

The Effect of Paraquat, Difenoconazole, and Butylphenyl Methylcarbamate (BPMC) on CO₂ Emissions and Phenolic Acids in Peat Soil

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ABSTRACT

Pesticides are widely used in agriculture, including on peat soil. The objective of this study was to analyze the effect of the application of paraquat, difenoconazole, and butylphenyl methylcarbamate (BPMC) on CO₂ emissions and concentrations of phenolic acids in a peat soil. Peat soil sample was taken in District of Pulang Pisau, Central Kalimantan. The peat soil was applied with 1.89 mg kg⁻¹ paraquat, 1.72 mg kg⁻¹ difenoconazole and 1.65 mg kg⁻¹ butylphenyl methylcarbamate (BPMC), then the soil was incubated for 1, 2, 4, 5, 7, 10, 14, 21, 26 and 30 days. The results showed that the application of pesticides on peat soil increased CO₂ emission, and decreased CH₄ emission and phenolic acid concentrations up to 30 days of incubation. The CO₂ emissions were derived from C of degraded pesticides and from C of phenolic acids, although the oxidation reaction was not accompanied by the change of soil pH.

Keyword: CO₂ emission, phenolic acids, butylphenyl methylcarbamate (BPMC), difenoconazole, paraquat, peat soil

ABSTRAK

Pestisida banyak digunakan di lahan pertanian, termasuk di tanah gambut. Penelitian ini bertujuan untuk mempelajari pengaruh pestisida terhadap emisi CO₂, dan konsentrasi asam fenolat pada tanah gambut. Contoh tanah gambut diambil dari Kabupaten Pulang Pisau, Provinsi Kalimantan Tengah. Contoh tanah tersebut diberikan pestisida dengan bahan aktif paraquat (1,89 mg kg⁻¹), difenoconazole (1,72 mg kg⁻¹) dan butylphenyl methylcarbamate (BPMC, 1,65 mg kg⁻¹) dan selanjutnya diinkubasi di laboratorium selama 1, 2, 4, 5, 7, 10, 11, 14, 21, 26, dan 30 hari. Pemberian pestisida pada dosis anjuran selama 30 hari meningkatkan emisi CO₂ [metode titrasi], dan menurunkan emisi CH₄. Pemberian pestisida selama 30 hari meningkatkan emisi CO₂, dan menurunkan emisi CH₄ dan konsentrasi asam-asam fenolat di dalam tanah gambut. Emisi CO₂ berasal dari oksidasi C asam-asam fenolat dan bahan-bahan aktif pestisida, dimana reaksi oksidasi ini tidak disertai dengan perubahan pH tanah.

Kata kunci: Emisi CO₂, asam fenolat, butylphenyl methylcarbamate (BPMC), difenoconazole, paraquat, tanah gambut

INTRODUCTION

The improvement of marginal land can be an option to overcome the national food security problem, and peatland is one of the potential lands that can be developed into new agricultural land (BBSDLP 2008). Peatland in Indonesia is generally formed by wood residues containing higher lignin compared to the peatland in the temperate climate

area (Stevenson 1994). During anaerobic condition, degradation of peat containing high lignin will produce phenolic acids. Several phenolic acids identified in soil are vanillate acid, p-coumaric acid, p-hydroxybenzoic acid, salicylic acid, galate, sinapate, gentisate and syringic acid (Tsutsuki and Kondo 1995, Sabiham 2010). A previous study showed that phenolic acids tend to be phytotoxic for plants and can inhibit the growth of plants (Stevenson 1994). Furthermore, the carbon emission from peatland has caused many problems for environment. The study of Barchia (2002) reported that the carbon emission from peaty paddy field in

CO₂ ha⁻¹ yr⁻¹. In addition, the study of Nurzakiah *et al.* (2014) reported that the CO₂ fluxes from peatland in dry season are higher than in the rainy season. The major factors influencing the CO₂ emission on peat soils are the soil water content and groundwater level.

The use of pesticides on agricultural land including peatland can control effectively weed growth, pest and plant disease. The most well-known pesticide used in the farming activities is bipyridilium herbicide that contains paraquat as the active ingredient (Susilawati *et al.* 2005). The study on CO₂ emissions on peat soil applied with pesticide has not been widely conducted in Indonesia. The previous study of Bartha *et al.* (1967) indicated that application of high dosage of carbamate pesticide (250 mg L⁻¹) on sandy loam soil in New Jersey decreased the CO₂ concentrations in the soil after 10 days of incubation. Another study by Sahid and Kasim (1994) showed that application of alachlor and metolachlor herbicides with a dosage of 20 and 150 mg L⁻¹ on mineral soil has increased CO₂ concentration until 25 days of incubation due to the effect of microbe respiration. Both studies have given an insight to conduct the current study that focuses on the effect of pesticide application using common dosages applied by the farmers on CO₂ emissions and phenolic acid concentrations in peat agricultural soil.

The objective of this study was to analyze the effect of pesticide application on CO₂ emissions and phenolic acid concentrations in peat soil.

MATERIALS AND METHODS

Study Site and Pesticide Use

The soil sample used in the current study was collected from Pulang Pisau District, Central Kalimantan Province at a depth of 0-20 cm.

Several types of pesticide were applied in this study including herbicide with paraquat as an active ingredient, a fungicide with difenoconazole, and insecticide with butylphenyl methylcarbamate (BMPC). The dosages of pesticides applied were 3 liters ha⁻¹ Gramoxone (containing paraquat), 1 liter ha⁻¹ Triazole (containing difenoconazole) and 1 liter ha⁻¹ Bassa (containing BPMC). The amount of each pesticide applied in each treatment was about 20 ml, which equals to a certain dosage of active ingredient per kg peat soil, *i.e.* paraquat 1.89 mg kg⁻¹, difenoconazole 1.72 mg kg⁻¹, and BPMC 1.65 mg kg⁻¹. The incubation vessel used in this study was made from PVC tube with a diameter of 4 inches.

Research Design

The study was conducted using a Completely Randomized Design (CRD) with two factors and three replicates. The first factor was the types of pesticide, namely P = Paraquat, D = Difenoconazole, V = BPMC, and T = without pesticide. The second factor was the incubation periods, namely 01 = 1 day of incubation, 02 = 2 days, 04 = 4 days, 05 = 5 days, 07 = 7 days, 10 = 10 days, 11 = 11 days, 14 = 14 days, 21 = 21 days, 26 = 26 days and 30 = 30 days of incubation. The incubation periods were determined based on pesticide retention time in soil (DT50), which could take up to 2 weeks (EPA 1998).

Treatment Application

The experiment was conducted as follows: (1) About 264 g of peat soil (water content 316%) was placed into an incubation vessel; (2) After that, about 20 ml of pesticide was applied to the soil; (3) Then, about 10 mL NaOH solution was standardized using oxalic acid to capture CO₂ and the tube containing the NaOH solution was placed inside the vessel. The concentration of NaOH was 0.95 mol L⁻¹; and (4) The incubation vessel was closed with a plastic wrap and an elastic band to make sure that there would be no air coming into the vessel. The illustration of incubation vessel was shown in Figure 1.

CO₂ Emission Measurement

Measurement of CO₂ emissions was carried out using a titration method proposed by Verstraete (1987) in Anas (1989). The measurements of CO₂ emissions were conducted at the end of each incubation period by titrating the NaOH solution with HCl solution that had been standardized previously using sodium borate. The emission of CH₄ was determined using Gas Analyzer.

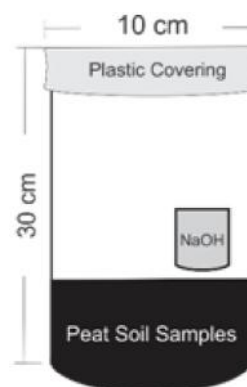


Figure 1. Illustration of incubation vessel.

Phenolic Acid Measurement

The types and concentrations of phenolic acids in the peat soil were determined at the end of each incubation period. About 5 g of soil sample was added with 25 ml of aquadest and then the suspension was shaken for 30 minutes. Then, the suspension was centrifuged at 3000 rpm for 60 minutes. About 20 ml of the supernatant was filtered using 0.45 µm millipore filter. After that, the filtrate was analyzed using HPLC (Angeles 2005). The phenolic acids including ferulic acid, sinapic acid, p-coumaric acid, vanillate acid, syringic acid and p-hydroxybenzoic acid were analyzed.

Initial chemical properties of the soil including organic-C content, total-N, fiber content, decomposition rate and phenolic acid concentrations were determined. The soil pH was measured before and after the incubation period.

Data Analysis

The data of CO₂ emissions were simulated using the *first order kinetic* equation using Sigmaplot software version 12.3 (Sugiyono 2007). In addition, the correlation test between CO₂ emission and phenolic acid concentration was performed. The first order kinetic equation used in this study is as follows:

$$f = a(1 - \exp^{-b \cdot x})$$

- f = CO₂ emission (mg kg⁻¹)
- a = maximum CO₂ emission (mg kg⁻¹)
- b = CO₂ emission rate constant (hr⁻¹)
- x = observation period (hr)
- exp = 2.7182

RESULTS AND DISCUSSION

Chemical and Physical Properties of Peat Soil

The peat soil used in the current study is categorized as oligotrophic according to its chemical properties (Hardjowigeno 1996). The chemical properties of the peat soil are presented in Table 1.

The pH of peat soil is 4.69, which is higher than the pH of natural peat soil (pH 3-4). This is probably due to the soil has been used for agricultural activities since 1980, therefore, the soil organic matter might have been leached through the drainage water, resulting in an increase of soil pH. The organic-C content in the soil is 39.5%, which confirms that the soil is a peat soil. According to USDA classification, the soil that contains organic matter between 30% - 50% is considered as Histosol (USDA 2014). The fiber content of the peat soil is

Table 1. Chemical and physical properties of peat soil.

Chemical properties	Value
pH (H ₂ O)	4.69
C-organic (%)	39.45
Fiber volume (%)	46
Munsell color	10 YR 3/1
Decomposition level	Hemic

Table 2. Types of phenolic acids and their concentrations initially identified in the peat soil.

Phenolic acids	Concentration (ppm)	
	1 st replication	2 nd replication
Ferulic acid	9 × 10 ⁻³	9 × 10 ⁻³
Syringic acid	tu	tu
Sinapic acid	83.10	86.40
p-coumaric acid	tu	tu
Vanillate acid	2 × 10 ⁻³	2 × 10 ⁻³
p-hydroxybenzoic acid	tu	tu
Total phenolic acid	83.11	86.47

Note: tu = Not Detected

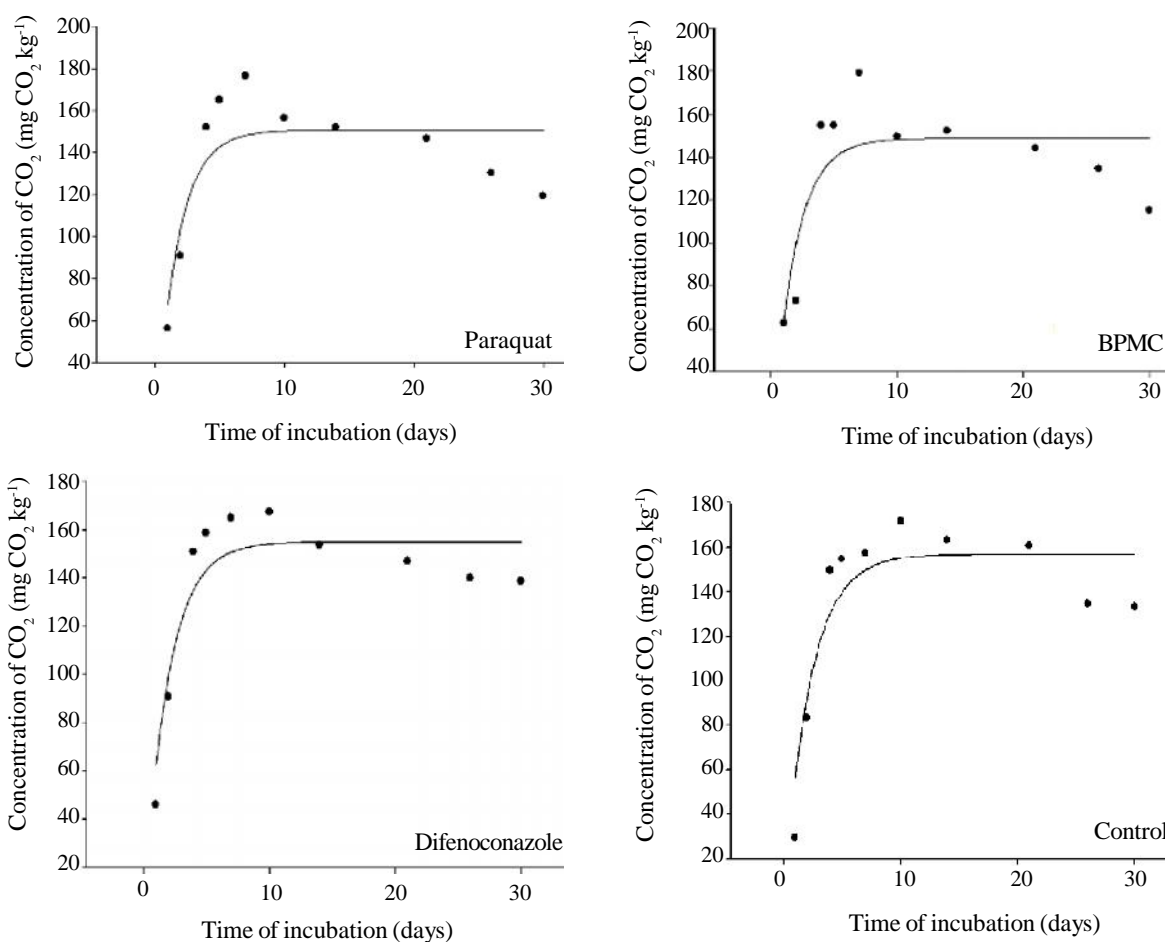


Figure 2. The CO₂ emissions from peat soil applied with pesticides.

46%, with the colour of 10YR 3/1 and pyrophosphate index of 2, therefore, the peat is categorized as Hemic according to the criteria of peat maturity level (Lynn *et al.* 1974).

The phenolic acids identified in the peat soil used in the current study were ferulic acid, sinapic acid, and vanillate acid (Table 2). According to Tan (1993), these phenolic acids are derived from lignin containing materials, *i.e.* hardwood and softwood. On the other hand, *p*-hydroxybenzoic acid and *p*-coumaric acid were not identified in the soil sample. The results confirmed that the peat soil used in the current study is not formed from grass residues.

The studies of Driessen (1978) and Stevenson (1994) indicated that the ombrogen peat in Indonesia contains around 64% of lignin derived from wood residues.

CO₂ Emissions After Incubation Period

The application of pesticides increased the maximum CO₂ emissions during 30 days of incubation (Figure 2). The amount of maximum CO₂ emission in each treatment followed the order of *paraquat* (159.62 mg CO₂ kg⁻¹) > without pesticide application/control (156.95 mg CO₂ kg⁻¹) > *difenoconazole* (154.97 mg CO₂ kg⁻¹) > BPMP

Table 3. The first order kinetic equations of CO₂ emissions in peat soil applied with pesticides.

Treatment	Equation	a (mg kg ⁻¹)	b (hour ⁻¹)	R ²	p
Paraquat	$f = 150.62(1 - \exp^{(-0.59 * x)})$	150.62	59×10^{-2}	0.73	p > 0.001
Difenoconazole	$f = 154.97(1 - \exp^{(-0.51 * x)})$	154.97	51×10^{-2}	0.84	p > 0.001
BPMP	$f = 148.61(1 - \exp^{(-0.56 * x)})$	148.61	56×10^{-2}	0.69	p > 0.001
Control	$f = 156.95(1 - \exp^{(-0.44 * x)})$	156.95	44×10^{-2}	0.83	p > 0.001

(148.61 mg CO₂ kg⁻¹). The results showed that in general CO₂ emission in the soil without pesticide application (control) was higher than that in the soil applied with pesticides, except that in the soil applied with paraquat. The results could also mean that pesticide application on peat soil can reduce CO₂ emissions, except in the paraquat treatment.

According to *the first order kinetic equations*, the constants of CO₂ emissions (b) derived after pesticide applications are *paraquat* ($59 \times 10^2 \text{ h}^{-1}$) > *BPMC* ($56 \times 10^2 \text{ h}^{-1}$) > *difenoconazole* ($51 \times 10^2 \text{ h}^{-1}$) > without pesticide application/control ($44 \times 10^2 \text{ h}^{-1}$). The results showed that the organic-C degradation rate in the peat soil applied with active ingredients of pesticides varies. In addition, the results indicated that pesticide application on peat soil increased CO₂ emissions. The increase of CO₂ emissions in the soil applied with pesticides was probably due to the decomposition or oxidation of C derived from pesticides into CO₂. The degradation periods (DT50) of each pesticide active ingredient vary. The study of Djojsumarto (2006) reported that DT50 of *BPMC* is 7-9 days, *paraquat* is 14 days and *difenoconazole* is 53 days. The degradation period of pesticide active ingredients was influenced by its chemical structure. *Paraquat* and *BPMC* have more simple chemical structures compared to *difenoconazole*, therefore, they are easily degraded, which further result in the highest maximum CO₂ emission. Even though the peat soil without pesticide application (control) releases a high amount of maximum CO₂ emission, however, *the first order kinetic equation* of this treatment

has small constant value instead. This phenomenon may be due to the delayed rate of initial C degradation that causes the average degradation rate to be small. The amounts of CO₂ emissions derived from the degradation of the active ingredients of *paraquat*, *difenoconazole*, and *BPMC* were 1.39 mg kg⁻¹ CO₂, 1.18 mg kg⁻¹ CO₂ and 1.16 mg kg⁻¹ CO₂, respectively. The total amount of CO₂ emission derived from the degradation of all the active ingredients is still lower than the CO₂ emission from the control treatment (without pesticide application) after 30 days of incubation. The results indicated that the source of CO₂ emission is not only from pesticide degradation but probably also from phenolic acid decomposition. The study of Manna *et al.* (2013) showed that fungicide application on paddy soil can increase CO₂ emission from the soil, however, the increase is not only due to fungicide application, but also due to microorganism activity and alkaline phosphatase activity in the soil.

CH₄ Emissions After Incubation Period

Besides CO₂, methane (CH₄) is another form of carbon emission released into the atmosphere. Methane (CH₄) is one of the greenhouse gases that can be emitted by soil through methanogenic bacteria activity. About 80% of CH₄ is produced biologically by a group of anaerobic bacteria in a reductive environment (Ehhalt and Schmidt 1978) with a potential redox lower than -200 mV, and the bacteria grow optimally at temperature of 30-40 °C (Kirk 2004). Methane (CH₄) will never be produced before the reduction processes of oxygen, nitrate, ferrum

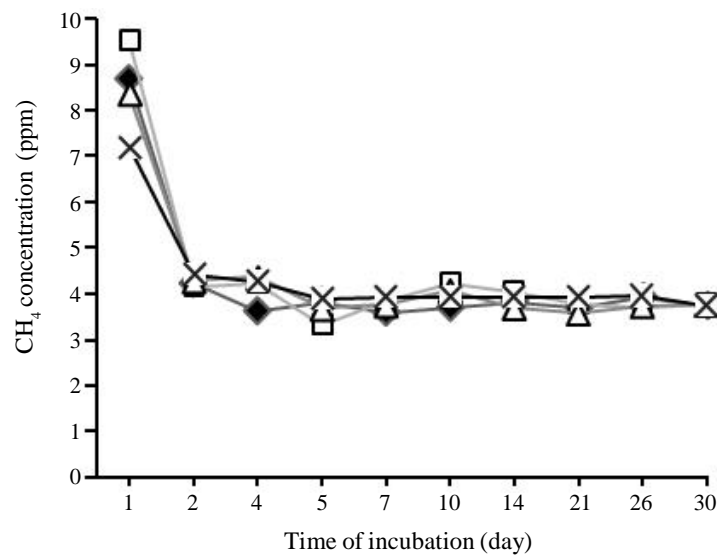


Figure 3. The CH₄ emissions during the incubation period. —◆—: *BMPC*, —□—: *Difenoconazole*, —△—: *Paraquat*, —X—: Control.

Table 4. Phenolic acid concentrations in peat soil applied with pesticides during the incubation periods.

Treatment	Ferulic acid	Syringic acid	Sinapic acid	p-coumaric acid	Vanillate acid	p-hydroxy-benzoic acid	Total acid
(mg L ⁻¹)							
P-H1	1.0 × 10 ⁻²	tu	tu	5.7 × 10 ⁻²	1.6 × 10 ⁻²	tu	8.3 × 10 ⁻²
P-H2	4.5 × 10 ⁻²	tu	4.93	tu	3.3 × 10 ⁻²	tu	5.01
P-H4	6.5 × 10 ⁻²	tu	9.85	tu	3.5 × 10 ⁻²	tu	9.95
P-H5	0.19	tu	10.30	tu	3.6 × 10 ⁻²	tu	10.53
P-H7	0.29	tu	4.48	tu	1.7 × 10 ⁻²	tu	4.79
P-H10	*	*	*	*	*	*	*
P-H14	2.84 × 10 ⁻²	0.15 × 10 ⁻²	0.45 × 10 ⁻²	-	-	0.25 × 10 ⁻²	3.69 × 10 ⁻²
P-H21	5.15 × 10 ⁻²	tu	11 × 10 ⁻²	-	-	0.1 × 10 ⁻²	16.25 × 10 ⁻²
P-H26	7.85 × 10 ⁻²	tu	0.1 × 10 ⁻²	-	-	0.2 × 10 ⁻²	8.15 × 10 ⁻²
P-H30	2.3 × 10 ⁻²	tu	0.01 × 10 ⁻²	-	-	0.2 × 10 ⁻²	2.51 × 10 ⁻²
D-H1	Tu	2.4 × 10 ⁻²	21.05	1.5 × 10 ⁻²	tu	tu	21.09
D-H2	2.2 × 10 ⁻²	1.4 × 10 ⁻²	19.04	1.9 × 10 ⁻²	tu	tu	19.09
D-H4	2.2 × 10 ⁻²	1.4 × 10 ⁻²	12.76	1.4 × 10 ⁻²	tu	tu	12.82
D-H5	0.15	1.3 × 10 ⁻²	17.69	2.5 × 10 ⁻²	1.4 × 10 ⁻²	tu	17.89
D-H7	0.20	2.9 × 10 ⁻²	7.84	5.9 × 10 ⁻²	tu	tu	8.13
D-H10	*	*	*	*	*	*	*
D-H14	7.15 × 10 ⁻²	tu	0.3 × 10 ⁻²	tu	tu	tu	7.45 × 10 ⁻²
D-H21	7.95 × 10 ⁻²	tu	0.2 × 10 ⁻²	tu	tu	tu	8.15 × 10 ⁻²
D-H26	7.75 × 10 ⁻²	tu	0.3 × 10 ⁻²	tu	tu	0.2 × 10 ⁻²	8.25 × 10 ⁻²
D-H30	1.45 × 10 ⁻²	tu	0.1 × 10 ⁻²	tu	tu	0.2 × 10 ⁻²	1.75 × 10 ⁻²
B-H1	4.5 × 10 ⁻²	tu	5.37	1.2 × 10 ⁻²	tu	tu	5.43
B-H2	2.2 × 10 ⁻²	1.4 × 10 ⁻²	16.80	1.4 × 10 ⁻²	tu	tu	16.85
B-H4	Tu	Tu	16.80	1.8 × 10 ⁻²	tu	tu	16.82
B-H5	0.24	0.7 × 10 ⁻²	20.60	1.1 × 10 ⁻²	tu	tu	20.87
B-H7	0.19	1.9 × 10 ⁻²	15.90	1.9 × 10 ⁻²	tu	tu	16.14
B-H10	*	*	*	*	*	*	*
B-H14	2.3 × 10 ⁻²	tu	0.1 × 10 ⁻²	tu	tu	0.1 × 10 ⁻²	2.5 × 10 ⁻²
B-H21	2.75 × 10 ⁻²	tu	Tu	tu	0.1 × 10 ⁻²	tu	2.85 × 10 ⁻²
B-H26	11.35 × 10 ⁻²	tu	0.3 × 10 ⁻²	tu	0.1 × 10 ⁻²	0.2 × 10 ⁻²	11.95 × 10 ⁻²
B-H30	1.85 × 10 ⁻²	tu	0.1 × 10 ⁻²	tu	0.2 × 10 ⁻²	0.3 × 10 ⁻²	2.45 × 10 ⁻²
T-H1	0.18	tu	25.53	tu	9 × 10 ⁻²	tu	25.73
T-H2	3.6 × 10 ⁻²	tu	15.45	tu	1.2 × 10 ⁻²	tu	15.50
T-H4	4.5 × 10 ⁻²	tu	14.33	tu	0.7 × 10 ⁻²	tu	14.39
T-H5	4.4 × 10 ⁻²	tu	16.12	4.4 × 10 ⁻²	0.9 × 10 ⁻²	tu	16.22
T-H7	3.9 × 10 ⁻²	tu	12.32	5.4 × 10 ⁻²	1.1 × 10 ⁻²	tu	12.42
T-H10	*	*	*	*	*	*	*
T-H14	*	*	*	*	*	*	*
T-H21	9.85 × 10 ⁻²	tu	0.2 × 10 ⁻²	tu	tu	tu	10.05 × 10 ⁻²
T-H26	8.45 × 10 ⁻²	tu	0.1 × 10 ⁻²	tu	tu	tu	8.55 × 10 ⁻²
T-H30	1.45 × 10 ⁻²	tu	0.1 × 10 ⁻²	tu	u	0.2 × 10 ⁻²	1.75 × 10 ⁻²

Notes: tu = not detected, B = Peat soil + BPMP, D = Peat soil + Difenconazole, P = Peat soil + Paraquat, T = Peat soil without pesticide application, H = Incubation period (day)

(III), mangan (IV) and sulfate have been finished (Smith *et al.* 2003). This process is mostly influenced by temperature, organic matter content, pH, humidity, and potential redox of the soil (Moore and Dalva 1993).

The CH₄ emissions from peat soil during 30 days of incubation period showed a decreasing trend in each treatment. The wet soil condition during the incubation period, although it was not stagnant, could create a perfect condition for methanogenic bacteria

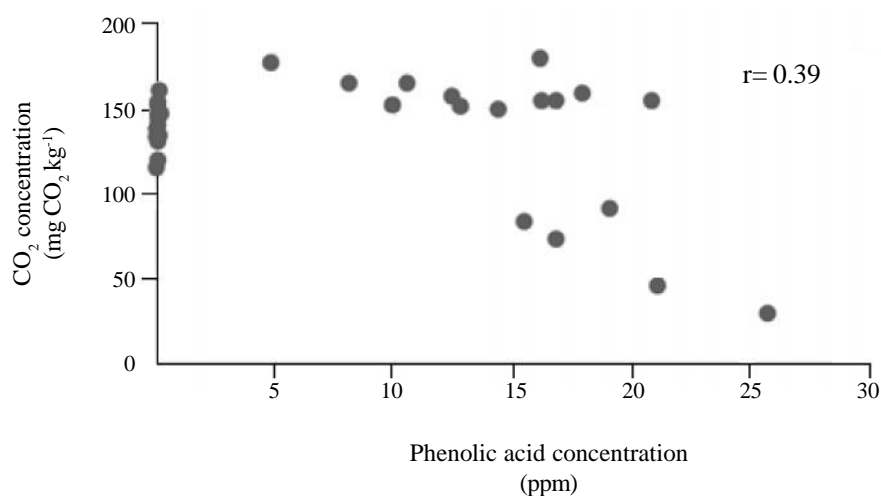


Figure 4. Correlation between cumulative CO₂ emission and phenolic acid concentration in peat soil.

to grow, resulting in CH₄ emissions. In addition, the pH of peat soil (pH 4.5-5 at day 1 until 7 of measurement) was one of the supporting factors for methanogenic bacteria to grow. Especially at the beginning of incubation period, the CH₄ emissions in the soils applied with pesticides were higher than that in the control treatment, although the difference was not significant.

Phenolic Acid Concentrations After Incubation Period

The concentrations of phenolic acids in the peat soil applied with pesticides at 30 days of incubation were in general lower than that at the beginning of incubation periods (Table 4). In addition, the total concentrations of phenolic acids in the soil applied

with pesticides were lower compared to that in the control treatment (without pesticide application). The decrease of phenolic acid concentrations after application of pesticides on peat soil indicated that the oxidation of C derived from phenolic acids has been occurred. The types of phenolic acids identified in the peat soil applied with pesticides is various for each treatment.

In the soil with *paraquat*, *difenoconazole* and *BPMC* applications, all types of phenolic acids can be detected (ferulic acid, syringic acid, sinapic acid, p-coumaric acid, vanillate acid, and p-hydroxy benzoic acid), while in the soil without pesticide application, only 5 phenolic acids can be detected, namely ferulic acid, sinapic acid, p-coumaric acid, vanillate acid and p-hydroxybenzoic

Table 5. Respiration of soil microorganism measured on peat soil applied with pesticides.

Treatment	24 hours	48 hours	96 hours	120 hours	168 hours	Average
	mg C-CO ₂ kg ⁻¹ day ⁻¹					
<i>Paraquat</i>	25.61	24.44	18.92	11.31	12.22	18.50
<i>Difenoconazole</i>	20.95	24.44	18.77	10.89	11.47	17.30
<i>BPMC</i>	28.52	20.37	19.21	10.64	12.39	18.23
Control	13.39	22.70	18.62	10.64	10.97	15.26

Table 6. pH of peat soil applied with pesticides.

Period (hour)	Treatment		
	<i>Paraquat</i>	<i>Difenoconazole</i>	<i>BPMC</i>
24	4.90	5.05	5.00
48	4.30	4.50	4.80
96	4.40	4.50	4.50
120	4.77	4.65	4.70
168	4.90	4.00	4.80

acid. The differences may be due to the transformation of phenolic acid into another form of phenolic acid. The different active ingredients contained in each pesticide will bring out the different phenolic acid transformation processes. The result is in accordance with the types of phenolic acids initially identified in the peat soil, *i.e.* ferulic acid, sinapic acid, and vanillate acid (Table 2), and subsequently after incubation, other phenolic acids were detected such as syringic acid and p-coumaric acid. According to Stevenson (1994), the transformation process of phenolic acids into different forms is mediated by microbes, then the phenolic acids are changed into quinon by phenoloxidase enzyme, and the phenolic acids will be degraded into simple organic compounds, such as humic acid and fulvic acid. The study of Gupta *et al.* (1986) showed that the sinapic acid degradation is mediated by *Rhodotorula glutinis*, which produces syringic acid, 3-methyl gallate acid and 2,6-dimethoxy-1,4-benzoquinone. The study of Anwar *et al.* (2004) about the oxidation of peat soil using CuO (cupric oxide) observed that p-hydroxybenzoic acid was firstly decomposed, followed by syringic acid and vanillate acid. Similar pattern was also observed in the current study, particularly in the peat soil without pesticide application (control treatment) and peat soil applied with paraquat. This result confirmed that the different pesticide active ingredients applied on peat soil will result in the different phenolic acid transformations. This difference is probably related to the different impacts of soil microbial activity on the different pesticide active ingredients.

Relationship between CO₂ Emission and Phenolic Acid Concentration

The coefficient of the correlation between CO₂ emission and phenolic acid concentration was 0.39 (Figure 4). The result indicated that CO₂ emission is weakly correlated to phenolic acid concentration; the higher CO₂ emission, the lower phenolic concentration is (Sugiyono 2007). The points in the figure showed that the increase of CO₂ emission could be originated from the oxidation of phenolic acid C.

The initial concentration of sinapic acid measured in the peat soil was very high, *i.e.* 86.47 mg L⁻¹ (Table 2), however, after incubation the concentrations of sinapic acid in the peat soil without pesticide application decreased up to 1.75 x 10² mg L⁻¹ (Table 4). Furthermore, the concentrations of phenolic acids in the peat soil applied with pesticides (paraquat, difenoconazole and BPMC) also decreased after incubation. According to Stevenson

(1994) decomposition and degradation of phenolic acids will produce CO₂ and H₂O as well as phenolic acid in different forms. The degradation process of phenolic acids is called demethoxylation process and the unveiling of ring structure. The unveiling of ring structure causes decomposition that produces CO₂, CH₄, and H₂O, depending on soil redox potential. Therefore, we may conclude that the CO₂ emissions released by peat soil in each treatment are from degradation and decomposition of phenolic acids and the active ingredients of pesticide applied, and microorganism respiration.

The results of respiration measurements showed that the amount of CO₂ released by respiration of soil microorganism decreased during the incubation period (Table 5). The phenomenon is probably caused by the decrease of carbon source in the soil during the incubation period. The study of Arimurti (1997) reported that the respiration of soil microorganism in mineral soils taken from several land uses in West Kalimantan is about 8.80 - 11.08 mg C-CO₂ kg⁻¹ day⁻¹. In addition, the study of Adhayanti (1997) showed a lower microorganism respiration measured in mineral soils taken from several land uses in Lampung, *i.e.* 4.57-8.57 mg C-CO₂ kg⁻¹ day⁻¹. Based on the results of both studies, both mineral soil and peat soil have no significant different in microorganism respiration level.

pH of Peat Soil

The pH of peat soil applied with pesticides showed a constant trend, *i.e.* 4.30 - 5.05 (Table 6), indicating that the application of pesticides on peat soil did not change the soil pH. The result of current study is in contrast with the study of Usui (2011) that showed that the application of herbicide (HA-ACN, (2-amino-3-chloro-1,4-naphthoquinon) 9%) on paddy soil increased the soil pH and decreased the CO₂ emissions along with the accumulation period. On the other hand, according to Bennicelli (2008), the application of the pesticide (Glyphospat) on Histosol increased the dehydrogenase enzyme activity, pH, Eh, and CO₂ production after 42 days of incubation.

CONCLUSIONS

The application of pesticides on peat soil, especially paraquat has increased the CO₂ emissions, while the application of *difenoconazole* and BPMC has decreased the CO₂ emissions. In addition, the application of pesticides decreased the amount of phenolic acids in peat soils. The CO₂ emissions were expected resulting from the oxidation of phenolic acid C and the active ingredients of

phenolic acid C and the active ingredients of pesticides applied. On the other hand, the application of pesticides on peat soil showed no significant effect on CH₄ emissions.

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