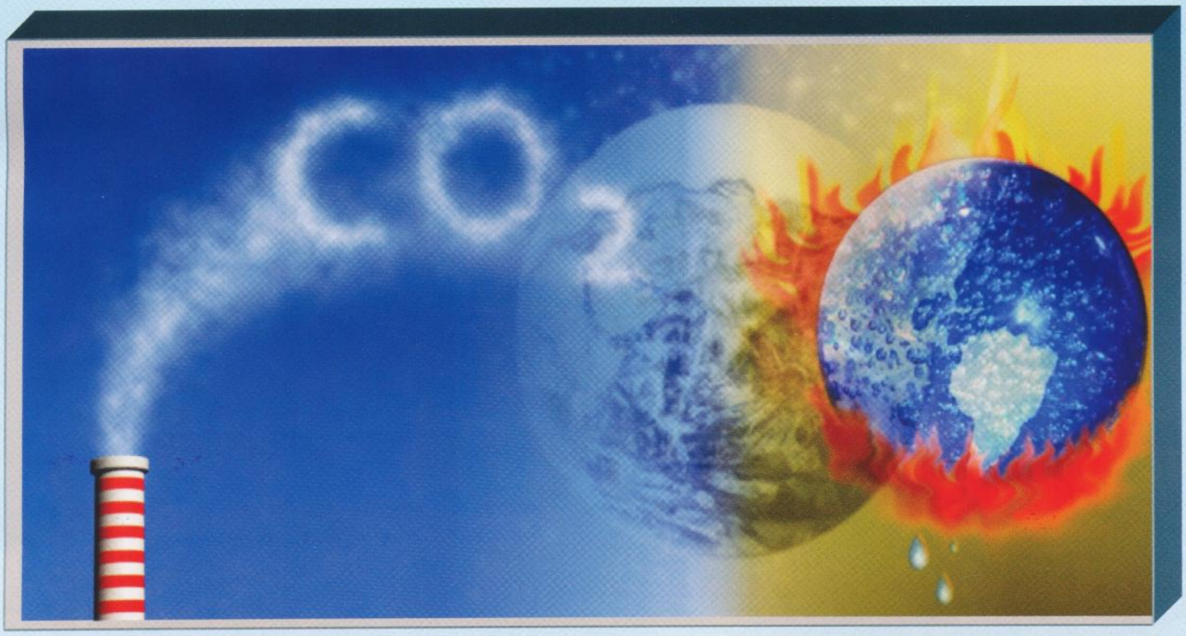
BERITA IKM
Chemistry
in MALAYSIA

DECEMBER 2009

INTERNATIONAL CONFERENCE ON NATURAL RESOURCES & ENVIRONMENTAL MANAGEMENT AND ENVIRONMENTAL SAFETY & HEALTH (NREM & ESH) 2009



Climate Change: Scientific Basis, Observed Changes, Projection and Impacts

Effects of Palm Canopy on Soil CO_2 Flux in an Oil Palm Plantation on Tropical Peatland

A Quarterly Magazine of Institut Kimia Malaysia (IKM)

ISSN No. 0216-9631
ISSUE No:97

Effects of Palm Canopy on Soil CO_2 Flux in an Oil Palm Plantation on Tropical Peatland

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ABSTRACT

Soil CO_2 flux is one of the major components of global carbon cycle. It is therefore important to investigate the impact of environmental factors on soil CO_2 flux. In this study, the spatial variation in soil respiration (SR) along a transact between two palms was examined. Three (3) transacts (replicates) of five (5) SR chambers were placed at equal distance of 1.5 m in between the two oil palms (distance within row = 9.0 m). Soil CO_2 flux in each individual chamber was measured once every month from February to April 2009. The gas samplings were carried out between 1000 – 1130 h. The Soil CO_2 flux showed differences between the chambers at different distances from the palms. The highest CO_2 flux of 1312.42 mg CO_2 m^{-2} h^{-1} were obtained at 3 m from the palm followed by 1.5 m and 4.5 m at 745.58 mg CO_2 m^{-2} h^{-1} and 888.96 mg CO_2 m^{-2} h^{-1} respectively. These might be attributed to the influence of oil palm canopy and root density on spatial variation of the CO_2 flux. These results highlighted the importance of biotic factor influencing the environmental (abiotic) variability on the rate of soil CO_2 flux.

INTRODUCTION

Carbon dioxide (CO_2) is one of the important greenhouse gases that is increasing in the atmosphere because of human activities and it has contributed about 70% of the enhanced greenhouse effect to date compared with methane and nitrous oxide. As of March 2009, CO_2 in the Earth's atmosphere is at a concentration of 387 ppm by volume (NOAA/ESRL, 2009). CO_2 provides the dominant means through which carbon is transferred in nature between a number of natural carbon reservoirs, a process known as carbon cycle (Houghton, 2005).

In the peatland ecosystem, soil CO_2 flux plays a vital role in the global CO_2 flux (McCarthy & Brown, 2006). The soil CO_2 flux also known as soil respiration includes root respiration (autotrophic) and microbial respiration (heterotrophic). Carbon dioxide released during the decomposition of organic matter in tropical peatlands is largely controlled by the rainfall, water table, and temperature as the value varies markedly both daily and annually (Melling *et al.*, 2005). Generally, the highest CO_2 emission is observed during dry season with low water table. Microscopic CO_2 emission is influenced by the metabolic activities of roots, decomposers and other soil organisms (Law *et al.*, 1999). Despite the importance of these factors and their interaction that contribute to CO_2 emission, there are relatively few published studies on greenhouse gas (GHG) from peat soil under oil palm cultivation (Henson, 1994; Melling et al., 2005; Melling & Goh, 2009).

Most researches had concentrated on the spatial variation of more than 100 m at a study site and less concern is focused on distance less than 10 m. In fact, there is a study which shows that not only the variation of soil respiration and moisture is large at scales of 100 m or more, the variation at location less than 10m can be large too (Martin & Bolstad, 2009). Indeed in this study, it is very important to observe the variation in soil respiration and to justify for the placement of the chambers along a transect between 2 immature oil palms at 1.5 m, 3 m and 4.5 m for a greenhouse gas (GHG) study.

STUDY SITE DESCRIPTION

This study was conducted in an oil palm plantation located at the Southwest of Sibu, Sarawak, Malaysia. A plantation site bearing two-year oil palms were selected for sampling. The oil palms were planted in a triangular pattern with a planting distance of 9.0 m x 9.0 m x 7.9 m with a palm density of 153 palms per ha. The height of the oil palms trees were 1.5 - 2 m. Three replications of 5 stainless steel open-ended chambers were placed at equal distance of 1.5 m in between 2 oil palms (distance within row = 9.0 m) (*Fig. 1*). The main characteristics of the sampling site are shown in *Table 1*.

Table 1: Main characteristic of the sampling site. Values are mean ± SD.

Characteristics	Value
pH (1:2.5)	3.38 ± 0.16
Bulk density (g cm^{-3})	0.22 ± 0.029
Loss of ignition (%)	95.36
Total C (%)	54.58 ± 2.37
Total N (%)	1.38 ± 0.33
C:N	42.33 ± 10.33
CEC (cmolc kg^{-1})	44.04 ± 4.92
Base saturation (%)	20.18 ± 8.63

The peat soils of the study site was classified as Typic Tropofibrist in the USDA soil classification system (Soil Survey Staff, 1992) and Fibric Histosols in the FAO classification (FAO-UNESCO, 1974), with an average peat depth of 10m. The Von Post's humification value (Parent & Caron, 1993) showed a humification value of H5-H3. An input of 0.5 kg SOA/palm and 0.75 kg of MOP/palm was applied in March and April 2009 respectively.

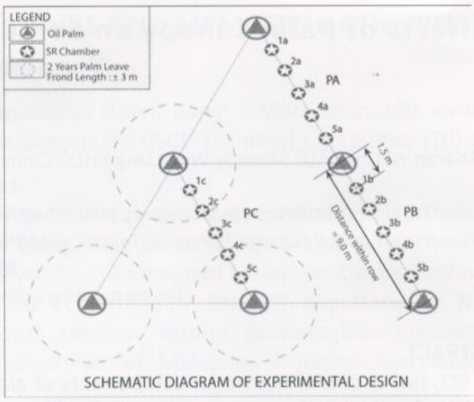

Fig. 1: A systematic sampling design for CO_2 flux measurement.

ENVIRONMENTAL VARIABLES

The environmental variables and the mean soil CO_2 flux are shown in *Table 1* and *Fig. 2*. As shown in *Fig. 2c*, the highest soil temperature at 5 cm was observed at 4.5 m from the sampling palm (29.24 °C). The lowest soil temperature at 5 cm was recorded at 1.5 m (28.00 °C).

Mean rainfall throughout the study period (Feb – Apr 2009) was 441.70 mm. The water table (*Fig. 2d*) was generally low and constant with a mean of -106.42 cm. The lowest water table had been observed at 4.5 m with -109.62 cm. The soil water-filled pore space (WFPS) and relative humidity (RH) of the study site are shown in *Fig. 2e* and *2f*. The WFPS exhibited a constant value for chambers C1 (62.76 %) and C2 (62.3 %). However, chambers C3 to C5 possessed lower WFPS from 50.42 % to 51.21 %. The RH observed at the three distances was in the range of 58.55 % to 63.29 %.

SOIL CO_2 FLUX

The Soil CO_2 flux showed differences between the chambers at different distances from the palms. The highest CO_2 flux of 1312.42 mg CO_2 m^{-2} h^{-1} were obtained at 3 m from the palm followed by 1.5 m and 4.5 m at 745.58 mg CO_2 m^{-2} h^{-1} and 888.96 mg CO_2 m^{-2} $h^{-}1$ respectively. Chambers located at 1.5 m from the palm had lower air and soil temperatures.

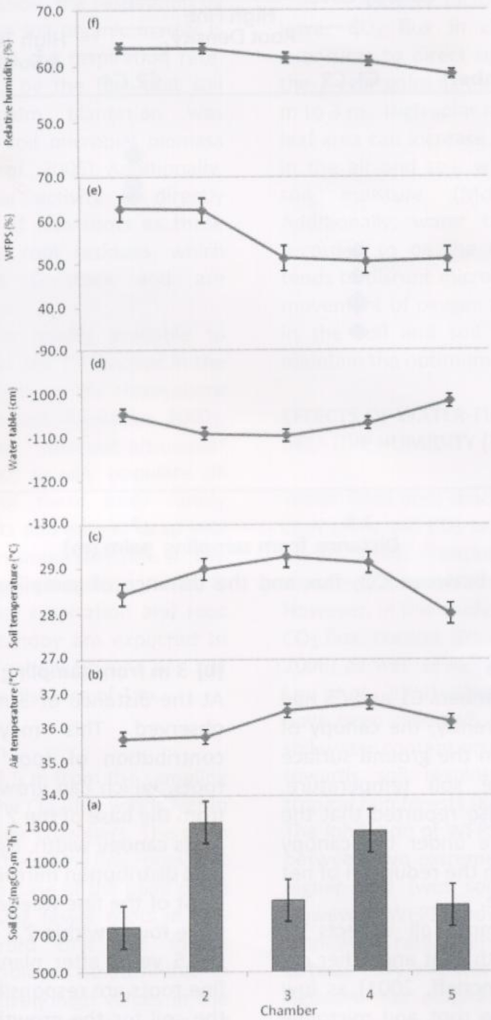

Fig. 2. Soil CO_2 flux of the chambers (a), air temperature (b), soil temperature at 5cm (c), water table (d), water filled pore space (e), and relative humidity (f). Data represent means ± *SE* (*n* = 3). Error bars indicate SE of the mean.

INFLUENCE OF PALM DISTANCE ON CO_2 FLUX

The three (3) different distances showed a flux variation in the soil CO_2 flux (*Fig. 3*), showing that biotic and abiotic interactions can strongly affect soil CO_2 flux. Palm canopy, fine roots (biotic) and water table (abiotic) are observed to be the significant factors affecting the spatial variation of CO_2 flux rate at the distance within row. The shadings by palm canopy are likely to affect soil CO_2 flux through changes in hydro-meteorological variables, such as soil temperature and soil moisture (abiotic) (Tanaka & Hashimoto, 2006), whereas fine roots have different physiological functions in terms of C/N ratio, metabolic activity and nutrient uptake capacity as compared to coarse roots (Wells & Eissenstat, 2001; Pregitzer, 2002).

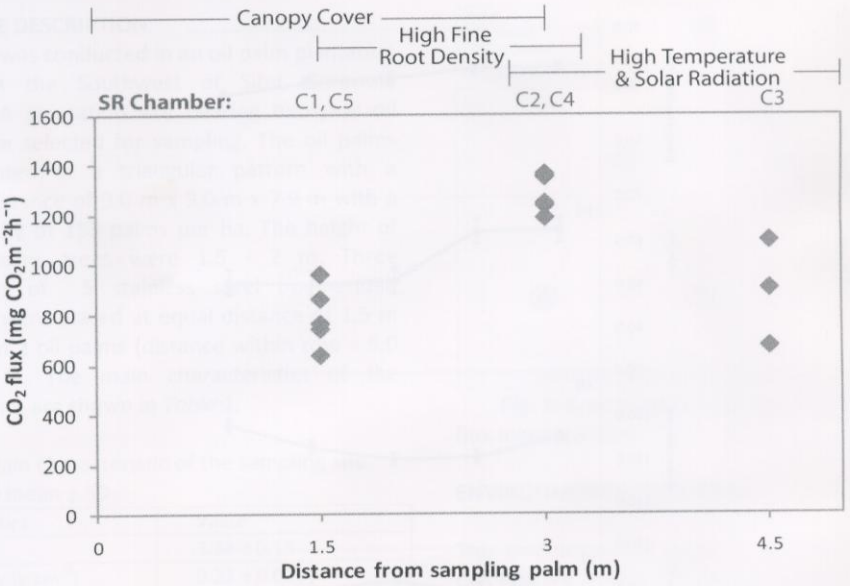

Fig. 3: The relationships between CO$_2$ flux and the distance of sampling chambers within planting distance of two palms.

(a) 1.5 m from sampling palm

At the distance of 1.5 m, chambers C1 and C5 had the lowest CO$_2$ fluxes. Apparently, the canopy of the palm provides shading on the ground surface that eventually affects the soil temperature. McCarthy & Brown (2006) also reported that the surrounding soil temperature under the canopy substantially declined through the reduction of net radiation onto the soil surface.

Temperature influences almost all aspects of respiration process, along with light and other co-varying factors (Fang & Moncrieff, 2001) as low temperature tends to reduce root and microbial respirations. At the distance of≤1.5 m, the roots of the 2-year palm consist of mainly coarse (old) roots. Coarse root respiration rate is reported to be lower than that of fine roots (Gansert, 1994; Pregitzer *et al.*, 1998; Widen & Majdi, 2001). These explain the lower CO$_2$ flux at the distance of 1.5 m. Additionally, water table at this point was recorded to be the highest due to the effect of compaction (before planting) and consolidation (after planting) resulting in a 'sinking' phenomenon thus the higher water table.

(b) 3 m from sampling palm

At the distance of 3 m, the highest CO$_2$ flux was observed. This may be attributed to the contribution of root respiration from the fine roots, which can grow to a distance of 2 to 3 m from the base of the 2 years old palm, as extensive as its canopy width. Ng *et al.* (2003) reported that root distribution mirrors canopy development, and most of the fine (feeder) roots of immature palms were found within 2.5 m of the palm base in palm ≤ 2.5 years after planting (YAP). The spread out fine roots are responsible in absorbing nutrients in the soil for the growth of palms. The respiration rate from the fine root is reported to be higher than coarse roots and is positively related to tissue N content (Pregitzer *et al.*, 1998; Ryan *et al.*, 1996; Burton *et al.*, 2002).

In addition, there are inherent variations between the fine root and coarse roots in terms of nutrient and water uptake or transport, resulting in different rates of metabolic activities such as growth respiration between fine and coarse roots (Lambers *et al.*, 1996; Vose & Ryan, 2002). Additionally, most of the root biomass is found within 1 m from the soil surface with most active roots are found in the uppermost 0.5 m from the surface (Ng *et al.*, 2003.)

In the oil palm plantation, the respiration by soil microbes that decompose soil organic matter is the major factor affecting the soil respiration rate. This hypothesis is supported by the fact that soil respiration in the oil palm plantation was significantly correlated with soil microbial biomass and soil C content (Adachi *et al.*, 2006). Additionally, it is known that microbial activity is directly proportional to the density of fine roots as these roots produce exudates and root residues, which enhance the underground C stock and are metabolized by soil microflora.

These C sources, which are readily available to microorganisms, contribute to fast C turnover in the soil and higher microbial activity in the rhizosphere when compared to root-free soil (Kuzyakov, 2002). Mycorrhizal fungi such as vesicular-arbuscular mycorrhiza (Nadarajah, 1980) usually populate oil palm roots. The hyphae of these fungi ramify between the cells of the roots and extend deep into the soil, where they play an important role in the uptake of nutrients, particularly phosphate (Corley & Tinker, 2003). Thus, microbial respiration and root respiration at the edge of canopy are expected to contribute towards the enhancement of soil respiration as expected at the distance of 3 m.

(c) 4.5 m from sampling palm

Chamber C3 was located at 4.5 m from the sampling palm. It was observed that the CO_2 flux was lower in the chamber C3 than the other chambers. The main reason is the distribution of the palms fine roots that decreased gradually from the base of the palm up to the distance of 4.5 m, causing fewer roots at this point. It was also reported that the spatial heterogeneity of soil respiration can be attributed to the palm distance with relatively high values in the vicinity of trunks and lower values in the middle of interrow (Epron *et al.*, 2004), which is a common pattern in oil palm plantations (Lamade *et al.*, 1996). In oil palm plantations, higher root biomass is found near the trunks of oil palm where as in some other plantation ecosystems such as Eucalyptus, no gradient of fine root biomass was reported. Instead, the decreasing soil respiration with increasing distance to tree was related to the decrease in the amount on leaf litter surrounding the tree (Epron *et al.*, 2004).

Another factor that may contribute to the lower CO_2 flux in chamber C3 was the higher exposures to direct sunlight as the palm canopy of the 2-year palm can only reach up to a range of 2.5 m to 3 m. High solar radiation through a decrease in leaf area can increase the surrounding temperatures in the air and soil, which eventually decreases the soil moisture (McCarthy & Brown, 2006). Additionally, water table at this point was also recorded to be the lowest. Limited soil moisture tends to disrupt microbial activities as it reduces the movement of oxygen and water-soluble compounds in the soil and soil water content is needed to maintain the optimum microbial respiration rate.

EFFECTS OF WATER-FILLED PORE SPACE (WFPS) AND RELATIVE HUMIDITY (RH) ON SOIL CO_2 FLUX

Water-filled pore space (WFPS) plays a crucial role in controlling soil CO_2 production and emission (Linn & Doran, 1984; Franzluebbers, 1999) and is used to represent the moisture condition of soil in this study. However, in this study, WFPS has no influence on soil CO_2 flux. Positive (Davidson *et al.*, 1998; Sotta *et al.*, 2006) as well as negative (Fang & Moncrieff, 2001; Lou *et al.*, 2004) effects of WFPS on the soil CO_2 flux have been reported. A similar overlapping effect of soil water content on the effects of soil temperature towards soil respiration has been reported for tropical rain forests (Kiese & Butterbach-Bahl, 2002). The inhibition of WFPS on CO_2 flux is significant only between two extreme level of soil conditions, at its higher end (wet soil) and lower end (dry soil). However, WFPS shows no evident effect on the respiration rate when the condition of the soil is in between dry and wet soil (Mielnick & Dugas, 2000). Reduced soil respiration under a high soil water content is caused by the decreased diffusion of oxygen has been reported in clay-rich soil but it is unlikely to happen in a well-drained peat soil (Davidson *et al.*, 1998; Epron *et al.*, 2004) as found in the oil palm plantations.

Relative humidity did not demonstrate any substantial relationship towards soil CO_2 flux in all three distance. However, spatial variation in the soil respiration is related to changes in the root biomass, litter amount, soil organic matter, microbial biomass, soil chemistry or physical properties; alone or in combination (Fang *et al.*, 1998, Epron *et al.*, 2004).

CONCLUSION

Spatial variation of CO_2 flux measurements within the planting distance of two oil palms was manifested in this study. The CO_2 flux variation at this small scale (9.0 m) is attributed to, not only soil temperature and moisture, but also distribution of fine roots and root microbial activities. The preliminary results highlighted the importance of the effects of canopy cover and root distribution below ground on soil CO_2 flux. However, the root biomass in the plots was not measured. Thus, the soil CO_2 flux as influenced by the effects of root cannot be determined. For a better understanding and a more accurate interpretation of CO_2 variation between individual soil CO_2 flux within a site (< 10 m), further studies need to consider the relationship between the flux rate, soil climate, root biomass, landscape and the chemical and physical properties of soil.

ACKNOWLEDGEMENTS

The authors gratefully acknowledges the contributions of all research staffs at Tropical Peat Research Laboratory Unit, Kuching for fields and laboratory analysis, and those who have helped towards the completion of this paper and generously contributed much useful information.

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