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The Effectiveness of Ameliorant to Increase Carbon Stock of Oilpalm and Rubber Plantation on Peatland

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ABSTRACT

Application of peatland amelioration can improve soil quality, reduce GHG emissions, and increase carbon sequestration. The research aimed to study the effect of peatland amelioration on oil palm and rubber carbon stock improvement. Research was conducted from August 2013 until June 2014. The researches on oil palm were done in Arang-arang Village, Kumpeh Subdistrict, Muaro Jambi District, and in Lubuk Ogong Village, Bandar Seikijang Sub-district, Pelalawan District. Both sites are in Jambi and Riau Province. The research on rubber was done in Jabiren Village, Jabiren Raya Subdistrict, Pulang Pisau District, Central Kalimantan Province. The study used a Randomized Completely Block Design (RCBD), in four treatments and four replications. The treatments were *pugam* (peat fertilizer enriched by polyvalent cation), manure; empty fruit bunch compost, and control (no application). The measurement of C stock was performed 10 months after application using nondestructive methods. The results showed that peatland amelioration treatments had no significant effect to improve C stock on oil palm in 6 years old and 7 years old of rubber. After 10 months of amelioration application, the treatments increased C - stock of oil palm and rubber were 2.1-2.4 Mg ha^{-1} and 5-11 Mg ha^{-1}, respectively. Longer time observation may be needed to study the effect of ameliorant on C-stock of annual crops.

Keywords: Ameliorant, annual crops, carbonstock, *pugam* (peat fertilizer)

INTRODUCTION

Peatland is commonly grouped as marginally suitable for agricultural development. The main limiting factor is rooting media (which contents of organic acid on the level that will poison the plants), lack of nutrient, and the drainage which does not support the plant growth (Wahyunto *et al*. 2013; Subiksa *et al*. 2011; Hartatik *et al*. 2011; Mutert *et al*. 1999), so that to achieve an optimal productivity, beside the fertilization, the amelioration should be done as well.

Lime (calcite), mineral soil, manure, dolomite, and ash, can be advantaged as the ameliorant for peatland (Subiksa *et al*. 1997; Mario and Sabiham 2002; Dohong 1999; Maftu'ah *et al*. 2013), but mainly addressed to decrease the soil acidity and to increase the content and availability of nutrient. The research conducted by Dohong (1999) and Sabiham (1997) showed that the amelioration of peatland using natural material that consist of polyvalent cations, like slag, laterite mineral soil, or river mud were effective on overcoming the negative effect of high level of organic acid.

The other problem that needs to be anticipated if the peatland is cultivated for the development of intensive farming is the increase of greenhouse gas (GHG) emissions (Page *et al*. 2002; IPCC 2007; Hooijer *et al*. 2006; 2010; Hashidoko *et al*. 2010). Dariah *et al*. (2014) reported that CO_2 flux from the area least affected by roots were 38±9.5 and 34.1±15.9 Mg ha^{-1} yr^{-1} from the 6 and 15 years old palm plantations, respectively. Jauhiainen *et al*. (2005) previously reported 35 Mg ha^{-1} yr^{-1} CO_2 emission from drained peatland in Kalimantan. Based on CO_2 flux measurement on peatlands in Jambi and Riau, Sumatera Island, Husnain *et al*. (2014) concluded that the land use types of peatland (including oil palm, acasia and rubber plantations, bareland and secondary forest) showed no significant differences in the CO_2 flux. Drainage is the main factor of the increase in the rate of emission from peatland that has been cultivated intensively (Chimner and Cooper 2003; Hooijer *et al.* 2006; 2010; Canadell *et al*. 2007; Parish *et al*. 2008; Couwenberg *et al.* 2010; Page *et al*. 2011; Dariah *et al*. 2013; Marwanto and Agus 2014). The other management factor like fertilization and liming can enhance the emission of GHG as well (Dariah *et al*. 2013; Maswar 2012; Mikkinen *et al*. 2007; Silvola *et al.*1985; 1996).

The enhancement of GHG emission as result of conversion on peat forest to agricultural land is an environmental issue that becomes constraint on the development of peatland, especially tropical peatland for farming purpose (Hooijer *et al*. 2006, 2010; Joosten 2007). Therefore, some options are needed, including amelioration action on the peatland which capable of pressing the emission level of GHG and increase carbon sequestration. Some research results showed that the peatland amelioration that used the material which contains polyvalent cation, beside capable on overcoming the negative effect of high levels of organic compounds, also can lower the level of GHG emission from peatland, so that can increase the peatland stability (Subiksa *et al*. 2009; 2012; Sabiham and Sukarman 2012). Cruz-Guzman *et al*. (2003) stated that cations be able play a role in increasing the buffering capacity of peatland ecosystems. The other effect of ameliorant application that has not been studied enough is from the aspect of increasing carbon sequestration by plants, and it is showed by the change level of carbon stocks in plants as the effect of the improvement of soil quality. Albrecht and Kanji (2003) stated that the increase of carbon sequestration by plants is one of the realistic options in the mitigation of GHG emission. Keddy (2000) stated that the peat swamp ecosystem is the most productive systems to absorb carbon from the atmosphere through photosynthesis process of plants, which reached 13 Mg ha^{-1} yr^{-1} compared to tropical forests around 8 Mg ha^{-1} yr^{-1}. This research intended to study the effect of peatland amelioration application on C-stocks of oil palm and rubber plantation.

MATERIALS AND METHODS

Research Location

Research was conducted from August 2013 until June 2014. Research on peatland with oil palm as staple crops (age of 5-6 years) was conducted in two locations, namely Arang-Arang Village, Kumpeh Sub-District, Muaro Jambi Regency, Jambi Province that is located between $1^0$40'40.79''-$1^0$41'00.85'' SL and $97^0$48'48.56''-$97^0$49'33.63''EL, and Lubuk Ogong Village, Bandar Seikijang Sub-District, Pelalawan Regency, Riau Province with coordinate of $00^0$20'59,3''-$00^0$21'05,8'' SL and $101^0$41'15,6''-$101^0$41'22,9'' EL. The amelioration research on peatland with rubber plantation as staple crops (age of 6-7 years) was conducted in Jabiren Village, Jabiren Raya Sub-District, Pulang Pisau Regency, Central Kalimantan Province with coordinate of $2^0$30'30''SL and $114^0$09'30'' EL.

Research Methods

This research used a randomized completely block design (RCBD) with four treatments and four replications (block), kinds of amelioration that be tested on peatland with oil palm as a staple crops were *Pugam* (peat fertilizer enriched by polyvalent cation), manure, empty fruit bunch compost of oil palm**,** and control (without ameliorant) as the comparation. On the peatland with rubber plantation as the staple crops, ameliorants that were used would be similar with the oil palm, but the treatment of empty fruit bunch compost was converted into mineral soil, it's done so most of the material used were *in situ***.** The experimental plot size for oil palm was 64 × 54 m, with distance of the oil palm was 8 × 9 m, so the total oil palm on each treatment plot was 48 plants. The plot size on rubber plantation was 50 × 27 m, with the distance among the plants was 3 × 5 m, so the total of plants per plot were 90 plants**.**

The ameliorant application was done every six months, on the same time with the fertilizer application. Ameliorant was applied on a circle 200 cm from the center of the tree. The ameliorant dose on each treatment was showed at Table 1. Basic fertilizers that were given on oil palm, besides NPK Fertilizer (urea, SP-36, and KCl), were also Kiserit and micro fertilizers (Cu, Zn, and borax)**.** Basic fertilizers that given on the rubber plantation were urea, SP-36, and KCl. Fertilizer that was applied by spreading at a circle 200 cm from the center of the tree and stirred until 10 cm depth. The basic fertilizer was given for all of treatment, except on *Pugam* treatment, that without SP-36**,** because P element has already consisted in *Pugam*. Kinds and dose of basic fertilizer for oil palm and rubber plantation are shown at Table 2.

Analysis of Peat Soil and Ameliorant Characteristics

Composite of soil samples for chemical properties analyses was taken at 0-15 cm depth prior to treatment application. Soil samples were collected randomly surrounding the tree planting point in a circle with a radius of 200 cm from each block of treatment. In every block, three soil augers were made and each location was represented by four blocks resulting total samples collected of 12. The 12 samples were mixed homogeneously and a

Table 1. Ameliorant dose at each treatment and a step of administerin.

Treatment	Ameliorant application (kg tree^{-1})	
	1st amelioration	2nd amelioration*
	oil palm tree plantation at Riau and Jambi	
Control	-	-
PUGAM	5	3
Manure	10	6
Empty fruit bunch compost	15	9
	Rubber plantation at Central Kalimantan	
Control	-	-
PUGAM	2.0	1.0
Manure	4.0	2.0
Mineral soil	6.0	3.0

Note: *6 moths after 1stamelioration.

Table 2. The type and dosage of fertilizer for oil palm and rubber plantation.

Plant: Fertilizers*	Base fertilizer (kg tree^{-1})	
	1st Fertilization	2nd Fertilization**
Oil Palm:		
Urea	2	2
SP-36	2	2
KCl	2.5	2.5
Kiserit	1.2	-
$CuSO_4$	0.15	-
$ZnSO_4$	0.15	-
Borax	0.30	-
Rubber:		
Urea	0.25	0.25
SP-36	0.20	0.20
KCl	0.25	0.25

Note: * Pugam treatment was not given SP-36 and micro nutrient, ** 6 moths after 1st fertilization.

subsample of 0.25 kg was taken for analyses of pH, organic C, total N, P, K, exchangeable cations (Ca, Mg,K, Na), cation exchange capacity (CEC), base saturation, Al, H, and Fe.

Beside the analysis on peat characteristics, ameliorant characteristics were also measured, *i.e.* P, K, Ca, Mg, S, and polyvalent cations (Fe, Mn, Cu, Zn, Al, B, Pb, Cd, As, Mo, Hg).

The Observation of Plant Carbon Stock

The first C-stock measurement was conducted one week before the ameliorant application. First measurement result data is used as baseline data of plant carbon stock (the condition of C-stock before given the amelioration treatment). Second measurement, which was addressed to study the effect of amelioration was conducted around ten months after the first measure, or about ten months after the first ameliorant application and around 3.5 months after second ameliorant application. The measurement for carbon stock of oil palm tree (in Riau and Jambi) was conducted with non-destructive method (without destruction), the parameter that measured to estimate the dry weight biomass of oil palm tree was the height of tree that was measured from base of the bottom tree (in line with ground level) until the end of upper tree (in line with the bottom fruit brunches). The measurement of the oil palm tree height was conducted in every treatment plot (each plot was selected randomly eight sample plants).

The parameter that was measured to estimate the dry weight biomass of rubber tree (In Central Kalimantan) was the circumference of plant stem at around breast height (1.3 m from ground level). Measurement of the rubber tree stem circumference was conducted in every treatment plot (each was selected randomly 10 tree samples). The sampling on rubber tree was conducted more because the level of diversity on the rubber tree was higher than oil palm tree.

The dry weight biomass of oil palm trees was counted by *allometric* equation that was developed by ICRAF, as result from 'footprint on Indonesian oil palm production' C activity. The equation is:

DW = (0.0976*H)+0.0706,

Where: DW = tree's dry weight on t tree^{-1}, H=height of tree on meter.

The dry weight biomass of rubber tree was estimated by using *allometric* equation that was exclusively developed for branched tree (Ketterings, 2001), *i.e.*:

$$DW= 0.11ñD^{2.62} ,$$

Where: DW = Dry weight (kg tree^{-1}); ñ = density of wood (g cm^{-3}); and D= Tree diameter (cm).

The enumeration of carbon stock in plants was done with using this equation:

Plant's carbon stock = 0.46 * dry weight biomass. Conversion number of 0.46 showed that the average C content in biomass was about 46% (Hairiah and Rahayu 2007; Susanti *et al.* 2009).

The data analysis was done statistically to the observed variables, using analysis of variance (ANOVA) or diversity test with confidence interval of 95%. To show the effect of significant difference due to the treatment, Duncan's multiple range test (DMRT) was done at level of 5%.

RESULTS AND DISCUSSION

Peat Characteristic in Research Location

The result of soil analysis before the treatment (Table 3) shows that the pH of peat soil on every research location were very acid**.** Adriesse (1994) stated that the acidity of peat soil was linked to the contents of organic acids, *i.e.* humic and fulvic acids**.** The level of peat soil acidity was determined by the thickness of the peat, where the upper layer acidity of shallow peat soil is likely lower than thick peat (Suhardjo and Wijaya-Adhi, 1976). Peat in Arang-arang Village, Jambi was relatively shallow (155-316 cm) compared to peat in Lubuk Ogong Village, Riau and Jabiren Village, Central Kalimantan (550-647 m and 500-698 m) (Dariah *et al.* 2013). Data in Table 3 shows that although the soil pH in three research locations were slightly the same, which was very low, but the pH of peat soil in Arang-arang were relatively higher than the peat in Lubuk Ogong and Jabireun. These was in line with the content of humic acid in peat in Arang-arang which was relatively lower, especially if compared to the content of humic acid in peat soil on Lubuk Ogong. The existence of this organic acid is one of the limiting factors of the plants growth in peatlands, since the majority of organic acids are toxic for plants (Tsutsuki dan Ponnamperuna 1987; Tsutsuki and Kondo 1995). The administration of ameliorant containing polyvalent cation is one of the options to overcome this limiting factor (Subiksa 2012). While the polyvalent cation content like Al and Fe in the soil is categorized low or too low or in deficient level based on the criteria that set by Indonesia Soil Research Institute (2005). Melo (2014) also concluded that the enrichment of peat soil with micro element (in polyvalent cation) contributed in increasing the productivity of peatland.

The C-organic content on three locations were about 34-40%. The N content was very high (>0.75%), mostly from organic materials. Although the maturity level of peat on three research locations were low (value of CN ratio >25), but the peat in Lubuk Ogong had the higher maturity level compared to peat in Arang-arang and Jabireun, indicated by value of CN ratio of Lubuk Ogong which was lower (28) compared to peat in Arang-arang and Jabireun (43 and 49).

Based on the nutrient content, level of peat's fertility in Arang-arang was relatively higher than that of Lubuk Ogong, characterized by the content of bases (Ca and Mg) in peatland in Lubuk Ogong that was higher than Arang-arang. The potential P content (P_2O_5 extract HCl 25%) was also higher, although the available P content (P_2O_5 Bray) was relatively lower than peat soil in research location in Lubuk Ogong. The level of peat fertility in Arang-arang which relatively higher among three locations was caused by the peat thickness that relatively more shallow, that peat soil had already been affected by the mineral soil layer under it. The content of humic compounds (which is one of the limiting factor of the plant's growth in peatland), in peat soil in Arang-arang was relatively lower than the peat in Lubuk Ogong. The fertility of peat soil in Jabiren was lower than peat in Arang-arang and Lubuk Ogong as well, especially reviewed by the P element content and K (which is potentially or available), alkaline content (showed by Ca and Mg content) and base saturation.

CEC value (Cation Exchange Capacity**)** of peat soil in all three locations is classified very high (>40 $cmol_{(+)}kg^{-1}$), however the value of base saturation is very low, this indicates that the availability of nutrient, especially bases become low. Some other research's result indicated that majority of the peat

Table 3. Chemical properties of peat soil in the three study sites.

Parameter	Lubuk Ogong Riau	Arang-Arang Jambi	Jabireun Kalteng
pH	3,16	3,70	3,38
Organic-C (%)	38,08	39,48	33,60
Total N (%)	1,55	0,85	1,10
C/N	28	49	43
Humic compound (%)	20,82	10,57	11,57
P_2O_5 HCl 25% (mg 100 g^{-1})	38,86	42,2	21,07
K_2O HCl 25% (mg 100 g^{-1})	49,30	25,05	17,50
P_2O_5 Bray (ppm)	220,5	139,51	58,6
K_2O Morgan (ppm)	333,79	241,06	124,38
Ca ($cmol_c$ kg^{-1})	9,16	12,52	6,20
Mg ($cmol_c$ kg^{-1})	1,7	2,85	2,4
K ($cmol_c$ kg^{-1})	0,39	0,47	0,2
Na ($cmol_c$ kg^{-1})	1,0	0,66	0,5
Total of cation exchange valuae($cmol_{c\,(+)}$ kg^{-1})	13,2	16,49	9,3
CEC ($cmol_{c\,(+)}$ kg^{-1})			
Base Saturation (%)	85,5	107,09	80,6
Fe Dithionit	18,11	15,5	9,2
Al Dithionit	0,08	0,12	0,07
	0,17	0,03	0,17

in Indonesia, especially inland peat has the very low base saturation and high CEC (Hartatik *et al*. 2011, Suhardjo and Wijaya-Adhi 1976). The Polyvalent cation content, which is Al and Fe in the soil is classified very low, even the Fe has already been in deficiency level.

Ameliorant Characteristic

The result of the analysis ameliorant that was used in this research is shown in Table 4. *Pugam*, empty fruit bunch compost**,** and manure had pH about 7.0-8.6**.** The high pH condition is more proper given to kinds of soil that has low pH**,** like peat soil. However, the existence of polyvalent cation was the other factor that needs to be considered on choosing the ameliorant for peat soil, and regarding to that, the mineral soil, especially which categorized as laterite soil is relevant to be used as natural ameliorant content in peat soil (Sabiham 1997; Dohong 1999), because it has polyvalent cation content like Fe and Al that relatively high. The analysis result showed that the polyvalent cation content (Fe, Mn, Cu, Zn, Al, B, Pb, and Cd) in *Pugam* was so much higher than in manure, empty fruit bunch compost**,** and mineral soil. The nutrient content like P, Ca, Mg, and S in *Pugam* was so much higher as well, compared to manure, empty fruit bunch compost**,** and mineral soil.

Mineral soil had polyvalent cation content, especially Fe, Mn, and B that was so much higher than the two organic ameliorant used (empty fruit bunch compost and manure). However, the nutrient content like P, Ca, and Mg in empty fruit bunch compost and manure was relatively higher than of in mineral soil. The CN ratio of manure and peat fertilizer is categorized moderate. This thing showed the maturity level had been relatively good. The content of polyvalent cation like Fe, Mn, and B in manure was relatively higher than empty fruit bunch compost. But there was some element like P, Ca, Mg, S, and Zn that was relatively higher in empty fruit bunch compost than in manure.

The Effect of Peat Soil Amelioration on The Change of Oil Palm's Carbon Stock

The result of C-stock measurement that was done before amelioration treatment (Table 5) in the relatively same age (around six years) showed that. the average C- stock in oil palm plantation in Arang-arang is 10.2-10.7 Mg ha^{-1}, relatively higher than the carbon stock in oil palm plantation in Lubuk Ogong (9.1-9.7 Mg ha^{-1}). This thing probably affected by the differences of the maturity level of peat soil in these two research locations. The soil analysis result (Table 3) showed that the maturity level of peat soil in Arang-arang was relatively higher than peat in Lubuk Ogong. Based on statistic analysis result, the average C-stock inter-treatment plot before the ameliorant application whether it is in Arang-arang or Lubuk Ogong, it had no significant

Table 4. Ameliorant characteristics used in the study.

Parameter	Unit	Pugam	Manure	Emty fruit bunch compost	Mineral Soil
pH H_2O (1:5)		8,6	8,5	7,0	4,6
C/N	%	-	12	11	7,6
P_2O_5	%	13,15	0,56	4,75	-
K_2O	%	0,08	0,49	0,45	-
Ca	%	18,9	0,72	1,29	-
Mg	%	6,53	0,33	0,80	-
S	%	0,56	0,10	0,20	-
Fe	Ppm	9460	412	Nd	1890
Mn	Ppm	5608	47	39	1102
Cu	Ppm	1008	3	17	-
Zn	Ppm	1633	46	47	-
Al	Ppm	6920	Nd*	Nd	1700
B	Ppm	686	40	3	-
Pb	Ppm	17,3	Nd	Nd	-
Cd	Ppm	1,6	Nd	Nd	-
As	Ppm	Nd	0,7	0,8	-
Mo	Ppm	Nd	Nd	Nd	-
Hg	Ppm	Nd	0,1	0,0	-

*Nd: no detected.

Table 5. Changes in carbon stocks of oil palm plantation as the effect of amelioration treatment on peatlands in Riau and Jambi.

Treatment	Carbon stock (Mg ha^{-1})					
	Before amelioration		10 months After amelioration		Delta in 10 months	
	Average	Std dev.	Average	Std dev.	Average	Std dev.
Location	Lubuk Ogong, Riau					
Control	9,57 a*	1,03	11,79 a	1,62	2,22 a	0,97
Pugam	9,17 a	0,71	11,59 a	0,51	2,42 a	0,64
Manure	9,59 a	0,88	11,59 a	1,08	2,00 a	0,28
Empty fruit bunch compost	9,67 a	1,01	11,21 a	1,25	2,14 a	1,06
CV	7,7	-	11,1	-	34,9	-
Location	Arang-Arang, Jambi					
Control	10,20 a	1,31	12,01 a	1,37	1,81 a	0,36
Pugam	10,72 a	1,83	12,82 a	2,42	2,11 a	0,82
Manure	10,49 a	1,73	12,64 a	1,93	2,15 a	0,62
Empty fruit bunch compost	10,53 a	1,37	12,13 a	1,52	1,62 a	0,55
CV	7,0	-	7,9	-	27,5	-

* number in the same column followed by the same letter are not significantly different at 5% level by DMRT.

difference (with CV value <10%). That means before the treatment, the diversity of C-stock inter-plot was low (Table 5).

Ten months after the treatment, the research result showed that the application of ameliorant did not have significant effect on the C-stock of oil palm plantation in two locations (Riau and Jambi). The average addition of C-stock in oil palm plantation in Lubuk Ogong was about 2.1-2.4 Mg ha^{-1} and the average C-stock became about 11.2-11.9 Mg ha^{-1}.

Table 6. Changes in carbon stocks of rubber plantation as the effect of amelioration treatment on peatlands in Jabireun, Center of Kalimantan.

Treatment	Carbon stock (Mg ha^{-1})					
	Before aplication		10 moths After aplication		Delta in10moths	
	Average	Std dev.	Average	Std dev.	Average	Std dev.
Control	30,63 a*	3,55	41,33 a	7,04	10,70 a	7,22
Pugam	35,23 a	0,88	44,30 a	2,70	9,08 a	2,31
Manure	31,31 a	5,63	36,52 a	4,28	5,15 a	1,39
Mineral Soil	34,20 a	5,72	41,22 a	4,47	6,72 a	4,87
CV	13,01	-	13,39	-	46,47	-

** number in the same column followed by the same letter are not significantly different at 5% level by DMRT.

The enhancement of carbon stock in Arang-arang was about 1.6-2.2 Mg ha^{-1}, so the average carbon stock in this location became 12.1-12.8 Mg ha^{-1} (Table 5). Based on this research result, the application of ameliorant has not yet contributed in increasing the C sequestration by the oil palm tree.

The Effect of Peat Soil Amelioration on the Change of Carbon Stock of Rubber Plantation

The baseline result of C-stock (the measurement before the treatment) in rubber plantation on the age of seven years showed that rubber plantation's C-stock was about 31-35 Mg ha^{-1}. Based on the result of statistic analysis before amelioration treatment, the C-stock of rubber tree inter-treatment plot was not significant different, that means the diversity of C-stock inter-plot before the treatment was categorized as low (Table 6).

It turned out that the application of ameliorant did not have significant effect on the enhancement of C-stock in rubber plantation as well (Table 6). The average C-stock in rubber tree was about 37-44 Mg ha^{-1}. The differences level of the C-stock addition was high enough and it was about 5.1-10.7 Mg ha^{-1}. The relatively high CV value caused it has no different statistically.

The condition that ameliorant did not contribute to the plant's C-stock was likely because of the other factor that more dominant affects on the plant's carbon stock. The application of fertilizer was the factor that able to affect more dominant. Where in the dose of the fertilizer that was used in all of the treatment is categorized optimal, including in control treatment. In ten months range of time, the probability was not too short to be able to see the effect of the peat amelioration on plant's C-stock. However, although in this thing ameliorant did not have the significant effect to C-stock, the other function from ameliorant content is hoped to show the significant result. The research result of Dariah *et al.* (2013) and Subiksa (2012) showed the potential of ameliorant with the active polyvalent cations content in pressing CO_2 emission from peatland that intensively managed**.** Observation from Setyanto *et al.* (2014) also showed amelioration with empty fruit bunches compost effectively reduced CO_2 emissions from peatlands in Riau and Jambi.

CONCLUSIONS

Amelioration of peatland using *Pugam*, manure, empty fruit bunch compost, and mineral soil had no significant effect on C-sequestration by rubber and oil palm plantation, approved by insignificant difference between treatments on plant C-stock. Ten months after ameliorant application, the addition C-stock of oil palm plantations were about 2.1-2.4 Mg ha^{-1}, whereas the change C-stock of rubber plantations were about 5-11 Mg ha^{-1}. Although it had no significant effect on C sequestration by plants, the addition of ameliorant on peatland is expected would have a positive impact on the productivity of oil palm and rubber plantations and reduction in CO_2 emission levels.

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