Methane emission mitigation in paddy field utilizing rice husk biosilica

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Abstract

The increasing of paddy production has environmental impact because paddy cultivation contributes to 46.2% of the total greenhouse gas emissions from agriculture. The paddy cultivation emission amounted to 76% of methane. Meanwhile, the grain produced by paddy consists of 16.3% to 28% husk with 18 to 22.3% silica. Silica contained in the soil can increase the oxidation power of paddy root, thus it will reduce methane emissions. The objective of this research was to evaluate the reduction of methane emission from paddy field by using silica from rice husk. This research used an experiment with randomized block design based on eight treatments with three repetitions. The dose of biosilica was equal to 200 kg ha^{-1} of ameliorant in the form of ash, biochar, and compost. The methane analysis was carried out in 1, 5, 8, 12, and 15 weeks after planting. The methane was analized by GC with FID. Results showed that the ash produced from rice husk was the best single source of biosilica in paddy soil that can reduce methane emissions by 80.75%. The composition of ash, biochar, and compost (1:1:1) could increase the paddy growth and paddy production and reduce methane emissions effectively. The methane emission was reduced by adding silica to the soil through the dissolved silica mechanism. The dissolved silica increased pH and the root oxidation power of paddy.

Keywords: paddy field; husk; biosillica, emission; methane

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Introduction

Husk is a solid agricultural waste with large amount especially in rice supply areas during harvest time (Guntur, 2010), and it has not been used maximally (Ginanjar et al., 2014). Open burning of husk is bad for the environment, because burning of husk will form crystalline silica reaching 87% to 97% (Handayani et al., 2014). Husk contains high portion of silica ranging from 18% to 22% (Agung et al., 2013). If it is not managed properly, husks can cause pollution (Zhang et al., 2015).

Intensive rice cultivation for long period causes silica deficiency (Thilagan et al., 2014). Rice plants absorb silica in very large quantities during growing season so that the availability of silica in the soil is decreased (Bimasri et al., 2018). The application of silica on rice field can increase the growth and production of rice plants. Giving silicon fertilizer with a dose of 160 to 200 kg ha^{-1} can

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increase rice production by 2.02 tons ha^{-1} (Yasari, 2012).

The level of dissolved silica in soil solution affects the increase in soil pH and plant silica absorption (Yohana et al., 2013). The availability of silica in the soil can reduce the availability of Al, Fe and Mn which are toxic to plants (Dubey, 2014). Rice plants that get sufficient supply of silica are more resistant to biotic and abiotic pressures, do not collapse easily (Meharg and Meharg, 2015), and absorb more of nitrogen, phosphorus, and potassium (Akter and Shirin, 2012).

Rice plants release methane into the atmosphere which is formed in their root area due to root exudates (Mitra et al., 2014; Wiharjaka and Sarwoto, 2015). Rice cultivation contributes to 46.2% of greenhouse gas emissions from the agricultural sector (Indonesian Ministry of Environment, 2010). Methane emissions has 21 times the global warming potential of CO_2 (Panjaitan et al., 2015). On the other hand, silicate fertilization significantly decreases methane emission (Yan et al., 2015) as it can increase soil pH (Yanai et al., 2016). The application of silicate fertilizer can be an option to mitigate the methane emission because silica can increase oxygen levels in the rice root area (Dubey, 2014). This research was aimed to evaluate the reduction of methane emission from paddy field by application of silica from rice husk.

Material and Methods

This research was carried out in an irrigated paddy field which has been utilized for rice cultivation more than 80 years in F Trikoyo Village Musi Rawas Regency, South Sumatera Province Indonesia (S3°10′57.522″; E 102°56′45.1896″). The experiment was arranged in Randomized Block Design. The biosilica of rice husk applied was equivalent to 200 kg $ha^{-1}$of ameliorant such as ash, biochar, and compost. The experiment was conducted with 8 (eight) treatments and 3 replications for each. The treatment consisted of: 80.65 g ash (B1), 213.79 g biochar (B2), 336.13 g compost (B3), 40.33 g ash + 106.90 g biochar (B4), 40.33 g ash + 168.07 g compost (B5), 106.90 g biochar + 168.07 g compost (B6), 26.88 g ash + 71.26 g biochar + 112.04 g compost (B7), and a control group without silica application. There were 24 plots (2 x 2 m) in total. Every plot was planted with Mekongga variety. The biosilica was implemented 7 days before planting and the methane was sampled by a 40 x 40 x 100 cm lid. The seedlings were 21 days old during transplanting at 25 cm x 25 cm distance. The fertilizers used were 114.5 kg ha^{-1} N, 58.5 kg ha^{-1} P_2O_5, and 22.5 kg ha^{-1} K_2O. Rice plants were harvested 102 days after transplanting. The observed variables were plant height, number of productive tillers, maximum number of tillers, and the production dry grain per hectare. The gas was extracted 5 times: 1) early vegetative stage, 2) late vegetative stage with maximum number of tiller growth, 3) primordial stage, 4) grain maturation stage, and 5) after harvest. Methane contents were measured through Shimadzu GC-8A Chromatography Gas equipped by a flame Ionization detector (FID).

The flux of methane of a paddy soil was calculated based on the IAEA equation (1993).

$$F = \frac{dc}{\mathrm{dt}} x \frac{\mathrm{Vch}}{Ach} x \frac{\mathrm{mW}}{mV} x \frac{273.2}{273.2 + T}$$

where F is CH_4 gas flux (mg $hour^{-1}$ m^{-2}), dc / dt is concentration difference in CH_4 per time (mg kg^{-} $hour^{-1}$), Vch is volume of the box (m^3), Ach is the area of the box (m^2), mW is molecular weight of CH_4 (g mol^{-1}), mV is the volume of molecule determination CH_4 (22,411 L mol^{-1}), T is the average temperature during sampling taken (°C), and value 273.2 is the set of kelvin temperature.

According to Setyanto (2004), the amount of methane gas emissions produced in one hectare is formulated as follows:

$$\mathrm{E\,CH4} = 1 + \frac{F1 + F2 + F3}{(LS - N)} x\,(-N) x\ \frac{10.000\ m^2}{1.000.000\ \mathrm{kg}}$$

Table 1
Soil chemical properties of paddy field after treatment

Treatement	pH H_2O	C-organic (g kg^{-1})	N-total (g kg^{-1})	P-Supply (mg kg^{-1})	Fe (mg kg^{-1})	Al-dd (cmol kg^{-1})
Control	5.38	29.71	3.33	5.25	3.66	0.40
B1	5.72	31.94	3.70	8.70	2.17	0.12
B2	5.57	30.46	3.42	7.35	2.47	0.16
B3	5.55	33.43	3.70	8.55	2.66	0.16
B4	5.51	32.31	3.37	6.75	2.72	0.20
B5	5.45	33.06	3.53	5.70	2.54	0.32
B6	5.52	31.94	3.14	7.80	2.25	0.24
B7	5.41	36.03	4.08	7.50	4.49	0.32
Average	5.53	32.74	3.56	7.49	2.76	0.22

Table 2
The amount of dissolved silica of soil in each treatment

No.	Treatment	Dissolved silica (mg kg^{-1})	The amount of inceased silica (mg kg^{-1})	Percentage of inceased silica (%)
1.	B1	170.33	150.66	765.94
2.	B2	78.67	59.00	299.95
3.	B3	109.67	90.00	457.55
4.	B4	94.67	75.00	381.29
5.	B5	120.00	100.33	510.07
6.	B6	87.00	67.33	342.30
7.	B7	100.33	80.66	410.07
	Average	108.67	89.00	452.45

Table 3
Chemical content of ash, biochar, and compost

No.	Chemical content	Unit	Ash	Biochar	Compost
1.	Total Silica	%	99.20	37.42	23.80
2.	Dissolved Silica	mg kg^{-1}	26.00	10.77	22.80
3.	C-Organic	%	0.33	10.02	33.22
4.	N-Total	%	0.16	1.03	1.09
5.	C/N Ratio	-	2.06	9.73	30.48

where E CH_4 is the amount of CH_4 emissions (kg hour^{-1} ha^{-1}), F1, F2, F3, Fn are the cumulative flux of CH_4 in each observation (mg hour^{-1} m^{-2}), N is the seed age (days), LS is the last day of CH_4 gas collection (days), and H is the plant life between planting and harvest (days).

The data were analyzed using analyses of variance (ANOVA) and honestly significant difference (HSD) test at 1%.

Results

In the paddy fields that biosilica of rice husks were applied, soil pH, organic C, total N, and available P increased while the solubility of Fe and Al in the soil reduced. Soil pH increased from 5.38 to 5.53 (by 0.15%). The highest increment of pH was found in the soil applied with the ash, from 5.38 to 5.72 (Table 1). Rice husk biosilica increased the amount of dissolved silica (Table 2). The largest increase of silica dissolved in the soil was in the biosilica provision of paddy husk ash because of the highly dissolved silica (Table 3).

The provision of rice husk ash biosilica (B1) showed significant difference in B3 and control, but there was no significant difference in B2, B4, B5, and B6 (Table 4 and Fig. I). The highest emissions in paddy soils per hectare were in the control treatment with 6.48 kg^{-1} ha^{-1} (Table 5) while the lowest emissions were from biosilica of

Table 4
Methane emissions of each treatment and each observation period

Treatment	Methane emission (mg hour^{-1} m^{-2}) on				
	First growth (1 wat)	Maximum tiller (5 wat)	Grain filling (8 wat)	Grain maturation (12 wat)	After harvest (15 wat)
Control	132.12 a	193.04 a	193.69 a	94.92 c	78.51 a
B1	25.65 b	40.91 c	42.33 c	14.11 a	10.30 c
B2	34.63 b	44.74 c	50.03 c	20.52 a	16.73 c
B3	125.70 a	150.57 a	155.98 a	87.22 c	75.93 ab
B4	37.15 b	48.58 c	53.87 c	25.65 a	20.59 c
B5	48.74 b	60.08 c	67.98 bc	32.92 a	25.73 c
B6	97.49 ab	104.83 b	109.03 b	71.83 bc	57.92 b
B7	47.46 b	57.53 c	60.29 c	28.22 a	21.88 c
BNJ 0,01	76.15	42.14	42.54	28.13	20.45

The numbers followed by the same letter in the same column are not significantly different at 1%. wat = week after planting

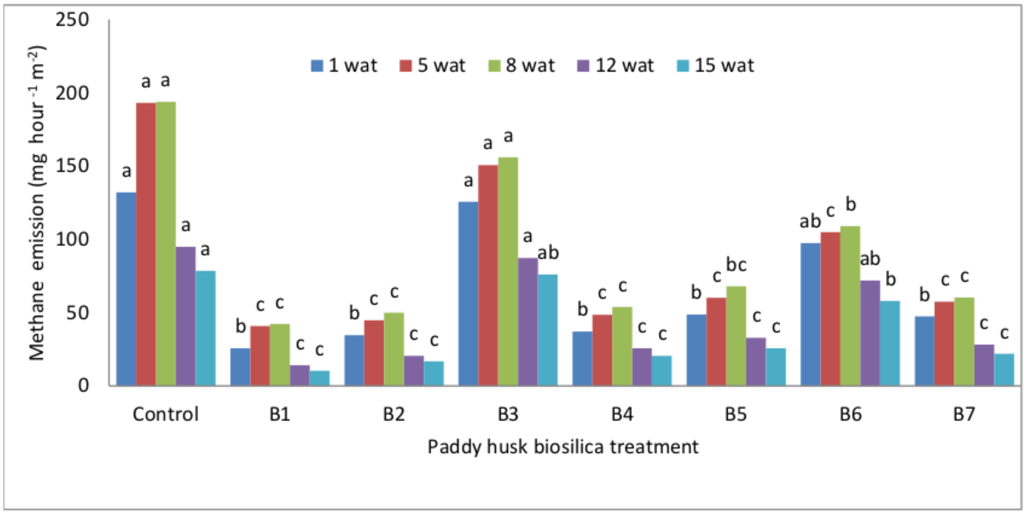

Fig. I. Methane emissions of each treatment and each observation period.

Table 5
The reduction of methane emissions in each treatment

Treatment	Methane emission (kg hour^{-1} ha^{-1})	The reduction emission (%)
Control	6.48	-
B1	1.25	80.75
B2	1.56	75.92
B3	4.40	32.15
B4	1.39	78.53
B5	2.20	65.99
B6	3.22	50.37
B7	1.57	75.75

paddy husk ash, amounting to 1.25 kg hour^{-1} ha^{-1} (Fig. II). Rice husk biosilica increased plant height by 6.40 cm - 32.86 cm, number of tillers by 1.39 - 15.09 tillers, number of panicles as many as 8.48 - 10.93 panicles, and yield of 0.16 - 0.86 tons ha^{-1} as compared with controls (Table 6).

Discussion

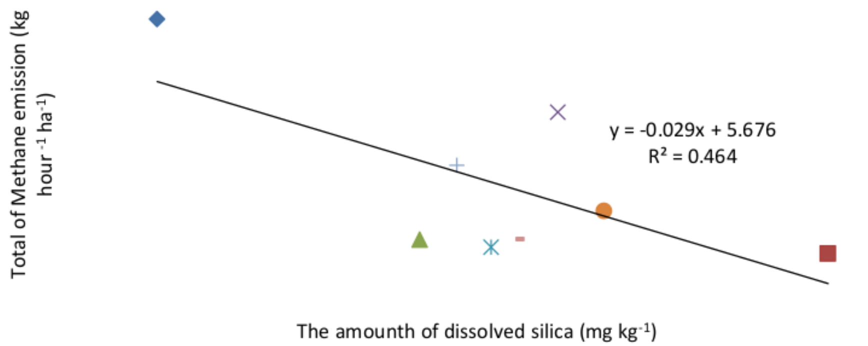

Fig. II. The relationship between the amount of dissolved silica and methane emissions

Table 6
Paddy growth and production in each treatment

Treatment	Plant Height (cm)	Tiller Amount (Tiller)	Productive Tiller (Tiller)	Production per hectare (ton ha^{-1})
Control	101.72 d	31.58 c	18.52 c	5.68
B1	108.12 cd	32.97 bc	20.77 bc	5.84
B2	129.96 ab	43.16 ab	27.00 ab	6.19
B3	133.27 a	45.22 a	27.86 ab	6.39
B4	110.05 cd	34.59 bc	23.76 abc	5.89
B5	119.99 bc	40.86 abc	23.77 abc	6.42
B6	134.55 a	45.61 a	29.43 a	6.50
B7	134.59 a	46.67 a	29.45 a	6.54
BNJ 0.01	12.32	10.16	7.21	

The numbers followed by the same letter in the same column are not significantly different at 1%.

The role of biosilica in solubility of silica in soil

Provision of biosilica of rice husks causes several changes in soil chemical properties. The increase in pH occurs due to binding of silica ions to Fe and Al, thus releasing OH^- (Matichenkov and Calvert, 2002). Silica solubility could bind Fe and Al in the soil (Yanai et al., 2016), reducing the solubility of Fe and Al and increasing the soil pH. The provision of biosilica reduced the solubility of Fe and Al from 3.66 mg kg^{-1} to 2.76 mg kg^{-1} and reduced Al solubility from 0.40 c mol kg^{-1} to 0.22 c mol kg^{-1}.

P supply in soil increased from 5.25 mg kg^{-1} to 5.70 mg kg^{-1} to 8.70 mg kg^{-1} or in average 7.49 mg kg^{-1}. The highest increment of P was found in the ash application which contained the highest dissolved silica. Silica is able to replace the position of P sorption on soil particles so that P becomes P is supply (Thilagan et al., 2014). Provision of ameliorant rice husks increases the amount of organic C and total N. The increase in organic C and total N occurs because rice husks containing silica also contain carbon and organic nitrogen. Ameliorant types of rice husk have different ability in increasing the solubility of silica. Paddy husk ash obtained from burning at temperatures above 600 ºC produces 90% to 98% silica (Shinokara and Kohyama, 2004; Agung et al., 2013).

Mitigation of methane in paddy field

In soils, the solubility of silica works as an electron acceptor in reducing methane emissions. Solubility of silica in the soil increases the amount of oxygen in rhizosphere (Dubey. 2014), and reduces the formation of methane (Ali et al., 2009). Paddy fields planted with rice husk ash (B1) biosilica of, the lowest methane. Silica increases soil pH and reduces methane production by methanotrophic bacteria.

The differences in gas emissions were due to differences in dissolved silica in each type of ameliorant. The highest methane emissions in paddy fields belonged to the control plot (without silica application). Methane emissions from early vegetative stage, late vegetative stage when maximum number of tiller grow, and primordial increased, but they decreased at ripening and after harvest. Methane emissions during primordial stage were the highest as compared to others. Increased gas emissions at the late vegetative stage and primordial from early growth were due to an increase in rice biomass volume. The increased volume of biomass increases the number of exudates containing carbohydrates, organic acids, amino acids, and phenolic compounds. These compounds utilize methanogenic bacteria as an energy source and methane production (Das and Baruah, 2008).

The emission decreased at grain maturation period. The reduction occured due to the reduction of plant physiological activity. Reduction of plant physiological activity decreased the amount of root exudates, and the activity of methanogenic bacteria that produce methane (Wiharjaka and Sarwoto., 2015). The reduction of methane emissions at grain maturation was due to the reduced inundation to accelerate grain maturation. Low ground water causes anaerobic decomposition and decreases the activity of methanogenic bacteria (Kartikawati et al., 2011).

The lowest methane emissions happened after harvesting period because root exudates were not formed and the activity of methanogenic bacteria decreased. Paddy soils without biosilica produced high methane emissions because of low silica and soil pH, low silica content, low oxygen concentration, and low oxidation capacity of rice rooting. The low ability of root oxidation results in methane production as a result of aerobic decomposition of organic matter and the activity of methanogenic bacteria not oxidized.

Biosilica of paddy husk ash reduced methane emissions by 80.75% compared to controls. The emission was reduced under rice husk ash biosilica application due to an increment of pH by binding to Al and Fe ions and OH production. Providing rice husk ash biosilica increased soil pH from 5.38 to 5.72. Among the biosilica treatments, rice husk compost highly increased methane emissions of 4.40 kg^{-1} ha^{-1}. This was due to the methane produced as a result of decomposition process of compost. Compost is an organic material that has not been completely decomposed. Provision of compost stimulates the activity of microorganism in the soil in producing methane.

The highest growth and yield of rice were recorded with the application of the combination of ash, biochar, and rice husk compost (B7). This treatment could improve soil fertility physically, biologically, and chemically. Silica increased the amount of nitrogen, phosphorus, and potassium uptake by rice for growth (Akter and Shirin, 2012). The availability of silica in the soil increases photosynthesis because the leaves become erect and capture the light optimally. Silica increases plants resistance to pests and diseases (Indonesia Soil Research Center, 2010). As a result, dry grain production harvested biosilica from 5.84 to 6.54 tons ha^{-1}, and control at 5.68 tons ha^{-1}.

Yield of rice applied with the composition of ash, biochar, and compost was higher by 0.86 tons or 15.14% compared to controls. This finding shows the role of silica in soil that can improve physical, chemical, and biological fertility of the soil (Yasari et al., 2012). Silica in the soil is able to improve its physical properties such as porosity and drainage (Sommer et al., 2006). Chemically, silica is able to increase pH and reduce the solubility of Al, Fe, and Mn (Cheng, 1982) and increase P, N, P, and K absorption (Akter and Shirin, 2012). Biologically, the provision of ameliorant rice husks increases the population of species, and the activity of bacteria that helps to increase soil fertility (Wiharjaka and Setyanto, 2008). Silica harderns cell wall, which results in higher resistance to pests and diseases.

Conclusion

Rice husk ash was able to mitigate the methane emissions by 80.75% from paddy field. The composition of ash, biochar, and compost (1: 1:1) based on silica content was the most effective way in increasing the rice yield and reducing methane emissions. Reduction of methane emissions occurred through the increasing of dissolved silica mechanism. It caused the increasing of pH and the root oxidion power of rice.

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