



CO₂ emission from subterranean nests of ants and termites in a tropical rain forest in Sarawak, Malaysia



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ABSTRACT

Ants and termites are highly abundant in tropical forest soil, but their role in soil CO₂ emission is poorly understood. Our goal in this study was to determine the CO₂ emission from nests of ants and termites in a tropical rainforest in Sarawak (Borneo), Malaysia. The study was conducted in Lambir Hills National Park, Miri. We located nests of ants and termites and measured CO₂ emission from the nests and from the surrounding control soils. Soil temperature and moisture content were also recorded at the nests and control soil locations. The ants and termites were identified to genera (and to species in many cases) and their body mass was determined. In total, we found 113 nests of 36 ant species and 20 nests of 10 termite species. CO₂ emission from ant and termite nests was significantly higher than that from the surrounding soils, suggesting ant and termite nests are hot spots of CO₂ emission from the soil. Because of nesting activities, soil moisture content was significantly lower in ant nests compared to that of the control soils. The effect of soil temperature and moisture content on nest CO₂ emission was less clear when compared to emission from the surrounding control soils. Significant differences in nest CO₂ emission were observed between different ant species, which could be partly attributable to differences in body mass.

1. Introduction

Most of terrestrial ecosystems exchange carbon dioxide (CO₂) with the atmosphere through respiration of plants, animals, and microbes and photosynthesis of plants. In forest ecosystems, soil CO₂ emission accounts for 40–94% of ecosystem respiration, which is the second largest flux in the forest carbon cycle (Chambers et al., 2004; Yuste et al., 2005). Tropical forests constitute 50% of terrestrial forest ecosystems (Malhi and Grace, 2000); therefore, slight changes in soil CO₂ emission from tropical forests may have a dramatic impact on atmospheric CO₂ concentrations. Consequently, understanding the variation and mechanisms of soil CO₂ emission in tropical forests is vital for the prevention of additional increases in atmospheric CO₂ at the global scale.

Soil CO₂ emission in tropical forests is generally higher than that in temperate and boreal forests (Raich and Potter, 1995), and highly

variable both temporally and spatially. In tropical seasonal forests, soil CO₂ emission often increases during the rainy season and decreases during the dry season, varying according to changes in soil moisture (e.g. Hashimoto et al., 2004). However, seasonal variation in soil CO₂ emission has also been reported in tropical rainforests where rainfall and temperature have no clear seasonality (e.g. Ohashi et al., 2008). Spatial variation in soil CO₂ emission is extensive in tropical forests, and sometimes negatively correlated with soil moisture content (Ohashi et al., 2008; Adachi et al., 2006). Hot spots of soil CO₂ emission also cause substantial spatial variation; hot spots are areas where large amounts of CO₂ emission occur, sometimes sporadically and randomly (Ohashi et al., 2007c, 2008).

Soil CO₂ emission originates from the respiration of living organisms in the soil, but primarily from plant roots and soil microbes (Hanson et al., 2000; Kuz'yakov, 2006). Therefore, their distribution and the changes in their CO₂ production in response to soil temperature

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and moisture conditions can cause spatial-temporal variation in soil CO₂ emission (Luo and Zhou, 2006). Soil CO₂ emission is controlled by physical processes in the soil, as well as biological processes. Transportation of gaseous CO₂ in the soil is driven by the concentration gradient along the profile from deep layers to the soil surface (Luo and Zhou, 2006). At the soil surface, CO₂ is released into the air by passive diffusion or more actively by air turbulence. Soil texture, porosity, and the distribution of gaseous CO₂ within the soil control CO₂ transportation. Soil living organisms could alter these processes indirectly because the soil CO₂ gradient may vary according to CO₂ production by the organisms, and soil structure may be modified by their behaviour.

It is known that soil macro fauna, such as earthworms, ants, and termites, extensively modify soil physical and chemical properties, such as soil structure, water regime, and/or chemical composition (e.g. Jouquet et al., 2011). These soil organisms are defined as ecosystem engineers and they can potentially influence soil carbon dynamics (Lavelle et al., 1997, 2006; Jouquet et al., 2011). However, their role in soil CO₂ emission is less understood than that of roots and soil microbes (Luo and Zhou, 2006; Kuzakov, 2006). In tropical forests, ants and termites are highly abundant, constituting 80% of the total biomass of insects (Wilson, 1990) and their relative importance in tropical soil functions can be higher than that in other ecosystems (Briones, 2014). Many previous studies conducted on mound-type ant nests in boreal and temperate forests have shown that CO₂ emission from the nests was significantly higher than that of the surrounding soil, suggesting that ant nests are hot spots for soil CO₂ emission (e.g. Ohashi et al., 2007b, 2012). Recently, Hasin et al. (2014) reported that subterranean nests of ants released higher CO₂ emissions than did the surrounding soil in a tropical seasonal forest in Thailand. They also found that the CO₂ emission from ant nests was different among species. Ants can alter CO₂ emission by their own respiration; however, they also do so by affecting other CO₂ producers and the CO₂ diffusion potential of the soil (Ohashi et al., 2007a). The temperature and moisture sensitivities of CO₂ emission may change because of ant nesting activities (Hasin et al., 2014). Their study suggested that ants may play an important role in soil CO₂ emission in tropical forests, but very little information is available.

Termites have been highlighted as a source of greenhouse gas emission more so than ants because of the microbial symbionts in their gut. Recent studies clarified that their production of CH₄, N₂O, and CO₂ is species-specific and varies depending on the soil environment and their food quality (Brümmer et al., 2009; Jamali et al., 2013; Brauman et al., 2015; Majeed et al., 2015). Results of previous studies conducted in the African and Australian savanna reported increased (Risch et al., 2012; Jamali et al., 2013), or consistent (Konaté et al., 2003; Brümmer et al., 2009) CO₂ emission from their mounds. In addition, an increase in CO₂ emission from the soil because of fungus-comb chambers of termites has been reported (Konaté et al., 2003). The contribution of termite mounds to the overall carbon balance has been shown to be negligible in tropical savannas (e.g. Jamali et al., 2013); however, recently De Gerenyu et al. (2015) estimated that CO₂ emission from termite mounds constituted up to 10% of total CO₂ emission in a tropical forest in southern Vietnam. In tropical rain forests, termites inhabit various locations depending on their feeding habits, and more than 66% of the total termite population may live underground as soil feeders (Abe and Matsumoto, 1979). Therefore, termite mounds, fungus-comb chambers, and their underground nests may have different effects on CO₂ emission. However, we are not aware of any studies that have documented the CO₂ emission from various kinds of termite nests and/or assemblages in tropical forests and determined differences in the CO₂ emission between species. In addition, variation in CO₂ emission from termite nests because of temperature and moisture changes is unknown.

In this study, our goal was to clarify CO₂ emissions from the nests of ants and termites in a tropical rainforest in Sarawak (Borneo), Malaysia. In particular, we focused on: (1) the differences in the CO₂ emission

among nests of various ant and termite species and surrounding control soils and (2) the relationship between CO₂ emission and soil temperature and moisture content. Additionally, we investigated (3) the relationship between nest CO₂ emission and individual body size of ants and termites to determine the effect of biological factors on nest CO₂ emission.

2. Material and methods

2.1. Study site

This study was conducted in Lambir Hills National Park, Miri, Sarawak, Malaysia (4°12'N, 114°02'E). The park covered 6500 ha and was located 10 km interior from the seacoast. The mean annual rainfall at Miri Airport, 20 km from the study site, for the period 1968–2001, was 2740 mm. The mean annual temperature was 27 °C, with little seasonal variation (Kumagai et al., 2005). The vegetation primarily consisted of a mixed dipterocarp forest that contained various species of dipterocarp trees, such as *Dryobalanops aromatica* Gaertn. f. and *Shorea beccariana* Burck. The continuous canopy of the forest was approximately 40-m tall, with emergent trees exceeding 50 m (Katayama et al., 2013). The soil was classified as a Ultisol with high sand and low clay content, high porosity (62–72, 15–22, and 54–68%, respectively), and low pH (4–4.3) (Ishizuka et al., 1998). Total nitrogen and carbon content were relatively high in the A horizon (0–5 cm), 115 g kg⁻¹ and 4.2 g kg⁻¹, respectively, but decreased to 0.6–4.9 g kg⁻¹ and 0.1–1.1 g kg⁻¹ in other horizons (Ishizuka et al., 1998), respectively. Borneo Island is one of the hot spots of biodiversity in the world, with more than 700 described species of ants (Pfeiffer et al., 2011; more than 1000 species are believed to occur there, including undescribed species, see Hashimoto, 2003) and nearly 100 recorded species of termites (Jones and Eggleton, 2000). Our study was conducted in the Canopy Biology Plot (Nagamitsu et al., 1999) and Canopy Crane Plot (Sakai et al., 2002). They are located adjacent to one another and cover 100 ha of the park. Numerous biological and meteorological studies have been conducted in these areas to characterise this forest (e.g. Kenzo et al., 2004; Kumagai et al., 2005). We conducted our experiment in September 2010 (P1), from April to July 2011 (P2) and from November 2011 to January 2012 (P3).

2.2. Experimental plots

2.2.1. Ants

We searched for entrance holes of subterranean ant nests using the food baiting method. We placed 110 traps baited with sugar solution, powered cheese, or a block of tuna on the forest floor. Solid bait was broken into small pieces to allow ants to move it away. Liquid bait was absorbed into a piece of cotton. Traps were placed on a 5 cm × 5 cm cotton sheet and were spaced 1–2 m apart. We followed ant workers attracted to the bait to determine the location of the nest hole.

We established an experimental plot with a 2 m × 2 m area that was centred on the nest hole (see Hasin et al., 2014). Nest CO₂ emission, soil temperature, and soil moisture content were recorded at the nest hole. If other nest holes of the same species were found in the plot, we treated them as belonging to the same colony and the data at the holes were collected and averaged with data from the primary hole (see Hasin et al., 2014). Additionally, we selected five to six control spots, which were not influenced by nests, in the area surrounding the nest entrance holes and recorded the same measurements. The distance between nest holes and control sites was a maximum of 180 cm, which was far enough not to be influenced by the nest holes. We examined the presence/absence of ant nests by removing the soil under the control spots to a depth of 20 cm after completion of all measurements in each plot. The absence of ants and ant nests confirmed the lack of influence by ants on the data from control soil. If we found any ant activity, the data were considered nest data and averaged together with the other

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