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SOIL PROPERTIES IN CANOPY GAP OF A *CUNNINGHAMIA LANCEOLATA* (LAMB.) HOOK STAND IN SOUTH CHINA

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Abstract

Impact of gap sizes created by an ice storm on soil properties was analyzed. Twelve natural treefall gaps were identified in a *C. lanceolata* stand in northern Guangdong Province, South China in March 2008. Transmitted light, soil moisture, soil organic matter, total N, total P, alkalized N, available P, urease, phosphatase and catalase were measured. Gap size was significantly positively correlated with canopy openness, and canopy openness significantly negatively related to soil organic matter, total N, alkalized N, urease and catalase. Canopy openness was unrelated to soil moisture, total P and available P. Results indicate that in the *C. lanceolata* stand, large canopy openness gaps may result in a microsite with poor fertility and a decrease in soil organic matter, N, urease and catalase.

Introduction

During 25 January - 6 February, 2008, a severe ice storm occurred in southern China lasting for several days and covering extensive geographic areas. This ice storm was the most spatially extensive ever recorded during the last 50 years of climatological data collected in China. However, it has remained exceedingly difficult to comprehensively evaluate the effects of the ice storms on soil properties of forests because those effects are stochastic and highly variable. Nonetheless, such studies are important for improving our understanding of the ecological impacts of ice storms on global climate change. The fall of many canopy trees results in increased total incident light at the ground level, which is an important factor affecting species diversity (Parker 2003). However, a few studies have evaluated light change caused by ice storms (Parker 2003).

Gaps created by ice storms also influence soil properties (Gálhidy *et al.* 2006; Scharenbroch and Bockheim 2007, 2014). Although Schliemann and Bockheim (2014) had addressed the effects of artificial gaps on soils, the relationship between some soil nutrients and gap size in natural gaps remains unclear (Schliemann and Bockheim 2014). In addition, most of these studies were carried out in hardwood forests (Scharenbroch and Bockheim 2007, Schliemann and Bockheim 2014), relatively a few studies had addressed gap effect on coniferous forests.

Cunninghamia lanceolata forests, one of major important forest types in China (Xue and Hagihara 2001), is widely used in construction, furniture, utensils and shipbuilding, with 9.21 million ha of plantation forest (Lei 2005). In northern Guangdong Province, large areas of *C. lanceolata* stands were damaged and by ice storm in 2008. While some trees loaded with lot of ice were uprooted, their crown was damaged and there was substantial branch breakage, resulting in gaps ranging from 10 m^2 to 80 m^2, which offers the chance to observe soil change (Muscolo *et al.* 2007b).

Soil organic matter has been considered as the single most important indicator of soil quality, due to its important influence on soil property (Muscolo *et al.* 2007b). Nitrogen and phosphorus are important nutrients for trees, which often control forest productivity in Southern China. Soil

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enzymes play essential roles in soil quality (Qian *et al.* 2007) and are also sensitive to environmental variations (Shi *et al.* 2008). The present study was designed to determine gap effects on light transmission, soil water, soil organic matter content, N and P availability, and soil enzyme activity in a *C. lanceolata* stand damaged by an ice storm.

Materials and Methods

Study was conducted in Lechang Forest Farm (650 - 750 m), Guangdong, South China (25°09′N, 113°30′E). Lechang Forest Farm covers an area of 5127 ha, in which *Cunninghamia lanceolata* stands account for 72%. The study site was situated on a 30° slope with a southwesterly aspect (SW 80°20'), belonging to subtropical monsoon climate. The average annual precipitation of 1522 mm falls mainly between April and August. Average monthly air temperatures range from 9.3 °C (January) to 28.2°C (July) with a mean annual temperature of 19.6°C. Mean diameters at breast height, tree height and density in the *C. lanceolata* plots were 18.0 cm, 12.7 m and 1667 trees/ha, respectively. The crowns of numerous *C. lanceolata* trees were broken during the ice storm and uprooting had occurred at some sites, resulting in gaps ranging from 10 m^2 to 80 m^2. The understory cover was low, consisting of *Woodwardia japonica* and *Adiantum capillus-veneris*. The soil at the studied site was according to The Unified Soil Classification System.

During plot selection in March 2008, 12 natural gaps under the *C. lanceolata* stand were chosen ranging from 10.0 to 80.4 m^2. The length and width of regular gaps were measured to calculate their area based on the size and shape of the natural opening (Scharenbroch and Bockheim 2007). Irregular gaps were divided into smaller blocks so that gap area could be calculated accurately (de Lima 2005). A canopy plot was selected a contrast of the forest gaps.

The light transmission in the gaps was assessed using an index of light availability, which was obtained from a hemispherical photograph of the forest canopy. A digital camera was installed (Coolpix 950 with a Nikkor 8-mm lens, Nikon, Tokyo, Japan) using a self-leveling platform (Delta-T Devices, Cambridge, UK) at 2 m height (above understory vegetation) in the center of each gap or plot (Campanello *et al.* 2007). Photographs were taken in overcast sky conditions between 12:00 and 12:30 hrs from March, 2010 to March, 2011. Images were analyzed with Gap Light Analyzer 2.0 software (Frazer *et al.* 1999), using the standard overcast sky model (UOC). The total transmitted light was calculated (Heithecker and Halpern 2006)**.**

Soil moisture of soil samples collected from 0 to 10 cm depth and was determined by weight loss after the moist soil was dried at 105ºC (Achata *et al*. 2012).

To determine soil chemistry and enzyme activity, five replicated soil samples were collected from 0 - 10 cm depth in each gap making a total of 60 measurement locations. The replicated samples of a given gap were separately mixed thoroughly to obtain composite samples for further analysis.

The soil pH was measured using a pH meter with deionized water (1 : 2.5 w/w, respectively) at 20°C. Soil organic C was estimated using the Walkley-Black procedure (Nelson and Sommers 1982, Midwest Laboratories, Inc., Omaha, NE 2005) and converted to organic matter by multiplying the percentage of C by 1.72. The total soil N and P were estimated using the Kjeldahl digestion (Bremner and Mulvaney 1982) and molybdenum blue colorimetry (Lu 2000) methods, respectively. The available N was determined by Kjeldahl method. The available P was measured by colorimetry. Activities of soil urease, phosphatase and catalase were determined by colorimetry, disodium phenyl phosphate colorimetric method and titration with potassium permanganate, respectively (Guan 1986). All nutrient analyses were conducted in triplicate.

All results are expressed on an oven-dry soil weight basis (105°C, 48 hrs). Means and standard errors of the means were calculated for soil organic matter and so on. Linear regression was used to investigate the relationship between gap size and each of the parameters. All linear regression analyses were conducted using SAS 9.2. Statistical differences are reported at the $p = 0.05$ probability level.

Results and Discussion

Across all gap plots, canopy openness ranged between 10.93 and 18.36%, and moisture content was 28.46 - 39.47% (Table 1). Soil organic matter was 22.33 - 65.55 g/kg, total N and total P were 1.41 - 3.01 and 0.48 - 0.81 g/kg, respectively, and alkalized N and available P were 88.58 - 221.00 and 1.91 - 4.06 mg/kg, respectively. Soil urease, phosphatase and catalase were 344.05 - 894.2 mg/kg/d, 196.20 - 400.07 mg/kg/h and 1.00 - 2.00 ml/g/h. The soil water content of the canopy-covered site was greater than that of the gap plots, whereas its soil organic matter, N, P and enzyme activity were similar to those in the small gap plots.

Table 1. Canopy openness and soil properties in the study plots.

Gap size (m^2)	Canopy openness (%)	Soil moisture (%)	SOM (g/kg)	Total N (g/kg)	Total P (g/kg)	Alkalized N (mg/kg)	Available P (mg/kg)	Urease (mg/kg/d)	Phos-phatase (mg/kg/h)	Catalase (ml/g/h)
10.1	10.93	39.47	59.84	2.55	0.48	188.32	3.18	894.21	363.82	2.00
10.4	12.22	31.55	65.55	2.96	0.81	221.00	4.06	876.50	345.86	1.50
13.2	12.37	37.01	43.51	2.74	0.55	185.93	2.79	513.74	400.07	1.51
16.5	11.78	34.49	61.26	2.48	0.68	190.54	2.79	717.72	308.61	1.38
16.8	12.19	34.70	64.57	2.87	0.66	186.58	2.50	646.98	311.61	1.67
28.9	13.97	28.46	58.46	2.63	0.73	198.80	3.67	622.24	358.03	1.67
31.3	12.46	32.20	44.54	2.44	0.66	178.40	3.18	520.25	335.88	1.42
31.8	11.67	37.13	49.97	3.01	0.72	211.97	3.67	767.63	375.79	1.38
38.6	14.20	34.29	50.99	2.59	0.62	194.42	3.60	583.62	310.28	1.63
52.0	15.15	34.83	55.98	2.66	0.67	191.82	3.47	599.24	303.40	1.25
60.6	15.24	30.40	33.15	1.98	0.60	138.12	2.40	503.33	274.36	1.34
80.4	18.36	31.94	22.33	1.41	0.54	88.58	1.91	344.05	196.20	1.00
Closed canopy site	5.62	49.34	37.41	2.65	0.70	201.52	3.72	607	347.23	1.57

Canopy openness showed a significantly positively relationship to gap size ($p < 0.05$) (Fig. 1). Soil water decreased with increasing canopy openness (Fig. 2). Soil organic matter, total N and alkalized N were significantly negatively correlated with canopy openness ($p < 0.05$), whereas total P and available P were unrelated to canopy openness. With increasing gap size, activities of urease and catalase significantly decreased ($p < 0.05$), and phosphatase activity decreased with increasing canopy openness, but was marginally related to canopy openness ($p < 0.1$, Fig. 3).

Previous studies in temperate forests reported that canopy openness increased with opening size on the whole gap scale (Canham *et al.* 1990; Gálhidy *et al.* 2006). Present results support these findings, e.g. canopy openness increased with gap size. Some researchers also reported greater canopy openness in gaps compared to adjacent closed canopy plots (Scharenbroch and Bockheim 2007, Schliemann and Bockheim 2014).

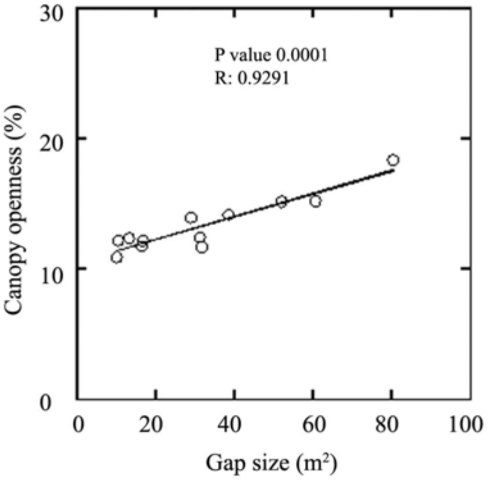

Fig. 1. Linear regression of canopy openness against gap size.

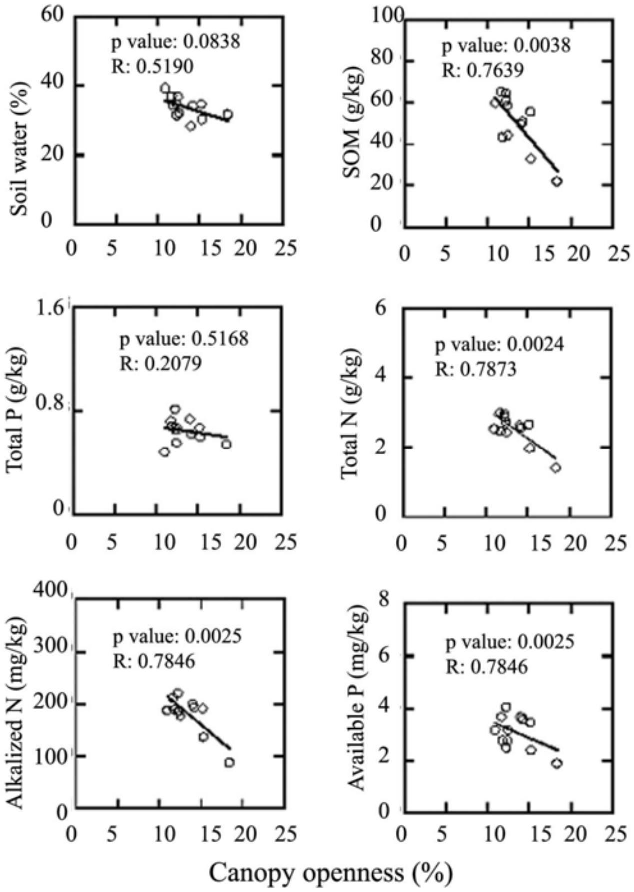

Fig. 2. Linear regression of soil moisture and chemical properties plotted against canopy openness.

The effect of canopy openness on the pattern of soil water is less apparent when compared to the effect on gaps. Previously it was reported that increased precipitation and a decreased transpiration in gaps resulted in higher soil water in large canopy openness gaps (Ritter *et al.* 2005). Schliemann and Bockheim (2014) reported a negative relationship between canopy openness and soil water because runoff and evaporation increase with canopy openness. Present results suggest that the relationship between canopy openness and soil water is not apparent. Soil water may increase in larger canopy openness gaps because of the reduced plant uptake of water (Müller and Wagner 2003), or it may decrease because of the higher levels of evaporation through the higher daytime temperatures (Muscolo *et al.* 2007b). Moreover, both precipitation and transpiration may be influenced by mature trees around gaps. Because roots of these tree roots can penetrate into gaps (Baker *et al.* 2013), which may cause redistribution of soil water from gaps to the closed forest (Schliemann and Bockheim 2014)

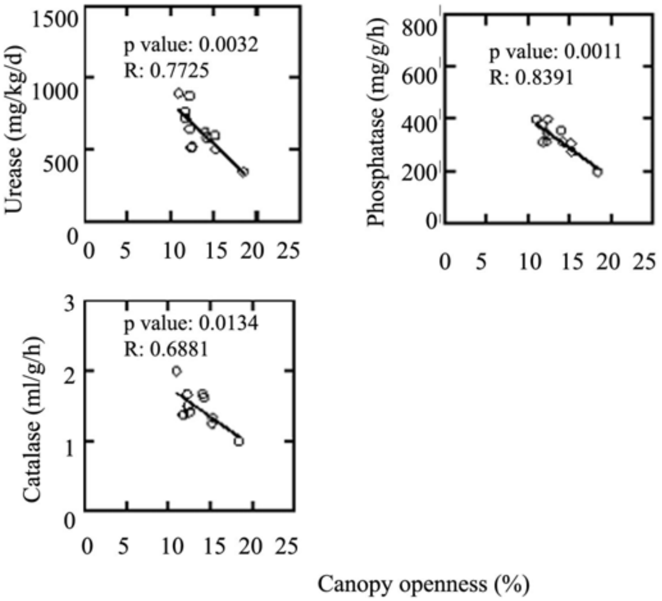

Fig. 3. Linear regression of soil enzyme activity plotted against canopy openness.

This study demonstrated that soil organic matter content decreased with increasing canopy openness. Litter decomposition may be greater in large canopy openness gaps than in small canopy openness gaps. The amount of green leaves from crown debris in large canopy openness gaps may be greater than in small canopy openness gaps, whereas green needles decompose more rapidly when compared to freshly fallen needles because of their rich labile organic fraction (Girisha *et al.* 2003). Moreover, organic matter losses from soil surface erosion in the large canopy openness gaps may be greater than in the small canopy openness gaps because the hillside field at the study sites had a slope of about 30°. The light intensity was higher in larger canopy openness gaps and may also affect the process of litter decomposition on the forest floor (Arunachalam *et al.* 1996) and result in a slow accumulation of litter. Muscolo *et al.* (2007b) also found that organic matter content in medium-sized gaps was lower than that in small canopy openness gaps.

N content decreased with increasing canopy openness. Nutrient losses in gaps may be due to increase in substrate availability and mineralization rates and decrease in nutrient uptake by plant roots (Zhang and Zak 1995). The continuous decrease in N content with increasing gap size may be due to leaching losses. Ritter *et al.* (2005) also reported that nitrate loss increased in newly created forest gaps when compared with the surrounding undisturbed forest. Scharenbroch and Bockheim (2007) also reported that nutrient leaching increased in large canopy openness gaps. Present results did not show a clear relationship between soil P and canopy openness. Larger canopy openness gaps may have reduced soil nutrient uptake of undergrowth plants, this was favorable for microbial mineralization of soil nutrients, and can result in higher P content in these gaps. On the other hand, larger canopy openness gaps may limit soil P content by strong leaching losses.

Enzymatic activity is closely correlated with soil organic carbon and N content (Lu *et al*. 2008). The effects of soil properties on enzyme activity have been studied in detail. Organic matter not only supplies substrates that stimulate microbial growth (Zhan *et al*. 2010) but may also affect enzymatic activity in the environment (Tomlinson *et al*. 2008). The present results regarding the impact of organic matter and N on activities of soil urease and phosphatase are consistent with the findings of Sahrawat (1983), Nannipieri (1994), Yu *et al*. (2006). Urease and catalase activity decreased significantly with increasing canopy openness. Changes in enzyme activity can be caused by change in soil water content or substrate availability. The present results indicate that soil water, soil organic matter and N are inversely significantly related to canopy openness. Enzymatic activities reflect the microbiological activity in soil (Stege *et al.* 2009). Muscolo *et al.* (2007a) found that activities of urease and phosphatases were higher in small canopy openness gaps than medium canopy openness gaps, which was in line with a high soil microbial metabolism in small canopy openness gaps found in this study. Zhang and Zak (1995) found large canopy openness gaps in a *Castanopsis kawakamii* forest resulted in significantly reduced microbial biomass due to decreased soil water. Wagner and Wolf (1998) reported that microbial activity increases as soil water increases. Therefore, it may be suspected that the large canopy openness gaps in this study may form areas with low soil water and poor substrate conditions that are unfavorable to soil enzyme activity resulting in decreased microbial activity.

In this study, the chemical and biological properties of soils were apparently modified by the creation of gaps following ice damage. With an increase in gap size, light transmission increased, while soil organic matter and N decreased significantly. The activities of urease and catalase increased with an increase in gap size, probably because of changes in soil organic matter and N content. Large gaps may represent regions of strong light transmission and poor substrate availability due to increase in litter decomposition and nutrient leaching in the larger gaps. The effects in larger gaps were different from those in smaller gaps, especially in relation to soil organic matter and N content and soil microbe-related enzyme activity.

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