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Carbon dioxide emission and carbon sequestration potential in Alfisol

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Abstract

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Carbon dioxide (CO_2) is one of the greenhouse gases, which also promotes global warming. It can be formed from the decomposition of organic matter like rice straw in the soil. The laboratory study was conducted to determine CO_2 production and carbon (C) sequestration from fresh and wheathered rice straw applications on Alfisols. The rice straw with the dose of 0 (control), 5, 10, 20, 30 tons/ha, respectively, of fresh and weathered was used on two hundred grams of Alfisol soil, and incubated for 56 days. The evolution of CO_2 was regularly observed every 7 days for all treatments during the entire incubation period. Soil organic C was measured at the end of incubation period. The results showed that amending Alfisol soil with rice straw enhanced CO_2 production compared with the control. Cumulative CO_2-C flux (emission) from fresh straw was higher than from weathered one. On the other hand, soil organic carbon from weathered straw was higher than fresh one. In average during 56 days, about 5.76 % of C was emitted as CO_2, and the remaining 94% C still retained in the soil as soil organic C. Return of rice straw back into the soil might enhance soil C storage and could improve soil fertility and environment quality.

Keywords: CO_2-C flux; soil organic carbon; fresh straw; wheatered straw

Introduction

Intensive management practices and low addition of organic residues may decrease the content of the soil organic matter (SOM) (Khalil et al., 2005; Zhang et al., 2008). Furthermore, soil organic carbon (SOC) plays a key role in the improvement of chemical, physical and biological soil properties (Kundu et al., 2007; Ouedrago et al., 2007; Dalal et al., 2011), nutrient cycling, crop productivity and reducing greenhouse gases (GHGs) (Duiker and Lal, 2000). Thus, maintenance of SOC is essential for the sustainability of agricultural production. The lost SOM could be replenished by the application of organic matter such as straw (Goyal et al., 1999; Glasser et al., 2001; Abro et al., 2012).

Rice straw is an organic C source which contains nutrients such as N, P, and K. Moreover, the straw is available throughout years as many as the harvest time. The straw was usually handled by disposing or burning it. In a long-term, this handling might decrease organic C in soil and the decrease of soil productivity. Therefore, it is advisable to return the straw in the form of fresh or rotten straw to improve the properties of the soil chemistry, physics, and biology (Brady and Weil, 2000).

Rice straw incorporation is one of the in situ soil managements, beside burning or composting before land preparation. But there are controversial result pertaining the rice straw incorporation. Previous studies showed that incorporation of the rice straw had a negative effect that is, produce phyto-toxic substances during their decomposition (Elliott et al., 1981) and reduce rice yield due to N immobilization process (Rao and Mikkelsen, 1976; Cassman et al., 1997). Other studies indicated positive effect of incorporation of rice straw such as increasing soil organic C (Wang et al., 2015), microbial population (Man and Ha, 2006), soil moisture content, decreasing bulk density and delaying crack density (Mousavi et al., 2012).

Organic residue returned to the soils is decomposed which involves the mineralization of the labile C fraction by decomposer organisms resulting in formation of microbial by-product and accumulation of recalcitrant organic compounds which incorporate the stable SOC pools. The mineralization and humification processes are accompanied with CO_2 production. Meanwhile carbon-dioxide (CO_2) emission became a concern correlated with the global issue. Therefore, an action which can decline the greenhouse effect is needed (Lal, 2004). The returned organic residue may increase the potential sink of carbon in cultivated soils (Six et al., 1999) and affects CO_2 in the atmosphere (Lal, 2004).

There has been a considerable studies about the decomposition of organic residues in relation with temperature and humidity (Abro et al., 2012), moisture and nitrogen levels (Abro et al., 2011), residue composition such as C and N contents (Ajwa and Tabatabai 1994, Naher et al., 2004), carbon-nitrogen ratio (Tian et al., 1993) and differences resource quality (Singh et al., 2007). However, there is still a scarcity of information in relation with the soil C pool and the release of CO_2 to the atmosphere from the rice straw at different levels and degradation rates. Hence, this study was conducted to determine the carbon mineralization of different quality of rice straw under different levels in term of C sequestration and CO_2 emission.

Materials and Methods

The soil sample was taken from the surface layer (0-20 cm) of Alfisols located at Karanganyar District, Central Java, Indonesia. The experiment was arranged in a Completely Randomized Design composed from two factors: rice straw types (fresh and wheatered) and dose of rices straw 5, 10, 20 and 30 ton ha^{-1}. The experiment was done with four replications.

The straw was washed with distilled water and dried at 70°C, cut into small pieces (< 1 cm), grounded and mixed thoroughly with soil then transferred into pots for an equivalent of 200 g soil for incubation. The samples were wetted slowly with calculated amount of deionized water to maintain water level at field capacity. The pots were then incubated at the constant temperature of 25°C. All the pots were taken out and opened periodically and aerated for a few minutes. At the same time the soil water content was checked and adjusted by weighing then adding distilled water to maintain water levels. The CO_2 evolved was measured at 7, 14, 21, 28, 35, 42, 49, and 56 days. At the end of incubation, soil organic C, C-fulvic acid, C-humic acid, C and N microbial biomassa, and soil pH were measured.

The measurement of CO_2 evolution was conducted by placing the bottle containing 10 ml of 0.1 M KOH into the pot to bind CO_2. Then, the pot was sealed and left for incubation. Every seven-day, the bottle was taken for measurement and replaced with another bottle containing 10 ml of KOH. Next, the excess of KOH was titrated with 0.1 M HCl after $BaCl_2$ was added to the bottle. Lastly, CO_2 measurement was performed eight times during incubation on 7, 14, 21, 28, 35, 42, 49 and 56 days of incubation.

Soil organic carbon (SOC) concentration was determined using dichromate H_2SO_4-$K_2Cr_2O_7$ wet oxidation method of Walkley and Black (Eviati and Sulaeman, 2009).

Microbial biomass carbon and nitrogen (C-mb and N-mb). C-N microbial was determined by the fumigation-extraction method (Voroney et al., 1993) and calculated as soluble organic C in the fumigated sample minus the soluble organic C in the unfumigated sample and divided by 0.35. WSOC (water-soluble organic carbon) was extracted from a10-g fresh soil sample by 20 ml 0.5 M K_2SO_4 by shaking one hour and then filtered the extracts using a Whatman filter paper. SOC concentration was determined using dichromate H_2SO_4-$K_2Cr_2O_7$ wet oxidation method of Walkley and Black. The same K_2SO_4 soil extract was used to be determined N-mb, as total N using the Kjedahl digestion procedure (Eviati and Suleman, 2009).

Humic substances (HS): 5 g of soil sample were added into the bottle shake, extracted with 25 ml (solution of sodium pyrophosphate + NaOH 0.1 N), shook, left overnight and filtered. After filtering, the 5 ml of the extract was pipetted into a volumetric flask, added 7.5 ml $K_2Cr_2O_7$ + H_2SO_4 (concentrated), stirred and rested until it is cool. Lastly, the volume was completed with deionized water. C levels of humic acid and fulvic acid in solution was measured by spectrophotometer at 561 in wave length (Eviati and Suleman, 2009).

Fulvic acids fraction (FA): 5ml of the HS fraction were pipetted to a tube. Concentrated H_2SO_4 was added to lower the pH to 2.0, manually shaken then left overnight and filtered. As the result, the supernatant contained the FA fraction and the precipitate contains the HA fraction (Eviati and Suleman, 2009).

Humic acids fraction (HA): After fraction FA was obtained, the precipitated HA was dissolved with 0.1 N NaOH solution (70-80°C) into a 100 ml volumetric flask. The solution was evaporated to a volume of 5 ml. After that, it was added by $K_2Cr_2O_7$ solution and 7.5 ml of concentrated H_2SO_4, then stirred and left it until cool. The content of C-HA in solution was measured by spectrophotometer at 561 nm in wave length (Eviati and Suleman, 2009).

Statistical analysis: The data were analyzed by one-way ANOVA test followed by Duncan Multiple Range Test at the 5% level ($P < 0.05$). The entire statistical analyzes were performed with SPSS 17:00 and Microsoft Excel (Steel and Torrie, 1980).

Results and Discussion

Characteristics of soil and rice straw

Alfisols (0-20 cm) used in these reserch is slightly acid. Total N and P_2O_5 are low and correlated with the low C organic content in the soil. According Kelly and Stevenson (1995), main part of soil N is in the form of organic N that attached in soil organic C. Thereby, the low of available P is correlated with low organic C which becomes the source of P in the soil. (Brady and Weil, 2002). The soil characteristic is presented in Table 1.

Table 1. Soil charateristics

Soil properties		Value	Status*
pH H_2O (1:2,5)		5.93	Slightly acid
Organic C (%)		0.95	Very low
Total N (%)		0.11	Low
P_2O_5 available bray (ppm)		6.90	Low
K exchangeable (cmol(+)kg^{-1})		0.31	Low
Ca exchangeable (cmol(+)kg^{-1})		3.24	Low
Mg exchangeable (cmol(+)kg^{-1})		2.95	Moderate
Na exchangeable (cmol(+)kg^{-1})		0.77	Moderate
CEC (cmol(+)kg^{-1})		20.00	Moderate
Base saturation (%)		36.55	Moderate
Teksture	Sand (%)	27.49	Clay
	Silt (%)	16.96	
	Clay (%)	55.56	

* according to the Soil Research Institute, 2007

The maturity level and nutrient content of fresh straw is lower than weathered straw (Table 2) so it has low quality from the perspective of nutrient suply. Besides, from the C sequestration perspective, fresh straw has higher potential than weathered straw because it has much lignine that is difficult to decay.

Flux and emission CO_2-C from fresh and weathered straw

The evolution pattern of rice straw decomposition (CO_2 evolution) showed that the amount and type of rice straw resulted in the same trends in CO_2 evolution with the increasing incubation time. Carbon dioxide flux results from fresh straw were higher than weathered straw at all the studied durations except at 21[th] day (Fig. 1). The CO_2 evolution

Table 2. Characteristics of rice straw

Characteristics	Fresh straw	Weathered straw
C (%)	59.11	43.29
N (%	0.98	1.25
P (%)	0.69	0.49
K (%)	0.51	0.48
Si (%)	3.09	2.87
C/N	60.32	33.83
Lignine (%)	9.24	2.94
Polifenol (%)	3.87	2.6
Cellolose (%)	42.32	40.70
Abu ash (5)	24.48	13.16

was low in the first two weeks and gradually increased in the following weeks until the last day of incubation. The results were consistent with the findings of Abro et al. (2012) in which the rate of carbon dioxide flux from wheat straw incubation with different N doses and moisture levels was low in the first week incubation, and continuously increased until the last days incubation. There were also some contradicting results. In incubation study of rice straw under different moisture and flooding showed that maximum carbon dioxide flux was found at 7 days after incubation, then decreased with the increase of time except at the 49[th] day after incubation (Hossain and Puteh, 2013). Villegas-Pangga et al. (2000) and Rahman (2013) also found that more than 50% of C was release at 7 days incubation meanwhile Rahman (2013) found that maxsimum emission was recorded during the first week of incubation.

The low CO_2-C flux in the first week of incubation was due to insufficient of N availability for the growth of microbial decomposer since nitrogen was not added in this study. In support with this study, Abro et al. (2012) observed the low CO_2 emission in maize straw incubated without N addition, than with adding N. Meanwhile, the increasing the CO_2 emission after the third week was due to the released of N from the decomposition process. Villegas-Pangga et al. (2000) found that 5-37% of N were released within 20 days of rice straw incubation.

The CO_2-C flux showed a linear trend with significant variation during entire incubation period (Fig. 1). Carbon dioxide flux were not differnt at all the studied durations except at 7[th] and 56[th] day. The maximum cumulative of carbon dioxide emission was observed at 56 days after incubation. Mixing of rice straw with soil at different doses significantly increased cumulative CO_2-C at the 56 days of incubation (*p = 0,015*). These results were consistent with those of Rahman (2013), that the organic residues significantly produced higher CO_2-C than the control. Crop residues provided a

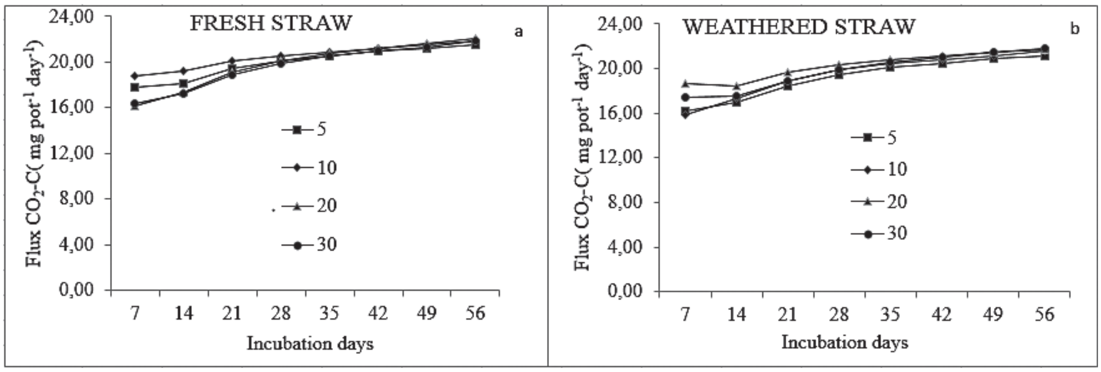

Fig. 1. The CO_2-C flux from fresh straw (*a*) and wheatered straw (*b*) at incubation

source of readily available C and subsequently influenced the CO_2-C emission (Lemke et al., 1999). The amount of rice straw was thought to be an important factor affecting CO_2-C emission. he cumulative CO_2-C showed quadratic trend with levels of fresh rice straw and linear trend with levels of wheatered straw at 56 days incubation (Fig. 2).

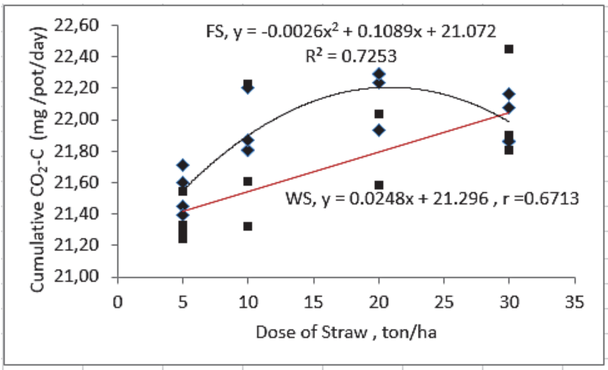

Fig. 2. Cumulative CO_2-C at any dose of straw

Cumulative CO_2-C emission of fresh straw was nummerically higher than wheatered straw, but not significantly different (Table 3). The similar results were also found in the observations of Ajwa and Tabatabai (1994) and Kriaučiūnienė et al. (2012). The degree of maturity between fresh straw and wheatered straw also gave different effect on the decomposition rate. In fresh straw with high ratio C/N, the availability of substrate especially compound organic C, which was easily degraded (cellulose), was still high and could meet the microbial decomposer's requirements for activities and growth. Meanwhile, the compound of organic C which easily degraded in wheatered straw had reduced gradually before it mixed with soil, therefore the decomposition rate also declined because the biodegraded process had happened before the straw was mixed with soil (Brady and Weil, 2002).

Table 3. Cumulative CO_2-C evolved during straw decomposition

Straw	Cumulative CO_2-C (mg d^{-1} pot^{-1})				
	Dose of straw (ton ha^{-1})				Average
	5	10	20	30	
Fresh	21.48 ab	21.63 abc	22.10 c	21.83 bc	21.81 A
Weathered	21.16 a	21.56 bc	21.71 bc	21.84 bc	21.57 A
Average	21.32 A	21.59 AB	21.91 B	21.84 B	

*The same letter after number showed not significant different at levels α 0.05

The cumulative soil CO_2-C flux was strongly related to the quantity of rice straw added (p = 0,004). The cumulative CO_2-C flux was the lowest in 5 ton ha^{-1} straw while the highest was in 30 ton ha^{-1} straw. There was no significant difference between 10, 20 and 30 ton ha^{-1}. This may be related to the activity of microorganisms that is nearly the same to using carbon as an energy source to build their body. In this study, there was a positive correlation in the variability of cumulative CO_2-C flux with C bm (r = 0.477), N bm (r = 0.369) (Fig. 3). The increasing amount of straw was not followed by an increase microbial biomass linearly. The straw at dose 10, 20 and 30 ton ha^{-1} showed the same C-mb, as well as N-mb except at 30 tons ha^{-1}. Duiker and Lal (2000), who working with maize straw, explained that the lack of effect of CO_2-C flux between 0, 8 and 16 tons might be the presence of un-decomposed crop residue on the soil. In addition, incorporation of rice straw also increased the pH (Table 3) and there was a positive correlation between CO_2-C cumulative and soil pH (r = 565). Hossain and Puteh (2013) stated that the increase of soil pH caused by incorporation of rice straw might enhance C mineralization and produce CO_2. Clearly, rice straw returned to the soil could increase CO_2 emission.

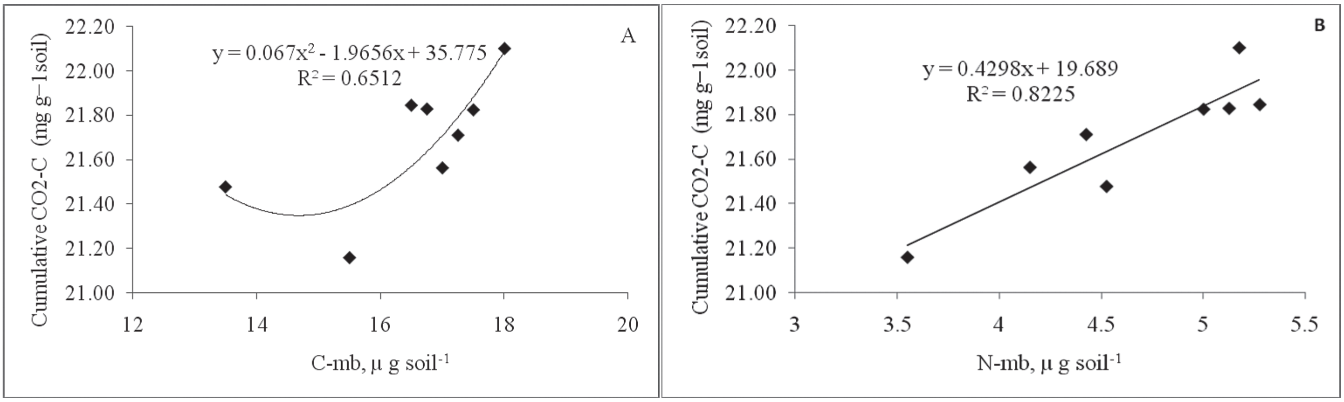

Fig. 3. The relationship between cumulative CO_2 with C-microbial (*A*) and N-microbial (*B*)

Soil organic C

The mixing of fresh straw and weathered straw into soil significantly increased the soil organic C compared to the control (p = 0,000). The soil organic C from fresh straw ranged between 0.98 and 1.22% while the wethered one ranged between 1.08 and 1.28%. Weathered straw showed the higher organic C level than the fresh one (Table 4). Weathered straw had low C/N because the decomposition process has been started before it was incubated into the soil and the easily dissolved organic C would be decomposed and left the resistant carbon compounds which later it could be a part in soil organic C (Brady and Weil, 2002). On the contrary, the fresh straw which had higher C/N ratio, the C mineralization rate run slower and soil organic C was also low. The SOC of weathered straw at dose 30 ton ha^{-1} was not different with fresh straw, but at the dose of 5 ton ha^{-1}, SOC with weathered straw is higher than fresh straw. The increase of soil organic carbon on the straw incorporation was a kind of C sequestration in the soil. The result was similar to Hossain and Puteh (2013), who found that incorporating rice straw increased the soil organic carbon. Rice straw is potential source of carbon since it had high carbon content, thus, it could improve organic C level in the soil (Zeng et al., 2010). Abro et al. (2011), who working with maize straw, also reported that the mixing of maize straw with soil increased the soil organic C level.

Carbon-fulvic acid (C-FA) and carbon-humic acid (C-HA)

Humic substances are important components of soil organic matter (SOM) which determine the physical, chemical and biological properties of soil. They also represent the principal surface reservoir of carbon and plant nutrients. The contents and quality of humic substances and SOM have been well studied and are affected by the amount and quality of residue incorporated into the soil (Novotny et al., 1999). Humic acids (HAs), a major fraction of SOM in most soils, are insoluble in water below pH 2, whereas fulvic acids (FAs), another important class of SOM constituents, are soluble at all pH. Both occur in soils mainly as a result of plant decay. HAs and FAs are much longer-lived than organic soil components such as leaf litter and maize straw (Stevenson, 1994).

The treatments increased the carbon content in the fufvic acid (C-FA) and humic acid (C-HA). This result was consistent with (Roppongi et al., 1994; Aoyama and Kumakura, 2001; Watanabe et al., 2007). Levels of straw had more pronounced impact on C-FA (p = 0,000) compared to variation due to type of straw. The same trend was obtained with C-HA (p = 0,000). The variation in C-FA and C-HA were different from all treatments. In both type of straw, C-FA significantly increases from 5 to 30 tons ha^{-1} straw, but the increasing doses of straw was not always followed by an increasing in C-HA. C-FA was increased about 0.22-0.34% and C-HA – 0.11-0,21%. The lowest C-FA was showed at 5 tons ha^{-1} fresh straw. On the other hand, the highest C-FA was observed at 30 tons ha^{-1} wheatered straw. The same value of C-HA showed at 10 and 20 tons ha^{-1} of fresh straw and wheatered straw (Table 4).

Incorporated plant residue in the soil increased C-FA and C-HA compared to the control. The content of C-FA

Table 4. C mineralization as percentage organic added for 56 days from soils amanded with any levels of fresh and weathered straw

Straw	C mineralized (% Organic C)				
	Dose of straw (ton ha^{-1})				Average
	5	10	20	30	
Fresh	30.95 c	22.61 b	13.78 a	7.96 a	18.82 A
Weathered	32.78 c	23.18 b	14.00 a	11.08 a	20.26 A
Average	31.87 C	22.90 B	13.89 A	9.51 A	

* The same letter after number showed not significant different at levels α 0.05

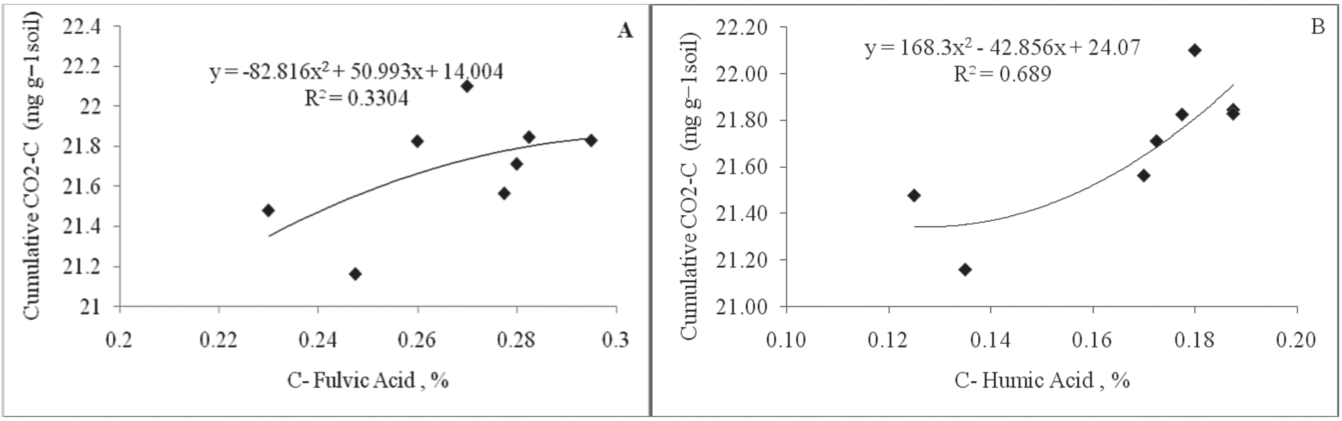

Fig. 4. The relationship between cumulative CO_2-C with C-Fulvic acid (A); C-Humic acid (B)

and C-HA was 44.79 and 52.78%, respectively, higher than the control. Meanwhile the C-FA and C-HA were higher in wheatered straw with 52.78 % and 62.50% increase over the control, respectively.

Humification process of organic matter in the soil resulted in humic compounds such as C-AF and C-HA, but it also released CO_2. This research showed the positive correlation between cumulative CO_2-C with C-FA (r = 0.217) and C-HA (r = 0.508**) (Fig. 4).

Conclusion

Incorporation of fresh straw and wheatered straw with various doses increased CO_2 emission, soil organic C, C-fulvic acid and C-humic acid. Cumulative CO_2-C flux (emission) from fresh straw was higher than from weathered straw. On the other hand, soil organic C from weathered straw was higher than from fresh straw. It proves that the more straw given until 20 tons ha^{-1} would increase CO_2 emission and soil organic carbon. During 56 days, about 5.52% of C was emitted from fresh straw meanwhile from the weathered straw it was only about 6% and the remaining 94% C still retained in the soil.

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