Response of temperature, moisture and CO$_2$ emission from different water levels at undisturbed peat soil column

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Abstract. Greenhouse gas (GHG) emissions from peatlands are influenced by many factors and most of them are difficult to control. Soil temperature and moisture regulate biological reactions in the soil leading to gas production. It is a complex mechanism, considering the difficulty in controlling soil moisture and temperature. The study aimed to assess the consequence of soil moisture and temperature alteration on Carbon Dioxide (CO$_2$) emission through water level management. Soil samples were collected using a 21 cm (diameter) and 100 cm (length) of polyvinyl chloride (PVC); each was dipped into big bucket to control water level. Water levels were controlled in daily basis. Three different water levels were arranged, i.e., at 15 cm, 35 cm and 55 cm beneath earth surface and were replicated 3 times. The results showed that water levels affected soil and water temperature. Non-linear relationship between temperature and CO$_2$ emission ($P<0.01$) was discovered in this research. The lowest soil moisture was recorded at -55 cm water level below surface, then by experiments at -35 cm and -15 cm water levels. Lower water level increased aeration of peat soil and created optimal conditions for microorganisms to oxidize organic matters that produced and emitted CO$_2$ into the atmosphere.

1. Introduction

Peatlands cover 420 M ha of world’s surface area, or approximately 3% of the land mass, and roughly encompass 20-30% of total sequestered C [1]. Despite their role to global environment, forested peatlands have largely been drained for agricultural and non-agricultural purposes due to economic development and human population growth issues. Indonesian peatlands cover 13.43 million ha, which are situated over Sumatera, Kalimantan, Papua and Sulawesi islands [2]. Drainage of natural peatlands is an essential step to convert peatlands to agricultural fields; however, it results in soil peat decomposition, subsidence and greenhouse gas (GHG) emissions [3].

Carbon dioxide (CO$_2$) emission from peat soils strongly depends on environmental factors i.e., temperature and soil moisture [4]. These factors are influenced by water management practices and land use [5]. Changes on soil environment have a significant impact on microbiological properties of soil. High temperature and aerobic condition on the tropical peatlands surface speed up the peat decomposition. Peat respiration was found increased with temperature [6]. However, the effect of temperature on GHG emissions over tropical peatlands is essentially understudied [7]. Soil moisture affects soluble substrates diffusion at lower soil water content and constrains oxygen diffusion at higher soil moistures; both of which limit the respiration of soil microbes [8]. Limited studies, however, have
been published on the consequence of altering soil-water temperature and soil moisture related to CO₂ emission within the context of peatlands [9]. Meanwhile, it is important to observe temperature and soil moisture status in response to water levels and GHG emissions [10]. With this paucity, this study was designed to investigate the soil-water temperature and soil moisture in controlling CO₂ emissions through water table management through experiment of soil column.

2. Methodology

2.1. Research location

The peat soil samples were gathered from Jabiren, Pulang Pisau regency, Central Kalimantan, Indonesia (S 02°30’52.5’’; E 114°10’11.6’’). Sampling utilized polyvinyl chloride (PVC) tube with dimension of 100 cm length and 21 cm in diameter. The tube was vertically injected into peat soil at 100 cm deep. It was carefully pulled up with the soil intact inside the tube after sealing the bottom. Ferns and grasses dominated land cover of the research site. Depths of peat soil ranged 5-7 m. Decomposition rate of peat material is categorized as hemic (moderately humified) and fibric (less humified). Meanwhile, sapric (most humified) peat type was found in the surface [11].

2.2. Experimental design

The Indonesian Agricultural Environment Research Institute (IAERI), Jakenan, Central Java, Indonesia hosted an experimental study for all soil columns. Excessive water was drained from soil column in order to adjust air-filled porosity. Holes were established in each soil column according to water level position. Investigation of water level was done at daily basis over each bucket. We established measurements over three different water levels (15 cm, 35 cm and 55 cm below soil surface) with triple replications using a randomized block design.

2.3. Gas measurement

Analysis of CO₂ involved gas sampling using 10-cm³ syringes and a cylinder dark closed chamber in weekly basis. Gas sampling were done 5 times in 5-minute interval, i.e. 5, 10, 15, 20 and 25 minutes. They were then transferred directly to the laboratory for further analysis. Gas composition was assessed though gas chromatography (GC), equipped with a thermal conductivity detector (TCD). A digital thermocouple was employed to measure the temperature of soil samples.

2.4. Statistical analysis

Association between CO₂ fluxes and soil-water temperature and soil moisture was analysed using regression. Significant levels were arranged at \( P < 0.05 \) and \( P < 0.001 \), using SAS 9.1.3 portable (SAS Institute 2003).

3. Results and discussion

The lowest soil moisture was observed at -55 cm water level beneath soil surface, then at -35 cm and -15 cm water level (Figure 1). In this research, soil moisture measured at -55, -35 and -15 cm were 78.1, 80.6 and 81.3%, respectively. Soil moisture at -15 cm water level below soil surface was different \( (P < 0.05) \) compare to the one at -35 and -55 cm. Peat moisture content is one of key factors involving in the decomposition of organic matter because it influences the microbial activities; with the optimum range between 64 and 89% [4]. Moreover, soil moisture affects the soluble substrates diffusion at lower soil water content and it becomes constrain of oxygen diffusion at higher soil moistures; both conditions are limiting issues to soil microbial respiration [8].
This research found that correlation between soil moisture and water level was found in positive linear relationship (Figure 2). Deeper water level lowered soil moisture. Within peatland context, drainage creates aerobic conditions and increases redox potentials. This leads to a favourable condition for enhanced activities of microbes and nitrogen mineralization [12]. Lowering water level increases peat soil aeration, leading to microbial optimization oxidation on organic matter oxidation and emit of CO₂ to the atmosphere. Peat moisture and water levels were found interrelated with CO₂ fluxes [13], hence, poorer peat moisture and water levels resulted elevated CO₂ fluxes. With that sense, peat moisture determines peat decomposition level that emits CO₂.

There were linear correlations between soil-water temperature and CO₂ emission, which observed at $P < 0.01$. Lowering water levels impacted to soil and water temperatures (Figure 3a and 3b). The soil and water temperatures become lower when the water level was low. Soil and water temperatures respectively spanned from 25.7 to 32.2°C and 27.1 to 33.1°C. Measured soil temperature, in average, was 29°C. Meanwhile, averaged soil temperatures were 29.2, 29.0 and 28.9°C at 15, 35 and 55 cm water levels, respectively. Mean water temperatures were measured at 30.0, 29.8 and 29.2°C, respectively. This could be explained most likely because there were holes in the cylinder wall of columns, which allow air circulation and water evaporation from the outside of the soil columns that made good aeration during the incubation experiment.
Figure 3. Relationship between soil (a) and water (b) temperature and water depth

Soil and water temperatures were intensely related to CO₂ fluxes (as shown in Figure 4). Soil temperature is a key factor for influencing soil biological reaction and affects the rate of gas production [14]. Temperature is the most crucial factor controlling CO₂ emissions because microbial community strongly reacts to temperature stress [15]. The highest CO₂ fluxes were emitted at 29° and 30° C of soil and water temperature, respectively. Optimum temperature for methanogenesis activities spans between 25 and 30°C [16]. Laboratory incubated temperate wetland soils showed CO₂ production strongly depended within 2-22°C range [17]. This condition is likely to occur, because temperature sensitivity of decomposition increases as soil organic matter pool instability decreases, so elevated temperature would rapidly decompose recalcitrant C compounds and slows or reverses the potential for C sequestration in wetland [18]. Moreover, microbial enzymatic activities are subtle to fluctuations in soil temperature and water content, which can affect carbon storage and cycling in soils and thus, produce CO₂ emission [19]. Water logging creates anaerobic condition and it has been revealed to strongly influence temperature response of C mineralization [20]. Respiration rates depend on the collective outcome of temperature and moisture content, with diverging effects upon the nature of peatlands and microbial community structure [6].

Figure 4. Correlation between soil (a) and water (b) temperature and CO₂ fluxes

4. Conclusion
This study outlined that when peatland water condition was near soil surface, less CO₂ was emitted. CO₂ fluxes are strongly affected by water levels and peat soil temperature. Respiration rates depends on the mutual influence of peat soil humidity and temperature. Soil water manipulations in peat soil
influence soil-water temperature and soil moisture which were the major driver of microbial activity to produce CO2 emission.

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