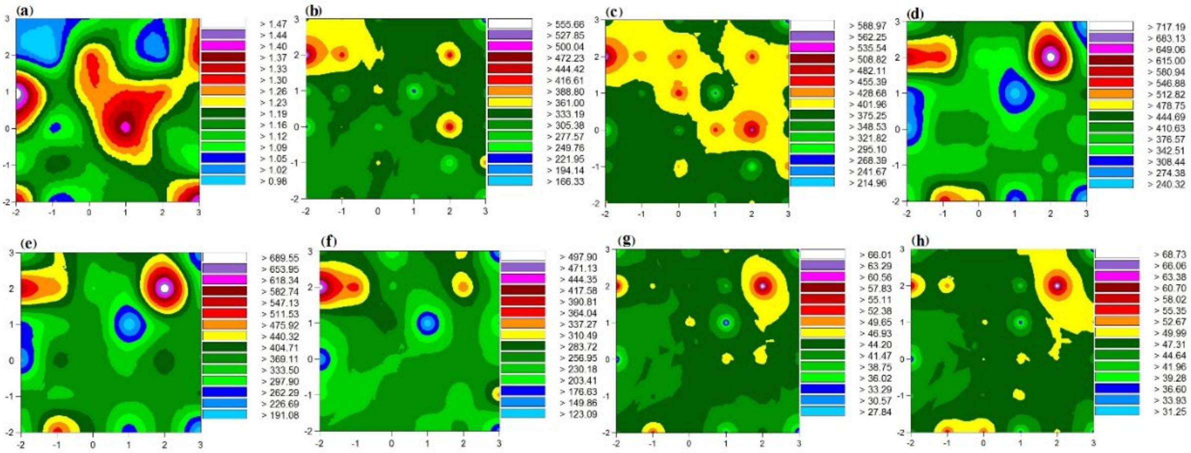

Figure 5 Map of spatial heterogeneity of soil physical properties in the under canopy during the summer season generated from program GS+ Geo Statistics for the Environmental Sciences. The different colour shows the rang of values as show on the right of each figure; (a) SBD (g cm^{-3}); (b) SWMC (g kg^{-1}); (c) SVMC (g kg^{-1}); (d) MMC (g kg^{-1}); (e) CWC (g kg^{-1}); (f) MWHC (g kg^{-1}); (g) SCP (%); (h) STP (%).

3) Soil physical properties and soil organic matter in different sized-gap and under the canopy

A one-way analysis of variance (ANOVA) was conducted for the effect of gap size on the values of the soil organic matter and soil physical properties. In this study, all of the soil physical properties investigated, except SCP and STP, were significantly affected by gap size, as shown in Table 2.

The multiple comparison analysis using Tukey's post hoc test ($p < 0.05$) for each soil property and soil organic matter are shown in Figure 6. The patterns of significant differences exhibited by SBD, SWMC, and SVMC were different. The value of SBD in medium-sized gaps was significantly different from its value in small and large gaps. The value of SWMC in small gaps was significantly different from its value under the canopy. The value of SVMC in medium-sized gaps was significantly different from its value in large gaps and under the canopy. Meanwhile, the patterns exhibited by MMC, CWC, and MWHC were the same: their values in small gaps were significantly different from their respective values in medium-sized gaps, and the values in large gaps were significantly different from the values under the canopy.

Table 2 The results of a one-way analysis of variance (ANOVA) conducted on the effect of gap size on the value of the soil organic matter and soil physical properties

Soil variable	*F* value	*P* value
SOM	7.955	0.000*
SBD	6.634	0.001*
SWMC	3.225	0.031*
SVMC	6.126	0.001*
MMC	4.098	0.012*
CWC	5.650	0.002*
MWHC	2.979	0.041*
SCP	2.166	0.105
STP	1.522	0.221

Remark: * The mean difference is significant at the 0.050 level; SOM = soil organic matter; SBD = soil bulk density; SWMC = soil water mass content; SVMC = soil volumetric moisture content; MMC = maximum moisture capacity; CWC = capillary water capacity; MWHC = minimum water-holding capacity; SCP = soil capillary porosity; STP = soil total porosity

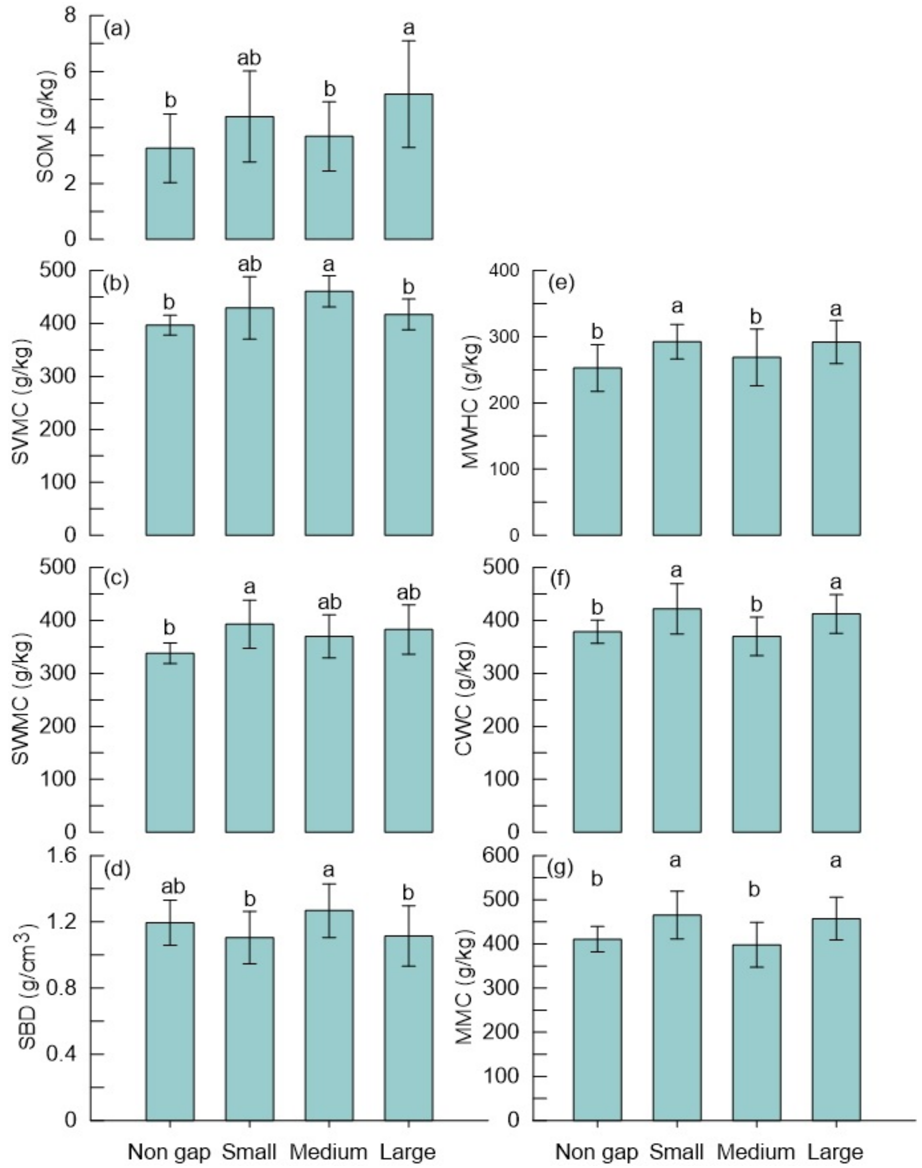

Figure 6 Bar graph and statistical analysis of soil physical properties in each gap size and under canopy (one-way ANOVA, Tukey's posthoc test, $p < 0.05$), (a): SOM = soil organic matter; (b): SVMC = soil volumetric moisture content; (c): SWMC = soil water mass content; (d): SBD = soil bulk density; (e): MWHC = minimum water-holding capacity; (f): CWC = capillary water capacity; (g): MMC = maximum moisture capacity, error bars show the standard deviation value; Different letters over bars indicate statistically significant results.

Discussion

The result from this study showed that the values of soil physical properties such as SVMC, SWMC, SBD, MWHC, CWC, MMC and soil organic matter between gap size and under canopy area were difference. Gap size did influence the soil organic matter, which lowest in medium gap size and highest in large gap size. A similar finding was reported at a subtropical humid forest of north-east India, that gap size affected organic matter [28] also similar to the report from the beech forest in northern Iran [29]. Organic matter is the main source of nutrients for the plant growth which decomposed from organic material by the microbial activity in soil [30]. The mechanisms that made the large gap size has a high amount of organic matter due to the large gap size provides high light intensity through the forest floor [20]. This high temperature of the forest floor generates the organic matter decomposition lead to high soil organic matter. Moreover, the large size of the gap might be led to more litter accumulated on the forest floor than other gap sizes. The highest organic matter in large gap size indicated that soil in large gap size had a higher potential to allow plant growth than other gap sizes. This result related to the study at Calabria pine stand noted that large gap size had the greatest amount of organic matter when compared with other sizes [31]. Gap size considerably affected the soil components. Normally, the soil consists of 25% water, 25% air, and 50% soil solids, which in turn consist of mineral matter, organic matter, and organisms [32]. SBD is relevant to the porosity of soil (the volume of soil which can be filled by water and/or air) [33]. In this study, we found that the soil in large gaps had higher pore space values (lower density) than the soil under small and medium gap sizes, or under canopy. This suggests that the soil in large gaps has the potential to support more root growth than the soil in the other treatments. However, this result is contrary to the study conducted in the same area in 2011, which reported that SBD was the highest in large gaps [19]. This contrasting result may be explained if SBD is a temporally and spatially dynamic factor [34]. High SBD restricts root growth by reducing the root elongation rate [35‒36]. Besides, the lower availability of pore space can also cause poor movement of water and solutes, and poor aeration of the soil [37]. High bulk density was shown to affect Dipterocarp seedlings by inducing root growth [38]. In another study, high SBD diminished plant production and N uptake [39]. However, even the highest value of bulk density found in this study (in the medium-sized gaps) is still in the range that is not considered to restrict plant root growth [4].

The moderate variability of soil OM was reported in other areas such as at the Loess Plateau region, China [40], and the Hainich region in Germany [41]. Based on the ratio of the nugget to the total variogram, our results showed that the degree of spatial dependence (data no show) decreased with gap size, indicating that increasing the gap size improved the heterogenization of SBD; in contrast, the smaller gaps showed homogenization. The nugget variance of SBD in all areas was very low, indicating that the spatial variability of SBD might cause by experimental error or other artificial factors. SBD is the physical property that was shown to be affected by grazing [42], tillage, and other field management methods [43]. Since this study site is forested, it is not affected by field management; this means that SBD might be affected by the amount of soil organic matter.

Soil physical properties, except for SBD, appeared to exhibit the strongest spatial dependence in the canopy area, followed by the small gaps. Conversely, most of the physical properties showed very weak spatial dependence in the medium and large gaps. These results indicate that gap area have a strong effect on the degree of spatial dependence of soil physical properties. This is consistent with a previous report, which found that the spatial variability of soil physical properties in gap areas was stronger than under the canopy [17]. This spatial variability of soil physical properties might be affected by the amount of soil organic matter. We found support for this hypothesis in the more significant correlation between the amount of organic matter and soil physical properties in the medium and large gaps, as opposed to small gaps and under the canopy, as shown in Table 2. The soil organic matter used to indicate soil health, which improved all soil physical properties [44]. Besides, the result of higher light intensity found in the large and medium gap sizes when compared to small gap size and under canopy areas [45] might support the organic matter decomposition with abundantly in the large gap size. Usually, soil physical properties vary by depth, soil texture, and the amount of organic matter [46]. The structure of organic matter can improve soil bulk density, soil porosity, and the soil water holding capability [47]. Reporting about the organic matter used to estimate the value of SBD shown the importance of soil organic matter with SBD [48], and with soil water characteristics [49]. Moreover, in this study, we found a positive significant correlation between organic matter and CWC (Table 2), which indicate that the organic matter also affected the soil water capacity [50].

The value of SWMC in the canopy areas was the lowest, while the value in the small gaps was the highest, followed by the large and medium-sized gaps. SVMC is the total moisture in the soil and is perhaps equal to soil porosity. Our results showed that SVMC was the lowest in the canopy areas and the highest in the medium-sized gaps. This is opposite to the results found for soil aeration degrees (SAD), where the lowest value occurred in the medium-sized gaps, while the highest was found in the canopy areas (data not shown). Combining the three parameters that describe soil composition, we found that gap size improved it, with soil in canopy gaps having a low bulk density and high-water content, especially in the small and large gaps, when compared with the areas under the canopy. Moreover, the results about the effect of light on the variety of microenvironment in the gap reported that the microenvironment in gap areas vary more than under canopy areas which support the species growth [20]. Plant growth depends on soil composition. Proper soil composition provides the optimum conditions for plant growth. A well-structured soil should have pores for water and air storage with the density not being too high, to allow the water to move down the profiles [51]. Considering all of the above and based on the values of SBD, SWMC, SVMC, and SAD, the soil composition in the large and small gaps was better than in medium-sized gaps and under the canopy.

We found that the value of the MMC, CWC, and MWHC which represent the water storage potential of soil was the highest in the small gaps, followed by large gaps, while the lowest value occurred in the areas under the canopy. The mechanism of forest gaps effect to the soil water storage might due to the higher rainfall input than under canopy and the low plant root which can reduce the water uptake when compared with under canopy area. This result is in agreement with the result for SWMC. It indicates that gap areas, especially when the gaps are small or large, could improve soil water storage better than areas under the canopy [52]. This might be related to the value of total potassium and carbon to nitrogen ratio (data is in a previous study [18]), which significant correlated with the MMC, CWC, and MWHC found only in small gap and large gap (data not show). These parameters can provide information about potential soil water storage, which is very important for plant growth [36].

Conclusion

Our results indicated that the gap size had a considerable effect on the soil properties investigated. The results indicate that introducing gap areas could improve the soil water storage better than areas that are under the canopy. Different sized gap has a different effect on each soil physical property. The weakest spatial dependence for most of the soil physical properties were exhibited in the areas under the canopy, followed by that in the small gaps. Conversely, the strongest spatial dependence was seen in large gaps. This result indicates that the gap area and the size of the gap had a strong effect on the degree of spatial dependence on soil physical properties.

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