**Soil CO$_2$ efflux in pastures and secondary forests on Hawaii Island**

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**Abstract:** Over half of the carbon (C) sequestration potential could be achieved by slowing deforestation and by allowing for reforestation on abandoned agricultural lands. It is broadly recognized that reforestation on abandoned farmlands in the tropics where high rates of deforestation and forest degradation occurs play a significant role in reducing CO$_2$ concentration in the atmosphere. However, understanding is still poor of soil CO$_2$ efflux and its control factors during the land-use conversion in the tropics. Using three paired sites containing secondary forests and pastures which were established from abandoned sugarcane fields, we examined the effects of conversion of agricultural land to forest and pasture on soil CO$_2$ efflux in Hawaii. We found that soil CO$_2$ efflux was higher (P < 0.01) in the secondary forests (3.93 ± 0.46 μm m$^{-2}$ s$^{-1}$) than in the pastures (2.33 ± 0.53 μm m$^{-2}$ s$^{-1}$). The Q10 values of the secondary forests and the pastures are 3.5 and 2.6, respectively. Our finding that secondary forests had a greater Q$_{10}$ indicated that they are more sensitive to temperature changes.

**Keywords:** Hawaii, land use change, soil carbon, soil respiration, sugarcane, tropical forest

**Introduction**

Land-use change in the tropics perhaps has a greater impact than in temperate areas on global C cycle and future climate change because about half of the world’s biomass C is stocked in tropical forests and 14% of the world soil C is located in tropical forest soils (IPCC 2000). Over half of the world’s C sequestration potential could be achieved by allowing for afforestation and reforestation on abandoned agricultural lands (Brown et al. 1996). It was reported that afforestation or reforestation could increase soil C stocks by 20%-53% in several decades (Del Galdo et al. 2003, Guo & Gifford 2002, Thuille et al. 2000). Besides afforestation or reforestation, management of permanent grass vegetation for C sequestration is the only other land-use approach accepted by the 1997 Kyoto Protocol to change Global C budgets (IPCC 2000). If properly managed, the tropical grasslands, covering 15 million km$^2$, can act as a significant C sink (Hu et al. 2001, Soussana et al. 2009). Therefore, studies on the role of soil processes and soil C efflux, a major component of C cycle of ecosystems, are needed to quantify the effects of reforestation and conversion of agricultural land to pastures on the global C cycle.

Measurements of soil CO$_2$ efflux are essential to obtain both a reliable understanding of the driving force of soil processes and an estimate of the sensitivities of ecosystem responses in C budgets to future climate change. Soil CO$_2$ efflux has been measured in various ecosystems all over the world and high spatial and temporal variability of soil CO$_2$ efflux has been reported, especially in the tropics (Raich & Schlesinger 1992, Davidson et al. 2002, Li et al. 2005). The soil CO$_2$ efflux is highly sensitive to changes in surface temperature and the potential increase in CO$_2$ release from soils caused by future elevated temperature may have a positive feedback effect on the atmospheric CO$_2$ and global change (Fang & Moncrieff 2001, Kirschbaum 1995). The rates of soil CO$_2$ efflux typically increase exponentially with increasing temperature and are often reported as a Q10 relationship (magnitude of increase in gas efflux with a temperature change of 10$^\circ$C). It was reported that the Q10 parameter can change with soil physical properties, soil moisture, and temperature (Davidson et al. 2002, Janssens & Pilegaard 2003, Xu & Qi 2001). However, there is little information on the temperature sensitivity of the soil CO$_2$ efflux from tropical Andisols.

On the island of Hawaii, agricultural activity was dominated by sugarcane production for more than 100 y. All these sugarcane lands were abandoned during the late 1980s to early 1990s, and were converted to pasture or left to regenerate to secondary forest. In this study, we selected three pairs of secondary forests and pastures that originated from the same abandoned sugarcane land, and compared soil CO$_2$ soil efflux and Q10 values between them. The objective of this study is to investigate the potential difference in CO$_2$ soil surface emissions between tropical wet secondary forest and pasture soils.

**Methods**

The study was conducted on Hawaii Island. The study area is characterized by a wet tropical climate. Mean monthly precipitation and temperature during the study period were 320 mm and 23.3 $^\circ$C, respectively. The sites are relatively flat with an average slope of <15$^\circ$ and an elevation of about 300 m asl. The silty clay loam soils are classified as hydrous, ferrihydritic, Acrudoxic Hydrudands of the Akaka and Kaiwiki series. The secondary forests and pastures were established on sugarcane farmlands that were...
abandoned in 1985. The secondary forests here are dominated by non-native tree species; Terminalia myriocarpa, Psidium cattleianum and Spathodea campanulata. The average tree height was about 6 to 8 m and the average diameter at breast height (dbh; 1.3 m) was 10 to 15 cm. The vegetation in the slightly grazed pastures was dominated by Brachiaria mutica, Cyperus gracilis and Panicum maximum, all non-native pasture grasses. All sites were within 5 km of each other, with similar land-use history and characteristics.

Soil CO$_2$ efflux was measured using a LI-COR6400 with soil CO$_2$ flux chamber (LI-6400-09, LI-COR inc., Lincoln, Nebraska, USA). The measurement of soil CO$_2$ efflux started in May 2007 and was repeated every month until April 2008. Typically, the measurements were taken from early morning to late afternoon. Soil temperatures at 10 cm depth were monitored at all measuring spots. The soil temperatures were measured using a soil probe thermocouple (6000-09TC) and data were recorded in a data logger. Soil moisture (0-30 cm average) was measured using a soil moisture meter (Lincoln Irrigation Inc., Lincoln, NE, USA). The Q10 value was calculated as: 

$$Q_{10} = \left( \frac{R_2}{R_1} \right)^{\frac{10}{(T_2-T_1)}}$$

where $R_2$ and $R_1$ are soil CO$_2$ efflux observed at temperatures $T_2$ and $T_1$ respectively. Significant differences among means of treatments were determined by Tukey’s test at $\alpha = 0.05$.

Soil CO$_2$ efflux measured at soil surface including microbial decomposition and root respiration provide critical knowledge for understanding soil C budgets and dynamics. Our finding that pastures had a lower respiration rate than the secondary forests is contrary to previous findings (Raich and Tufekcioglu 2000 – Biogeochemistry; Salimon et al. 2004, Global Change Biology Vol. 10) forests indicated that decomposition was slower for pastures. This conclusion may be compromised by considering root respiration because the secondary forests usually had greater root biomass than pastures and root respiration may account for 40-90% of total soil respiration (Thierron and Laudelout 1996; Epron et al. 1999; Xu and Qi 2001; Li et al. 2005). Soil temperature and moisture as well as their interaction have been shown to have significant effects on soil CO$_2$ efflux (Davidson et al. 1998, Xu & Qi 2001). In this study we did not find a significant correlation between soil moisture and soil CO$_2$ efflux (data not presented) but we found that soil CO$_2$ efflux was positively correlated with temperature. The Q10 values for both the pastures and secondary forests support previous studies with a range of values between 1.4-5.6. Our finding that secondary forest had a greater Q10 indicates that they are more sensitive to temperature changes.

**Fig. 1.** Soil CO$_2$ efflux ($\mu$m m$^{-2}$ s$^{-1}$) in the pastures and the secondary forests from May 2007 to April 2008.

**Results and Discussion**

We found that soil CO$_2$ efflux (mean ± SE) was higher ($P < 0.01$) in the secondary forests ($3.93 ± 0.46 \mu$mol m$^{-2}$ s$^{-1}$) than in the pastures ($2.33 ± 0.53 \mu$mol m$^{-2}$ s$^{-1}$). Clear seasonal patterns were absent in both the secondary forests and pastures (Figure 1). Soil CO$_2$ efflux in both the secondary forests and pastures reached the lowest level in January and February 2008. Soil CO$_2$ efflux was positively correlated with temperature in both the secondary forests ($R_2 = 0.73$, $N = 12$, $P < 0.01$) and pastures ($R_2 = 0.59$, $N = 12$, $P < 0.01$) (Figure 2). Q10 values in the secondary forests and pastures were 3.5 and 2.6, respectively.

Soil CO$_2$ efflux ($Y = 0.3138X - 3.3636$ ($R^2 = 0.73$, $N=12$, $p=0.01$)) in the secondary forests (A) and the pastures (B) and soil temperature in the secondary forests (C).
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Literature cited


