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Effects of water table level on soil CO_2 respiration in West Kalimantan forested and bare peatland: An experimental stage

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Abstract. *Astiani D, Burhanuddin, Taherdjadeh M, Curran LM. 2016. Effects of water table level on soil CO_2 respiration in West Kalimantan forested and bare peatland: An experimental stage. Nusantara Bioscience 8: 201-206.* Peatland forest is one of ecosystems that are susceptible to the alterations of water regimes. Our previous study demonstrated that hydrologic conditions are predominant variables in determining carbon respiration rates from peat soils. However, we have limited empirical measures of how hydrologic conditions (i.e., soil water table) affect the carbon respirations. A study had been conducted to ascertain the effects of water table levels on soil CO_2 respirations of West Kalimantan coastal forested and bare peatland. We simulated natural intact peat core condition by designing 25 of "a double bucket" water level experiment using 5 levels of water tables (0-40cm) and measure soil CO_2 respiration at soil surfaces. Results showed that water table levels significantly affected soil CO_2 respiration, as well as peat microclimate conditions. Results also demonstrated that forest canopy had significant effects on reducing peat CO_2 respiration through its function in maintaining site-environment conditions compared to bare peatland site. This study reveals that it is important to maintain peatland water level close to peat surface and to maintain forest/vegetation covered on peatlands to reduce soil CO_2 emissions.

Keywords: Double buckets experiment, landcover changes, microclimate, forested and open peatland

INTRODUCTION

Peatlands are wetland systems that are susceptible to alterations in their water regimes. It is anticipated that peatlands will be influenced by climate change primarily through modifications in hydrological regimes (Erwin 2009). The prominent impact of global warming on wetland ecosystems is mostly through alterations in precipitation and temperature regimes. Recent trends of climate change are increasing global temperature may also result in increased frequency and intensity of El Niño Southern Oscillation (ENSO) events. Several months of drier conditions may affect several plants and soil microbial processes, including soil emissions of CO_2, CH_4, NO, and N_2O (Sowerby 2008). El Niño events create major water table fluctuations in peatland (Mezhabuddin et al. 2014).

Hydrologic conditions are predominant variables in determining soil respiration rates (Chimner and Ewel 2004). In peatlands, lowering water-table levels have consequence in increasing soil respiration rates in boreal and temperate peatland (Silvola et al. 1996; Chimner and Cooper 2003) because of higher oxygen availability moving into unsaturated peat providing more active transportation and higher aerobic respiration. Current predictions of climate change will alter rainfall patterns in equatorial land Indonesia (Li et al. 2007; IPCC 2013). Alterations in precipitation patterns will have substantial impacts for peatland ecosystems as rainfall and rainfall patterns are the predominant controls on ecosystem processes such as net primary production (Churkina and Running 1998; Knapp and Smith 2001) and efflux of carbon dioxide from the soil (Davidson and Janssens 2006). In contrast to conditions in upland mineral soils that generally favorable for decomposition, resulting in relatively low carbon densities in peatlands and peatland forests where anaerobic conditions frequently persist, decomposition proceeds much more slowly. However, prolonged drought and land use changes activities could change the pattern of decomposition in these peatlands.

West Kalimantan tropical peatland forests are a seasonal forest type but irregular ENSO events have affected this region for centuries (Curran et al. 1999). Moreover, the development of drainage ditches within the peatland for small to large agriculture and plantation development needs, even non-ENSO years likely affect the hydrological condition of this ecosystem, and thus affect soil carbon emissions. However, unlike boreal and temperate peatlands, we have very limited empirical measures of how hydrologic conditions (e.g., soil water table, water moisture content), as well as soil temperature, influence the soil carbon respirations.

The research objective was to examine the effect of water table on soil carbon respirations in peatland. We also investigated soil microclimate conditions affected by the water table conditions.

MATERIALS AND METHODS

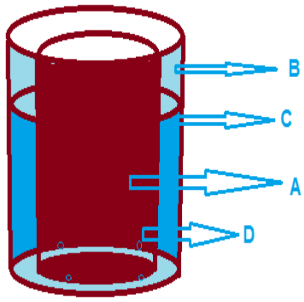
Study sites

These bucket experiments were conducted in ombrotrophic, coastal type peat in Kubu Raya District, West Kalimantan, Indonesia. The peatland landscape has been influenced by intensive canal development for agriculture purposes. Mean annual rainfall is 3212 mm ± 529 (mean ± s.d. rainfall data1990-2014, Supadio Station, Pontianak, West Kalimantan). Average ambient temperature is 26.5±0.5ºC (mean ± s.d. temperature data1990-2014, Supadio Station), with minimum and maximum temperature 22.6ºC to 32.2ºC. Rainfall data from 1990 has been collected from the closest weather station (Supadio Station) to our site. ENSO (months <100mm rainfall) and non-ENSO year rainfall data are grouped to show the average between both trends and were used as a baseline measure of water level experiment.

Effect of water table on soil CO_2 emissions

To investigate how soil water table influences the magnitude of peat CO_2 respirations, a set of bucket-experiments were conducted in February - March 2015. We simulated natural peat condition by a series of water table experiment using undisturbed samples of peat under both peat forest environment and opened area. We designed 25 of 'a double buckets' water level experiment using 5 (five) levels of water tables and measure soil CO_2 respiration at soil surfaces on Licor- 8100 soil collars. The double bucket was designed using a 25 cm diameter and 40 cm depth plastic bucket in the inside layer and a 42 cm diameter and 50 cm depth plastic bucket at outside layer. The inside layer bucket was perforated at with 4 of 5mm diameter holes at the bucket base to allow water moving into and draining toward outside bucket to imitate lateral and vertical natural water movement, and filled with 25 cm diameter x 40 cm depth undisturbed peat samples (see Figure 1A and B for illustration). A 25cm-diameter x 40 cm depth, made from stainless steel, peat sampler was designed for taking intact peat samples and let the peat samples undisturbed as in their nature. At the time of peat sample extraction, water levels were between 40-45cm. Based on preliminary data of rainfall and water table measurements taken to set depth levels of these water table treatments, the water depth classes will be divided into 0, 10, 20, 30, and 40 cm.

We applied Complete Random Sampling Method with the five levels of water level depth and 5 replications. The 25 experimental units were considered based on our earlier investigation, the duration in measuring a set of experiment (~2 hours) is optimal to measured them within 2 representative time span in a day (morning and afternoon) to minimize environment condition biases (e.g., peat H_2O, temperature, time). Complete Random Sampling Design experiments were duplicating for 7-10 days under peatland forest canopy and open area respectively.



Notes:
A = a 25cm diameter and 40cm height Inner Bucket filled with undisturbed peat samples
B = a 42 cm diameter and 50 cm height. Outer bucket filled with water leveled 0, 10, 20, 30, and 40 cm from peat surfaces
C = 4 of 0.5 cm hole at the bottom of inner buckets to allow water penetrating into peat
D = specified water level in outer bucket.

Figure 1.A. Sketch of regulated water level experiments

Figure 1.B. Photos of water level experiment activities

Li-Cor 8100 Automated soil CO_2 flux system (IRGA, Li-Cor 8100, Li-Cor Inc., Lincoln, Nebraska 68504, USA) was used to measured peat CO_2 respiration using 20 cm diameter soil collars. The PVC soil collar is inserted 10 cm beneath soil surface and 2 cm above soil surface and then connected to a Li-Cor 8100-102 soil flux survey chamber. The Li-Cor 8100 contains an infrared gas analyzer to measure soil surface relative humidity, CO_2 and H_2O concentrations. Attached with auxiliary sensor interface terminal to the Licor 8100 system, we also measured soil temperature with a temperature and water content probes at 10 cm peat depth.

Data analysis

Throughout the estimation of soil CO_2 respirations during water level experiment, data are presented as mean ± SE in selected intervals. One-way ANOVA analysis was used to test the differences of soil CO_2 respirations with water table depth. Soil micro-climate and specific microsite conditions were presented as mean and standard error (SE). Multivariate analyses were used to test the relative importance along with covariance of soil factors that control CO_2 respirations from peat.

RESULTS AND DISCUSSION

Preliminary results

The rainfall gaps range widely in months of June through September, 125 and 230 mm consecutively in ENSO and non-ENSO years, with the least amount of 37mm in August in ENSO years, whereas in April and December ENSO year rainfall exceeded non-ENSO years. From our randomly stratified measurements of water table depth in mid-June to September 2013 to 2014, the deepest water table level averaged -30 to -45 cm in forested peatland and in rainy season (November-January) the values ranged from -5 to -30 cm.

Our previous assessment on-site factors variables dictating soil CO_2 along the gradient of land use changes (published separately) indicated that their water table levels influence soil fluxes on each type of land covers such as forest, oil palm, bare, and agricultural on peatlands.

Water table levels on soil CO_2 respirations

Water levels demonstrated significant effects on peat CO_2 respiration both under forest canopy and opened area (Figure 2). The mean CO_2 flux of water table 0, 10, 20, 30 and 40 cm depth under forest canopy were 3.9 ± 0.42, 4.3 ± 0.24, 6.5 ± 0.3, 7.1 ± 0.5, and 10.3 ± 0.3 umol CO_2 m^{-2} s^{-1} respectively. Water level 10, 20, 30, and 40 cm increased peat CO_2 respiration of 10%, 67%, 82%, and 164% consecutively when compared to water level of 0 cm. Similar trend occurred on peatland at bare land, which increasing largely when water level was 20cm or further. They were 4.5 ± 0.7, 5.4 ± 0.5, 7.0± 0.26, 9.2 ±0.28, and 11.8 ±0.34 respectively for water levels 0, 10, 20, 30, and 40 cm, (see Figure 2). With similar trend to forested peatland, the bare land was increasing CO2 emission of 20%, 56%, 100% and 162% when water level was increasing from 0 to 40 cm.

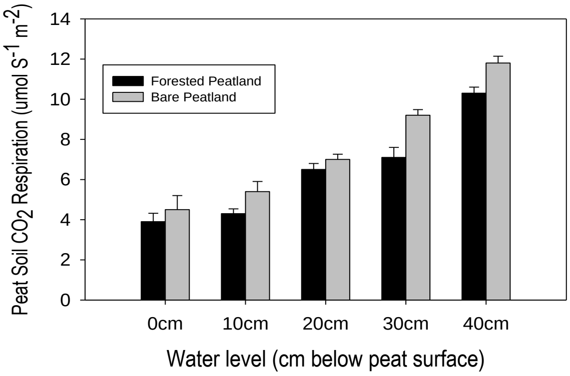


Figure 2. Peat CO_2 respiration under forest canopy and on bare peatland. One way Anova and Pairwise Multiple Comparison Procedures (Tukey Test) indicated significant difference in soil CO_2 respiration when water level increased to 20 cm and up

When comparing forested peat and bareland, it showed no significant different affecting the peat carbon fluxes ($t = 0.281$; $df = 8$; $p = 0.786$). However, the data trend shows that the respiration in open area was higher than the one under forest canopy (Fig 3). At water level 0 cm on forest peat surface and open peatland, mean peat CO_2 respiration were 3.9 umol CO_2 m^{-2} s^{-1} or ≈ 54,1 Mg CO_2 ha^{-1} y^{-1} and 4.5 umol CO_2 m^{-2} s^{-1} or ≈ 62.4 Mg CO_2 ha^{-1} y^{-1} consecutively. When water level increased to 40 cm, the mean fluxes increased more than double if compared to 0 cm (10.3 umol CO_2 m^{-2} s^{-1} or ~143.0 Mg CO_2 ha^{-1} y^{-1}, Moreover, at bare peatland, soil CO_2 fluxes at water level 40 cm reached ~164 Mg CO_2 ha^{-1} y^{-1}.

Our previous study in peatland landscape demonstrate that besides drainage ditches surround the peat landscape, monthly amount of precipitation was also dictated water level in a landscape. In Kubu Raya West Kalimantan, reducing/increasing 100mm rainfall will inflate or deplete water level ~3.6 cm (Astiani et al. 2014). Large-scale declines in water table levels during the dry season or on affected drainage peatland deepen the oxic surface peat zone, thereby increasing substrate availability for CO_2 and in turn, releasing decomposition processes. Many biogeochemical processes in the peat are largely governed by the position of the water table (Limpens et al. 2008). The upper peat layer of an undisturbed peatland (range about 5-15 cm) is unsaturated with water and oxic during the dry season and supports most biological activity, whereas the layer below is waterlogged and anoxic. The oxic-anoxic boundary shifts as a result of water table fluctuations, when water table lowered, the oxic layer deepen increasing decomposition processes.

There are many ways in which water can affect ecosystem processes. For example, in very dry conditions, drought can affect the diffusion of enzymes and substrates and basic mobility of micro-organisms. On the other hand, excess water or flooding can create anoxic conditions inhibiting the enzymatic activity allowing only slower and less efficient anaerobic decomposition process to occur (Freeman et al. 2001). Because the buildup of soil organic matter in soils is limited by water excess, this process suggests that decomposition is affected more by high water content than by primary production. Therefore on peatland, beside the present of forest cover and their level of degradation (Astiani 2014; 2016), drainage ditches and drought and may be particularly more important to peat hydric systems (Jensen et al. 2003; Davidson and Janssens 2006). Lowered water levels consequently will increase oxygen availability in soil surface and thus will increase biological activities and accelerate rate of organic matter decomposition (Martikainen 1993). The importance of drought in reducing soil carbon stores has also been highlighted in other studies (e.g. Cox et al. 2004; Ciais et al. 2005).

Effects of water table on soil properties

Result from our measurement indicated that soil temperatures on variety water-table level have not fluctuated under forest canopy. On the contrary, soil temperatures were decreased when water levels were lowered in open area (Figure 3.A). It is indicated that in these water levels range, soil temperature in open area was significantly influence of water table (Figure 3.B) with regression equation: Soil Temperature = 35.199 - (0.105 * water table level, cm), n = 729, r = 0.40, R^2 = 0.16, p=<0.001.

It also indicated that peat soil water content was conducted by water table level. Both forested and bareland sites showed similar trend, yet under forest canopy water content in forest consistently a bit higher than at open one. Soil CO_2 seems similar trend on both sites at variety of water table. However, soil surface CO_2 concentration under forest canopy was higher than open area. It is interesting that water vapor at open area show reducing when water lowered, yet meantime under forest canopy the trend has not occurred. Different behavior on effect of water level on site conditions shows that the combined effect of multi-site factors was mutually influenced each other.

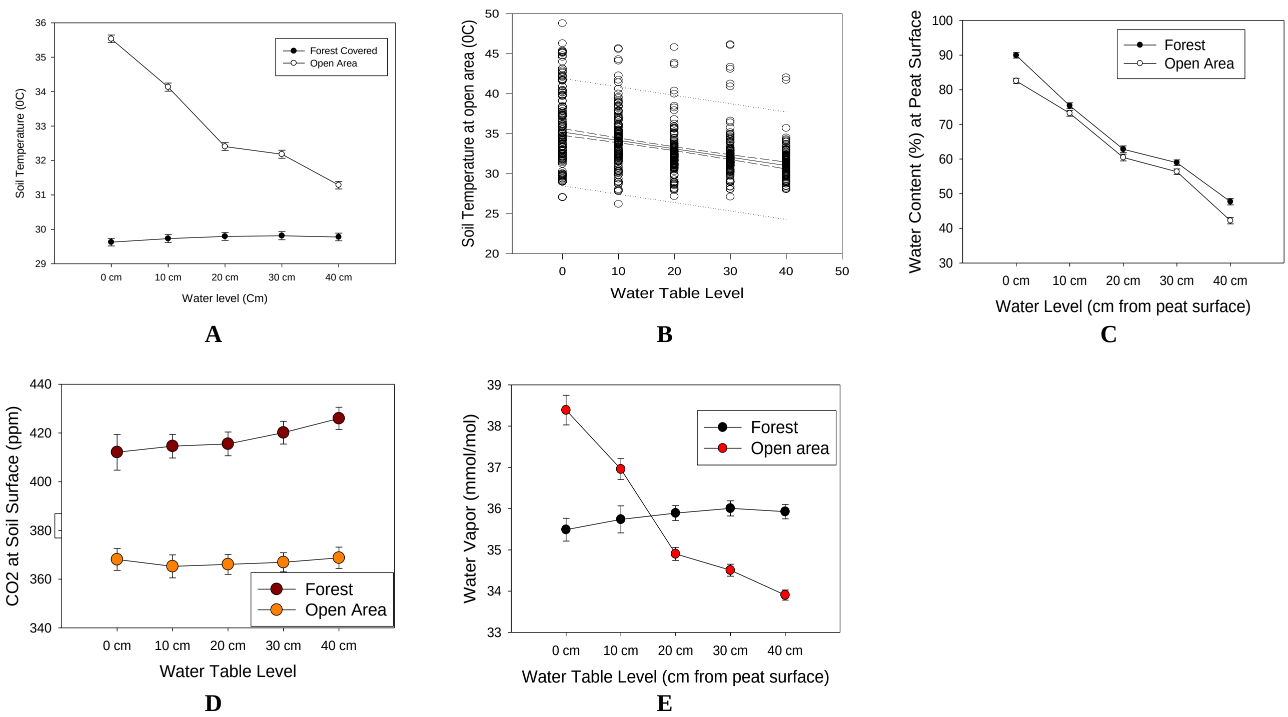


Figure 3. A. Soil temperature; B. Soil temperature vs water table level regression; C. Peat water content (%); D. Peat CO_2; and E. Peat water vapor; on variety of water levels under forest canopy and open area

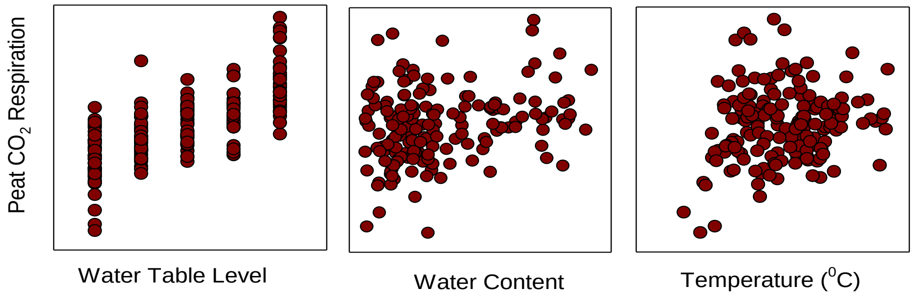


Figure 4. Scatter plot of correlation and multivariate regression of sites factors which significantly influence peat CO_2 emissions

Effects among site factors on soil respiration

Site factor analysis using Multivariate Linear Regression shows that among site factors, (i.e., water levels, peat surface H_2O, CO_2, water content, and temperature), water levels, water content, and temperature were controlling the peat carbon fluxes (R^2 = 0.59). The scatter plots and regression are presented in Figure 5. There was strongly positive correlation (r = 77%) among site factors compositely and peat CO_2 respiration. Among-site factors significantly affecting peat CO_2 respiration were water level, water content and soil temperature (Figure 4). Regression analysis demonstrates that these 3 site factors strongly influenced the soil fluxes. The equation model is: (sqrt Peat CO_2 Respiration) = 1.756 + (0.0297 * Water Table Level) - (0.0204 * Water Content) + (0.0220 * Temperature); n = 175; r = 0.77; R^2 = 0.59; Adj r^2 = 0.583; SE = 0.371; p<0.001.

Discussions

There have been many studies in investigating the efflux of carbon from the soil to climate change (e.g. Bellamy et al. 2005; Knorr et al. 2005; Kusler et al. 1999). Many of these studies have primarily focused on responses to temperature (Giardina and Ryan 2000; Davidson and Janssens 2006). However, only a few studies have examined changes in rainfall distributions and patterns on soil carbon efflux (Fay et al. 2000; Jensen et al. 2003; Davidson et al. 2004; Borken et al. 2006). The increased global temperatures result in increased rates of respiration, as highlighted by Davidson and Janssens (2006). However, Schulze and Freibauer (2005) pointed out that decomposition as the effect of soil temperature solely cannot account for trends observed in soil carbon losses. A combination of drought and high temperatures resulted in a reduction in carbon fixation in Europe in 2003, which is equivalent to four years of net carbon storage (Ciais et al. 2005).

Our previous study on peat CO_2 respiration under forest and small scale agriculture on peatland showed that water table consistently act a main significant factors among other (Astiani et al. 2015), even though our research was on smaller spatial scales such as in West Kalimantan peatlands, yet for CO_2 exchange in general, much less variation in exchange rates can be interpreted by environmental and ecological variables (e.g., Bellisario et al. 1999; Moore et al. 1994; Shannon and White 1996). It was also found that changes in the frequency and intensity of weather-related events, such as the local water table lowering during droughts, have a significant consequence on soil CO_2 fluxes. It has been shown that changing water tables give consequence to increase carbon mineralization rates 1.5 to 3 times (Aerts and Ludwig 1997). However, other studies also found small scale variation in relatively high water table levels has shown a minor effect on soil CO_2 flux rates (Chimner and Ewel 2004). Our research, however, is fulfilling a major gap that existed in our knowledge about soil CO_2 flux with variability of peat water table on tropical peatland forests.

Peat water level will control the dynamics of CO_2 through increased soil aeration, which improves soil respiration rates by the higher available oxygen for soil microorganisms (Bouwman 1990). Thus, the impact of soil moisture on soil respiration rates in tropical peatland is more dominant because the seasonal fluctuation in soil temperature in the tropics is relatively low and does not involve low temperature (Inubushi et al. 2003). However, when comparing the respiration rate and site factors among water levels between forested and bare tropical peatland, there were significant magnitudes of responses. Bare peatland consistently emits higher CO_2 than under forested land. These results were supported by Warren et al. (2016) and Hergoualch et al. (2013) that land cover change could impact on increasing soil carbon emission. These results indicate that forest canopy, besides its roles in sequestering atmospheric carbon, can also be beneficial in reducing CO_2 respiration from peatland soil. Therefore, since peatland forest degradation has significant impact on the canopy opening (Astiani 2016), it is important to maintain and enhance the quality of tropical peatland forest at present time.

It is concluded that water level significantly dictating soil CO_2 respiration in peatland landscape. Land cover type change from forests to bare lands was indicated in increasing peatland CO_2 emission. To mitigate the effect on the GHG emission from the half of Indonesian degraded peatland, care should be made to lower the impact on increasing CO_2 in the atmosphere by increasing water level closer to peatland soil surfaces. Peatland hydrology management could help to reduce large amount of CO_2 emitted from this tropical peatland.

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