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Response of Rice and Carbon Emission to Application of Ameliorant Dregs in The Peat Soil with Saturation and Unsaturation Condition

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***Abstract*— Fertility of peat land is very poor and makes it not suitable for crop without any high input. This condition was indicated by the very high soil acidity (low pH), low availability of macro (N, K, Ca and P), and micro (Cu, Zn, Mn and Bo) nutriens and high cation exchange capacity (CEC) but low base saturation (BS), the presence of toxic organic acid. The main organic acids, as a result of lignin biodegradation and the sources of C-release, are of aromatic group consisting mainly of derivate phenolic acids. The peat soil material was taken at depths from 0 to 30 cm, with weathering rate saprik and dregs from Indah Kiat Pulp and Paper at Perawang, Riau. These experiments using split plot design, the main plot is the condition of the water (unsaturated and saturated) and the subplot is ameliorant dregs consisting of 4 levels (0, 10, 15 and 20 ton ha-1), each combination was repeated 4 times. The activities were focused on the interaction of water condition and ameliorant dregs, and its influences to growth and yield of rice, C-emission (CO2 and CH4). The results showed that the aplication of dregs improves plant growth and increase the yield of rice (weight of dry milled grain) compared without dreg both at unsaturated condition and saturated conditions. The Cabon-release in the forms of CO2 and CH4 fluxes in saturated conditions is smaller than unsaturated conditions. The application dreg 10 t ha-1 increase the number of productive tillers and the weight of milled rice about 35 and 75% compared without dreg on saturated condition, whereas the increase is greater unsaturated conditions about 63 and 80%. The application of dregs 10 t ha-1 in saturated condition can reduce CO2 and CH4 emissions about 18.19% and 93.71% compared without dreg, otherwise the application dreg 10-20 t ha-1 increase the production of CO2 and CH4 in unsaturated conditions.**

***Keywords*— PutRice, peat soil, ameliorant dregs, CH4 and CO2 emission, saturated, unsaturated condition**

I. INTRODUCTION

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Indonesia has 188 milion ha land, including peatland about 20.9 million ha, (Wahyunto et al., 2005). Peatland fertility is very poor and makes it not suitable for crop without any high input. This condition was indicated by the very high soil acidity (low pH), low availability of macro (N, K, Ca, and P), and micro (Cu, Zn, Mn and Bo) nutriens and high cation exchange capacity (CEC) but low base saturation (BS), and the presence of toxic organic acid (Simbolon, 2009).

The main organic acid, as a result of lignin biodegradation and the sources of C-release, are of aromatic group consisting mainly of derivate phenolic acids. The concentration of such organic acids ranging from the highest to lowest is as follows: ferulic acid ≈ synapic acid > p-coumaric acid > p-hydroxybenzoic acid > vanilic acid > syringic acid (Sabiham, 2010). Phenolic acids are more phytotoxic for plants and causes stunted plant growth (Tsutuski, 1984; Stevens, *et al.*, 1994; Dohong and Sabiham, 2001), influence the biochemical and physiological processes of plants and nutrients uptake by plant (Driessen, 1978).

The drying and wetting processes on the peat materials affected the stability of organic acids, wich was indicated by loss of C- through CO_2 and CH_4 releases. The release of CO_2 and CH_4 from fibric peat was higher than that from hemic and sapric peats (Sabiham, 2010). Yagi and Minami (1990) reported that the highest rate of CH_4 emission during cultivation period (44.8 g CH_4 m^{-2}) was in rice field consisting peat.

The drainage of peat release oxigen (O_2) into the surface, with promotes decomposition. Emission estimates, for land use systems with a depth of 60 cm drainage is around 55 Mg CO_2 ha^{-1} $year^{-1}$ (Hooijier *et al.* 2010), based on a linear relationship between depth of water table and emissions.

Phenolic acids and C-release could be reduced to the granting of polivalen cations such as Al, Fe, Cu, Zn and Mn, thus reducing the bad effects. Where the stability of complexes between humic acid-metal getting weaker in the order of $Al^{3+} > Fe^{3+} > Cu^{2+} > Mn^{2+} > Zn^{2+} >> Mg^{2+} > Ca^{2+}$ (Tan, 2003). Nelvia (2009) reported that application of ameliorant Fe^{3+} and rock phosphates containing high Fe cation increased the stability of peat soil and reduced the carbon loss around 1.7 Mg of C ha^{-1} $year^{-1}$ (64%) in 5 cm of saturated condition, 1.3 Mg of C ha^{-1} $year^{-1}$ (58%) in two times of field capacity condition and 1.0 Mg of C ha^{-1} $year^{-1}$ (41%) in field capacity condition.

Dregs is the precipitate formed from liquid clarification process in the pulp mill recovery and no longer useful for the pulping process. Nelvia *et al.* (2008) reported that dregs contain polivalen cations such as Al, Fe, Cu, Zn, Mn, Mo, and also contains other nutrients such as P, K, Ca,and Mg, the application of 15 tons dregs / ha of peatlands increases stover dry weight, dry weight of corn kernels per ear, 1000 grain weight seeds respectively 127%, 35% and 40% compared without dreg. This research aimed to study the potential of using dregs to reducing C-release (CO_4 and CH_4) and increasing growth and yield of rice on peat soil in unsaturation and saturation.

II. Material and Methods

This research was conducted from July to December 2010 in a greenhouse of Agriculture Faculty of Riau University. Soil chemical properties of peat soils materials and dregs was analyzed at soil laboratory of Soil Research Bogor. The peat soil material was taken at depths from 0 to 30 cm, with weathering rate saprik and dregs from Indah Kiat Pulp and Paper (IKPP) at Perawang, Riau.

The peat soil material was taken at depths from 0 to 30 cm, with weathering rate saprik at Kerumutan village, Pelalawan Regency, Riau Province, while dregs from from Riau Indah Kiat Pulp and Paper (IKPP) at Perawang, Riau, dregs chemical properties can be seen in Table 1. These experiments using split plot design, the main plot is the condition of the water (unsaturated and saturated) and the subplot is ameliorant dregs consisting of 4 levels (0, 10, 15 and 20 ton ha^{-1}), each combination was repeated 4 times.

Implementation of research: peat soil material equivalent of 2 kg dry weight oven 105 ^oC and drges was mixed with appropriate treatment and then incubated at saturation and unsaturation condition for 1 month and then the IR-64 variety rice was planted. Basic fertilizers: Urea, TSP, and KCl each with a dose of 350, 150, and 150 kg ha^{-1} respectively.

To measure the flux of CO_2 and CH_4, a chamber for trapping the gases made from the fiberglass with the size of 0.75 m x 0,20 m x 0,20 m, was used Syringes were used to take the samples of gases from the chamber. The samples were then put on the vacuum bottles. In this research, Gas Chromatography Shimadzu 14-B and Chromatopac Shimadzu C-R6A were used to determine the CO_2 and CH_4 emissions. The emissions were calculated by using following equation (Boer *et al.*, 1996):

$$\Phi_M = \{(\delta[CO_2/CH_4]\delta t \times h_U \times 16.123\ (44.01) \times 273.2 \times (60/22.410))/(t_U + 273.2)\ mg\ m^{-2}\ h^{-1}\}$$

Where: $\delta[CO_2/CH_4]\delta t$ = change of the concentrations of CO_2 and CH_4 in chamber after the periode of t minute (s); h_U = the height of chamber; t_U = the average of air temperature in chamber; Value of 16.123 = the weight of CH_4 molecule, 44.01 = weight of CO_2; Value of 273.2 = temperature in Kelvin; 22.41 = volume of gas molecule; and Value of 60 meants 60 minutes (1 hour). Other parameters were observed between: plant height 42 days after planting, the maximum tillers and productive tillers number, straw dry weight and grain dry milled weight.

III. Results and Discussion

A. Chemical Composition of Peat

Several chemical characteristics of peats (Table 1) interesting to discuss. Although the total N is high, but the C/N ratio is very high, this means that N is a structural constituent of peat organic matter that is available N is low, thereby becoming a limiting factor for plant growth. cation exchange capacity (CEC) value is very high, but base saturation (BS) is very low, thus inhibiting the provision of nutrients, mainly K, Ca and Mg for plants.

The situation got worst because exchangeable Na, K, Ca and Mg is very low and therefore inhibit the growth and yield. Availability and total micro nutrient content are very low except for Fe is quite high, causing micro nutrient deficient for plants. According to Simbolon (2009) peat soil pH is very low, the availability of macro (N, P, K, Ca and Mg) nutrient are low and deficient micro (Cu, Zn, Mn, Fe, B and Mo) nutrient, CEC is very high but BS is low. Where the availability of Cu is the lowest compared to other micro nutrient because the Cu bounds to organic compounds functional groups such as carboxyl (COOH) and phenolic (-OH) to form organo—cation complex of Cu (chelate) that are not available for plants.

Several chemical charateristics (macro and micro nutrient) contained in drges quickly available in peat, because hasil the extraction with 2% citric acid is almost equal to the extraction with mineral acids ($HClO_4$ and HNO_3 pa) (Table 2). Dissociation of H ions from organic compounds cause the concentration of H^+ ions on peat soil is very high, H^+ ions can hydrolyze dregs so that it dissolves quickly. Results of analysis of havy metal content in the drges (Pb, Cd, As, Hg, Co, Ni, Cr, Ag, Sn and Mo) total are very low (Table 3), are not including those identified B3 waste so it can be dumped in landfill light weight category.

TABLE I
CHEMICAL CHARACTERITICS AND ASH CONTENT OF PEAT SOILS USED IN THIS RESEARCH

Chemical characteristics	Value	Chemical characteristics and ash content	Value
pH H_2O (1:5)	3.2	Base Saturation (%)	6
pH KCl (1:5)	3.0	Micro nutrient (Extract. DTPA)	
Organic-C (g kg^{-1})	437.3	Fe (µg/g)	475
Total-N (g kg^{-1})	6.5	Mn (µg/g)	1
C/N ratio	67.28	Cu (µg/g)	2
Exc.Ca (cmol (+)/kg)	2.27	Zn (µg/g)	2
Exc.Mg (cmol (+)/kg)	0.68	Micro nutrient (Extract. HNO_3	
Exc.K (cmol (+)/kg)	0.22	+ $HClO_4$ pa)	
Exc.Na (cmol (+)/kg)	0.26	Fe (µg/g)	3606
P_2O_5 (µg/g) (Bray I)	135.4	Mn (µg/g)	12.3
P_2O_5 (mg/100g) (HCl 25%)	32	Cu (µg/g)	3.1
CEC (cmol (+)/kg)	72.45	Zn (µg/g)	4.8
		Ash content (%)	15.89

TABLE III
CHEMICAL CHARACTERIZATION AND MOISTURE OF DREGS

Chemical characteristics	**Value**	**Chemical characteristics and ash content**	**Value**
pH H_2O (1:5)	9.3	Macro nutrient (Extract. Citric Acid 2%)	
Macro nutrient (Extract. $HClO_4$ & HNO_3 pa)		P_2O_5 (g kg^{-1})	1.8
P_2O_5 (g kg^{-1})	2.0	K_2O (g kg^{-1})	3.1
K_2O (g kg^{-1})	3.1	CaO (g kg^{-1})	409.7
CaO (g kg^{-1})	410.3	MgO (g kg^{-1})	23.2
MgO (g kg^{-1})	23.9	Na (g kg^{-1})	25.9
Na (g kg^{-1})	26.8	S (g kg^{-1})	
S (g kg^{-1})	7.2	Micro nutrient (Extract. Citric Acid 2%)	6.4
Micro nutrient (Extract. $HCLO_4$ & HNO_3 pa)		Fe (µg g^{-1})	3244
Fe (µg g^{-1})	5000	Mn (µg g^{-1})	914
Mn (µg g^{-1})	989	Cu (µg g^{-1})	105
Cu (µg g^{-1})	127	Zn (µg g^{-1})	206
Zn (µg g^{-1})	224	moisture (%)	15

TABLE IIIII
HEAVY METAL CONTENT OF DREGS

Chemical characteristics	**Value**	**Chemical characteristics**	**Value**
Extraction ($HClO_4$ + HNO_3 pa)		Extraction (citric acid 2%)	
Pb (µg g^{-1})	8.9	Pb (µg g^{-1})	0.1
Cd (µg g^{-1})	0.2	Cd (µg g^{-1})	nm
As (µg g^{-1})	3.8	As (µg g^{-1})	nm
Hg (µg g^{-1})	0.23	Hg (µg g^{-1})	nm
Co (µg g^{-1})	1.7	Co (µg g^{-1})	1.5
Ni (µg g^{-1})	98.6	Ni (µg g^{-1})	98.5
Cr (µg g^{-1})	167	Cr (µg g^{-1})	120
Se (µg g^{-1})	355	Se (µg g^{-1})	169
Ag (µg g^{-1})	nm	Ag (µg g^{-1})	nm
Sn (µg g^{-1})	nm	Sn (µg g^{-1})	nm
Mo (µg g^{-1})	nm	Mo (µg g^{-1})	nm

B. *The effect of application of ameliorant dregs in the peat at saturation and unsaturation condition on growth and yield of rice*

The aplication of dregs improves plant growth (plant height, number of maximum tillers, number of productive tillers and weight of dry straw) and increase the yield of rice (weight of dry milled grain) compared without dreg both at unsaturated condition and saturated conditions (Table 4 and Fig. 1). Rice can not grow well in peat, which is not applied ameliorant dreg, the cause is the low nutrient availability and high content of phenolic acids that are toxic to plants. Tim Sintesis Kebijakan (2008) reports that rice plants grown in peat soil with a thickness of over 2 m deficient Cu failed to form a grain. The peat composition is dominated by lignin of 65% to 80% and 78% to 93% for the peats of Jambi and Central Kalimantan respectively (Sabiham, 2010), and 71,46% for the peats of Riau (Nelvia, 2009). Orlov (1995) showed the processes of lignin disintegration that result in several derivate phenolic acids. Phenolic acids are more phytotoxic for plants and causes stunted plant growth (Tsutuki, 1984; Stevens, *et al.*, 1994; Dohong and Sabiham, 2001), influence the biochemical and physiological processes of plants and nutrients uptake by plant influence the biochemical and physiological processes of plants and nutriens uptake by plent (Driessen, 1978). Tsutsuki *et al.* (1994) stated that the concentration of phenolic acids at the range of 0.6 to 3.0 mM could hamper the root growth of rice up to 50%. Todano *et al*. (1992) reported that derivate phenolic acids, such as ferulic, synapic, p-cumaric, and p-hydroxybenzoic acids are phytotoxic for rice, particularly during the first stage of plant growth. He also mentioned that ferulic acid in peat is more toxic compared to the other derivate phenolic acids.

TABLE IVV
THE EFFECT OF AMELIORANT DREGS IN THE PEAT ON THE PLANT HEIGHT, MAXIMUM AND PRODUCTIVE TILLERS NUMBER AND WEIGHT OF DRY STRAW AND MILLED DRY GRAIN OF RICE

Water condition	**Dregs (ton ha^{-1})**	**Plant height (cm)**	**maximm tillers (number pot^{-1})**	**productive tillers (number pot^{-1})**	**dry straw (g pot^{-1})**	**milled dry grain (g pot^{-1})**
Saturated	0	47 c	20 d	17 c	20 c	20.0c
	10	66 a	33 c	23 bc	42 b	35.4a
	15	67 a	45 ab	31 a	61 a	54.8b
	20	67 a	47 a	30 a	62 a	54.9b
Un-saturated	0	52 b	20 d	19 c	27 c	29,8 c
	10	64 a	36 abc	31 a	43 b	53,7 b
	15	68 a	35 bc	28 ab	46 b	53,0 b
	20	66 a	36 abc	28 ab	52 b	45.3 a

Note: The numbers in the same columns which followed the same lowercase letter are not significantly different at α 5% DNMRT test.

a. Unsaturation condition

b. Saturation condition

Fig. 1. The growth of rice at vegetative and generative phase in unsaturated (a) and saturated condition (b)

The application dreg 10 t ha^{-1} increase the maximum number of tillers, number of productive tillers, straw dry weight and the weight of milled rice by 65, 35.29, 110 and 75%, respectively compared without dreg on saturated condition, whereas the increase is greater unsaturated conditions about 80, 63, 59 and 80%, respectively (Table 4). This is due to the improvement of the condition of the peat soil chemistry by ameliorant dreg in the form increase nutrient availability and decreasing the solubility of phenolic acids. Its caused by the dregs contain macro (P, K, Ca, Mg, S) and micro (Fe, Cu, Zn, Mn, Mo) nutrients or polivalen cations and quickly available in peat (Table 2). Reduced solubility of phenolic acids occurs due to the formation of complex compounds of phenolic acids with cations Fe, Cu, Zn, Mn, Ca and Mg are dissolved from the dreg. Sabiham (2010) reported that the concentration of derivate phenolic acids namely: ferulic, syanapic, p-cumaric, vanilic, syringic and p-hydroxybenzoic acids in peats decreased with the addition of mineral soil or basic slag, or the ombination of both materials.

C. The effect of application of ameliorant dregs in the peat soil at unsaturation and saturation condition on carbon emission

The Cabon-release in the forms of CO_2 and CH_4 fluxes in saturated conditions is smaller than unsaturated conditions, the application of dregs 10 t ha^{-1} in saturated condition can reduce CO_2 emissions about 18.19% and CH_4 emissions about 93.71% compared without dreg, otherwise the application dreg 10, 15 and 20 t ha^{-1} in unsaturated conditions increase the production of CO_2 and CH_4 (Table 5). Unsaturated conditions (aerobic) conditions where the peat is available high due to the high diffusion, so the more active microorganisms both the type and amount of the anaerobic conditions, the result would accelerate the process of decomposition of organic matter. While in saturated conditions (anaerobic) only anaerobic bacteria can live, thus CO_2 as a result of respiration and decomposition of organic matter will be higher in unsaturated than saturated conditions. Boer *et al.* (1996) reported that the amount of CH_4 emission rate depends on soil water conditions, flooded peatlands emit CH_4 greater than the land is not flooded. Research by Sabiham and Sulistyono (2000) in the laboratory showed that the highest CO_2 production obtained in aerobic incubation and significantly different with anaerobic incubation, while the highest CH_4 production was obtained on anaerobic incubation and significantly different with aerobic incubation.

TABLE V
THE EFFECT OF APPLICATION OF AMELIORANT DREGS IN THE PEAT SOIL AT SATURATION AND UNSATURATION CONDITION ON THE CO2 AND CH4 PRODUCTION

Water condition	Dregs (ton ha^{-1})	CO_2 production (mg pot^{-1} h^{-1})	CH_4 production (mg pot^{-1} h^{-1})
saturation	0	8.12 a	29.70 a
	10	6.64 b	1.87 c
	15	8.38 a	3.07 bc
	20	7.31 b	2.68 bc
unsaturation	0	18.72 b	6.69 b
	10	29.71 b	7.61 b
	15	52.57 a	19.39 a
	20	15.64 b	5.78 b

Note: The numbers in the same columns which followed the same lowercase letter are not significantly different at α 5% DNMRT test

The decrease in emissions of CO_2 and CH_4 in the saturated condition by administering dreg 10 t ha^{-1} is because dreg containing polyvalent cations and release such as Fe and Cu to the soil (Table 2). Fe and Cu cations form complex compounds between organic compounds with Fe or Cu cations, that is stable so it can not be decomposed by microbes. Giving dreg with the higher dose (15-20) has stimulate more rapid decomposition of organic matter, especially in unsaturated conditions, while the formation of complex organic compounds-metal running over time, The result is an increase in emissions of CO_2 and CH_4. Research Sabiham and Sulistyono (2000) in the laboratory showed that administration of Fe^{3+} cations as much as 5% maximum erapan can reduce 22.94% 23.01% CO_2 and CH_4 in the peat soil of the area Dendang Jambi and 27.67% and 32.97% CO_2 CH_4 in the peat soil of the Sampit, Central Kalimantan. The addition of 15 and 30 g of $Fe(OH)_3$ per kg of soil to lower the total CH_4 emissions by 43% and 84% during the growth of rice (Jackel and Schnell 2000). Where the stability of complexes between humic acid-metal getting weaker in the order of $Al^{3+} > Fe^{3+} > Cu^{2+} > Mn^{2+} > Zn^{2+} >> Mg^{2+} > Ca^{2+}$ (Tan, 2003).

IV. CONCLUSIONS

The application of dregs improves plant growth and increase the yield of rice compared without dreg both at unsaturated condition and saturated conditions. The application dreg 10 t ha^{-1} increase the maximum number of tillers, number of productive tillers, straw dry weight and the weight of milled rice by 65, 35, 110 and 75%, respectively compared without dreg on saturated condition, whereas the increase is greater unsaturated conditions about 80, 63, 59 and 80%, respectively.

The Cabon-release in the forms of CO_2 and CH_4 fluxes in saturated conditions is smaller than unsaturated conditions, the application of dregs 10 t ha^{-1} in saturated condition can reduce CO_2 and CH_4 emissions about 18.19% and 93.71% compared without dreg, otherwise the application dreg 10-20 t ha^{-1} increase the production of CO_2 and CH_4 in unsaturated conditions.

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