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Soil respiration from paddy field in relation to incorporated cover crop biomass composition

Md. Mozammel Haque[1,3*], Jatish Chandra Biswas[3], Akter M[3], and Pil Joo Kim[1,2]

[1]Division of Applied Life Science (BK 21 Program), Gyeongsang National University, Jinju, 660-701, South Korea.
[2]Institute of Agriculture and Life Science, Gyeongsang National University, Jinju, 660-701, South Korea.
[3]Soil Science division, BRRI, Gazipur, Bangladesh.

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Winter cover crops are cultivated during cold fallow season in temperate countries for green manure and animal feed. Literature on incorporated biomass composition in relation to soil respiration like CH_4-C and CO_2-C is not available. Therefore, soil respiration as affected by variable biomass composition was determined from paddy soil. Soil respiration rate (1280-1341 kg ha^{-1}) was significant when 197 and 204 day-old plants were incorporated. The CH_4–C and CO_2-C respiration rates were significantly correlated with cellulose, lignin, protein, and ash. However, CH_4-C respiration was negatively related with CO_2-C respiration. These implies that biomass composition is influenced by age of cover crops that ultimately dictates paddy soil respiration rates.

Key words: Rice field, biomass composition, age of biomass, CH_4-C, CO_2-C.

INTRODUCTION

Plant biomass decomposition is an important source of greenhouse gas (GHG) emission (Sinsabaugh et al., 2002). The decomposition rates depends on soluble and insoluble fractions of plants of which cellulose, hemi-cellulose and lignin form a complex chemical network that influences biological decomposition (Bertrand et al., 2006; Šnajdr et al., 2011). However, lignin is the recalcitrant component of green manured crops (Melillo et al., 1982; Berg and McClaugherty, 2008) to extracellular enzymes (Sinsabaugh et al., 2002; Allison and Vitousek, 2004; Šnajdr et al., 2011). Although biomass quality determines nutrient cycling, grain quality and production of crops (Bala et al., 2008; Mirza et al., 2010), its decomposition by enzyme activity may not always be reflected in soil environments.

Cultivation of seasonal mono-rice and winter cover crops are the farming feature in temperate regions. Usually non-leguminous (Barley) and leguminous (Hairy vetch) cover crops are used as green manure in South Korea (Kim et al., 2007; Zhang et al., 2007; Haque et al., 2015a) for supplementing rice crop's nutrient requirements and improving soil organic matter content (Elfstrand et al., 2007; Pramanik et al., 2013a; Haque et al., 2015a, b). However, paddy field is a major source of methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions (Sass et al., 1999; Haque et al., 2015a). In paddy soil, the organic amendment favors microbial activities, which results in increasing GHG emission from soil (Pramanik et al., 2012; Kim et al., 2013). Therefore, it is important to evaluate the efficacy of agricultural

*Corresponding author. E-mail: mhaquesoil@yahoo.com. Tel: +88-01718-133016.

practices for the mitigation of GHG emissions to avoid climate change.

Generally, barley and hairy vetch is cultivated for about 7 months before incorporation into soil. Since cellulose, lignin and hemi-cellulose contents depend on plant age, use of younger plants as green manure could contains less complexed organic molecules rendering faster decomposition. Moreover, substrates produced there on might encourage microbial activities for GHG production. Older plants generally decompose slowly and might have influence on soil respiration, but no literature is available in this regard, especially with paddy soil. The present study was, therefore, undertaken to evaluate paddy soil respiration as influenced by age and compositions of incorporated barley and hairy vetch biomass.

MATERIALS AND METHODS

Experimental site, cover crop harvesting, and rice cultivation

Experiment was conducted at the agricultural farm of Gyeongsang National University (36°50´N and 128°26´E), Jinju, South Korea. The selected soil was silt loam in texture and classified as typic Haplaquents with somewhat impeded drainage. The soil was characterized by pH (1:5 with H_2O), 6.2; organic carbon, 11.9 g kg^{-1}; available P, 35 mg kg^{-1} and bulk density, 1.39 g cm^{-3}. The recommended seeding rate of barley and hairy vetch as winter cover crop was 120 and 90 kg ha^{-1} for Korean paddy soils (Jeon et al., 2011; Haque et al., 2013). Mixture of barley and hairy vetch seeds were spread in the field on 1st November, 2011. Green manuring crops were harvested on 10, 16, 23 and 30 May, 2012 for incorporation into paddy soil at 3 Mg ha^{-1} before rice transplanting. Ages of biomass before incorporation were, 183, 190, 197, and 204 days. After incorporation, soil was flooded immediately and CH_4 and CO_2 gases were measured.

Thirty-days-old 3 seedlings $hill^{-1}$ of Dongjin cultivar, Japonica type rice were transplanted (15 cm × 30 cm spacing) on 6th June 2012. Recommended dose of chemical fertilizer (N-P-K=110-20-48 kg ha^{-1}) was applied in each plot. The basal fertilizer dose (N-P-K= 55-20-33.7 kg ha^{-1}) was applied just before transplanting, while 22 kg N ha^{-1} at active tillering stage (2 weeks after rice transplanting) and 33 kg N ha^{-1} and 14.3 kg K ha^{-1} were applied at 6 weeks after rice transplanting. Water level was maintained at 5 to 7 cm depth above the soil surface throughout the experiment. Rice was harvested on 15th October, 2012 and total grain and straw yield was recorded after air drying. Rice growth and yield characteristics were investigated at maturing stage.

Characterization of cover crop

Cover crop biomass was recorded after oven drying at 70°C for 72 h. Total C and N was estimated by CHNS analyzer (Leco, USA). Cellulose content was determined using a colorimetric method with anthrone reagent at 620 nm (Updegraff, 1969) and lignin content was determined using the APPITA P11s-78 method (APPITA, 1978), ash was determined using a muffle furnace at 550°C for 4 h (Yoshida et al., 1976). Percentage of protein content was estimated as (Jones, 1941):

$$6.25*N\% \quad (1)$$

CH_4 and CO_2 gas sampling and analysis

The transparent glass chambers having a surface area of 62 cm × 62 cm × 112 cm (Figure 1) were placed permanently in the flooded soil after rice transplanting for monitoring CH_4 emission rates. Eight rice plants were enclosed in a chamber. There were four holes at the bottom of the chamber to maintain water level at 5 to 7 cm depth above the soil surface. Independent with a closed chamber for estimating CO_2 emission rates, acrylic column chambers having a diameter of 20 cm and height 20 cm were placed into soil surface (Lou et al., 2004; Xiao et al., 2005; Iqbal et al., 2008; Haque et al., 2015a, b). All chambers were kept open in the field throughout the rice cultivation period except during gas sampling. The chamber was equipped with a circulating fan for gas mixing and a thermometer inside to monitor the temperature during the sampling time.

Air gas samples were collected by using 50 ml gas tight syringe at 0 and 30 min after chamber being closed. Gas samplings were carried out three times (8 am, 12 pm and 4 pm) in a day to get the average CH_4 and CO_2 emission rates. Collected gas samples were immediately transferred into 30 ml air evacuated glass vials sealed with a butyl rubber septum for analysis by gas chromatography (Shimadzu, GC-2010, Japan) with Porapak NQ column (Q 80-100 mesh). A flame ionization detector (FID), and thermal conductivity detector (TCD) were used for quantifying CH_4 and CO_2 concentrations, respectively. The temperatures of the column, injector and detector were adjusted at 100, 200, and 200°C for CH_4, 45, 75, and 270°C for CO_2, respectively. Helium and H_2 gases were used as the carrier and burning gases, respectively.

Estimation of CH_4 and CO_2

Methane and CO_2 emission rates were calculated from the increase in CH_4 and CO_2 concentrations per unit surface area of the chamber for a specific time interval. A closed chamber equation was used to estimate CH_4, and CO_2 fluxes from each treatment (Haque et al., 2013, 2015a, b; Pramanik et al., 2013b).

$$F = \rho \times (V/A) \times (\Delta c/\Delta t) \times (273/T) \quad (2)$$

Where, F is the CH_4 and CO_2 emission (mg m^{-2} h^{-1}), ρ is the gas density of CH_4 and CO_2 under a standardized state (mg cm^{-3}), V is the volume of the chamber (m^3), A is the surface area of the chamber (m^2), $\Delta c/\Delta t$ is the rate of increase of CH_4 and CO_2 gas concentrations in the chamber (mg m^{-3} hr^{-1}) and T (absolute temperature) is 273 + mean temperature in (°C) of the chamber. The seasonal CH_4 and CO_2 flux during entire rice cultivation period was computed by following formula (Singh et al., 1999):

$$\text{Seasonal } CH_4 \text{ and } CO_2 = \sum_i^n (R_i \times D_i) \quad (3)$$

Where, R*i* is the rate of CH_4 and CO_2 emission (g m^{-2} d^{-1}) in the i^{th} sampling interval, D*i* is the number of days in the i^{th} sampling interval, and n is the number of sampling intervals.

Soil sampling and analysis

Analysis of soil chemical properties were performed after rice harvest in 2012. Soil was collected at 0-15 cm depth from five different points in each plot, air-dried, and sieved (<2 mm). The chemical analysis included soil pH (1:5, with H_2O), available phosphate (RDA, 1988), DOC was extracted in the fresh soil using cold water (Lu et al., 2011), total carbohydrate (phenol-sulphuric acid method; Safari et al., 1992), and total C and N concentrations were measured by CHNS-932 analyzer (Leco, USA). A portion of the moist soil sample was dried at 105°C for 24 h to measure soil bulk density (BD, Blake and Hartge, 1986) according to the equation:

$$\text{Bulk density } (g/cm^3) = \text{Dry soil weight (g)}/\text{Soil volume } (cm^3) \quad (4)$$

Table 1. Biomass production and composition of mixed barley and hairy vetch cover crop.

Parameter	Age (days)				
	183	**190**	**197**	**204**	**$LSD_{0.05}$**
Biomass (Mg ha^{-1} dry wt.)	6.84	11.90	13.48	12.00	0.37
Inorganic components					
Total C (g kg^{-1})	41.25	41.76	42.20	42.28	0.26
Total N (g kg^{-1})	1.89	2.45	2.45	2.47	0.79
C/N ratio	21.82	17.04	17.22	17.11	0.57
Organic components (%)					
Cellulose	22.93	24.71	26.13	29.08	0.31
Hemi-cellulose	12.49	12.30	12.09	12.33	0.17
Lignin	16.41	17.53	18.16	18.43	0.77
Protein	11.82	15.31	15.44	17.06	0.29
ADF(Acid detergent fiber)	47.01	51.89	52.59	55.88	0.36
Ash	7.6	7.6	8.3	8.4	0.29

Soil porosity was calculated using BD and particle density (PD, 2.65 Mg m^{-3}) according to the equation:

$$\text{Porosity (\%)} = (1 - BD/PD) \times 100 \quad (5)$$

Statistical analysis

Statistical analyses were done using SAS software (SAS Institute 2003). A one-way ANOVA was carried out and Fisher's protected least significant difference (LSD) was calculated at the 0.05 probability level for making treatment mean comparisons.

RESULTS

Composition of cover crop biomass

Aboveground biomass significantly ($P \leq 0.05$) increased with growth duration upto 197 days before rice transplanting (Table 1). At 183 day, cover crop biomass productivity was low compared to 204 day-old plants. Carbon, N, cellulose, hemi-cellulose, lignin, protein, acid-detergent fiber (ADF), and ash contents of the cover crop increased with age of plants. Furthermore, the highest organic compounds were recorded with 204 day-old plants. The increase in physical and biochemical properties of plants between 197 day-old biomss and 204 day-old ones varied significantly (Table 1). However, most of the plant components studied were higher with 197 day-old biomass than 183, 190 day-old ones.

Soil respiration

CH_4-C respiration

Methane-C respiration from biomass incorporated paddy soil increased upto 40 days after rice transplanting (DAT) and then decreased, although the rates were different depending on age (Figure 3) and quality of cover crop biomass. The lowest CH_4-C respiration rate was observed with 204 day-old biomass and the highest with 183 day-old ones. Cumulative CH_4-C respiration from 204 day-old biomass treated plots was 443 ± 4.23 kg ha^{-1}, which was 10, 9 and 5% lower than 183, 190 and 197 day-old biomass incorporated treatments, respectively.

CO_2-C respiration

The CO_2-C respiration increased gradually upto 60 DAT and decreased thereafter among treatments (Figure 3). Eventhough CO_2-C respiration did not differ significantly between 183 and 190 day-old biomass, it varied significantly with 204 day-old compared to 197 day-oldbiomass incorporated soil (Table 2). The CO_2-C respiration was low at the initial stage and at later growth stages of rice. Furthermore, CO_2-C respiration rate was low before transplanting than post transplanting.

Soil respiration and biomass composition

Total soil respiration showed significant positive relation-ships with cover crop biomass components like cellulose, lignin, protein, and ash (Table 3). Nitrogen content had signicant and positive relationship with CH_4-C respiration but nonsignificant with CO_2-C respiration. Total soil respiration was influenced more by CO_2-C respiration than CH_4-C. Moreover, there was a negative correlation between CO_2-C and CH_4-C respiration rate.

Changes in soil chemical properties

The DOC concentration was higher at about 30 DAT.

Figure 1. Static closed chamber for trapping methane in rice soil.

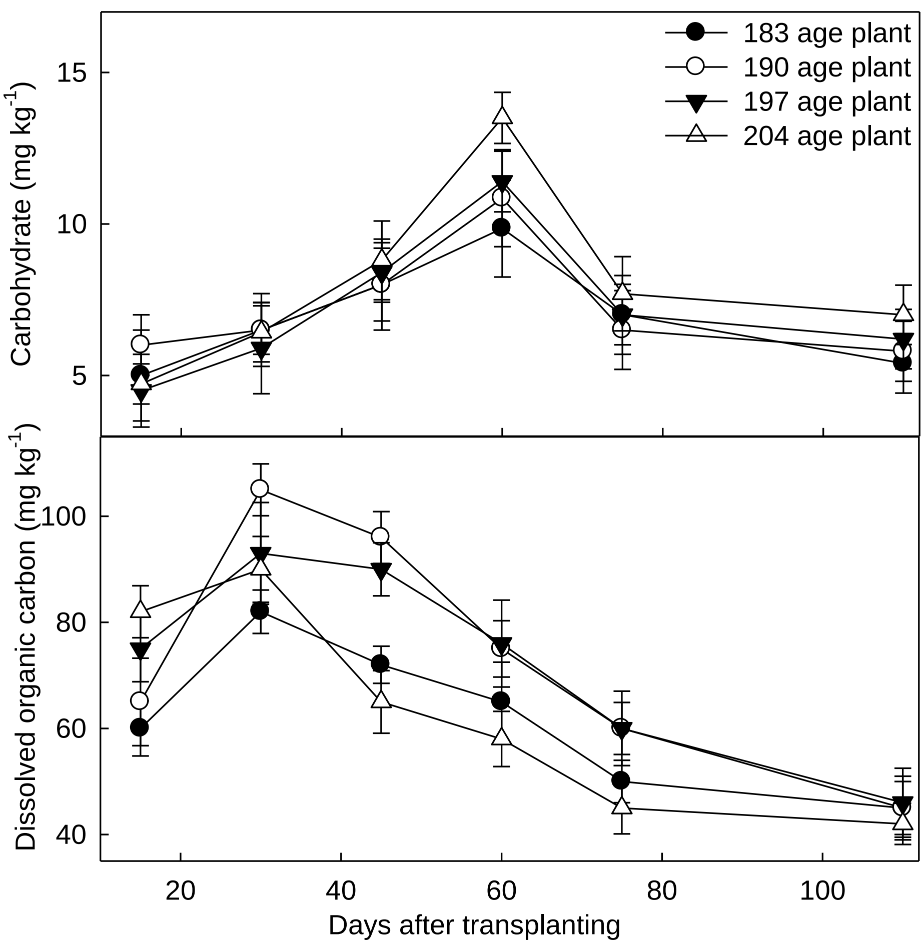

Figure 2. Determination of carbohydrate, and dissolve organic carbon during rice cultivation as affected by age (days) of incorporated biomass.

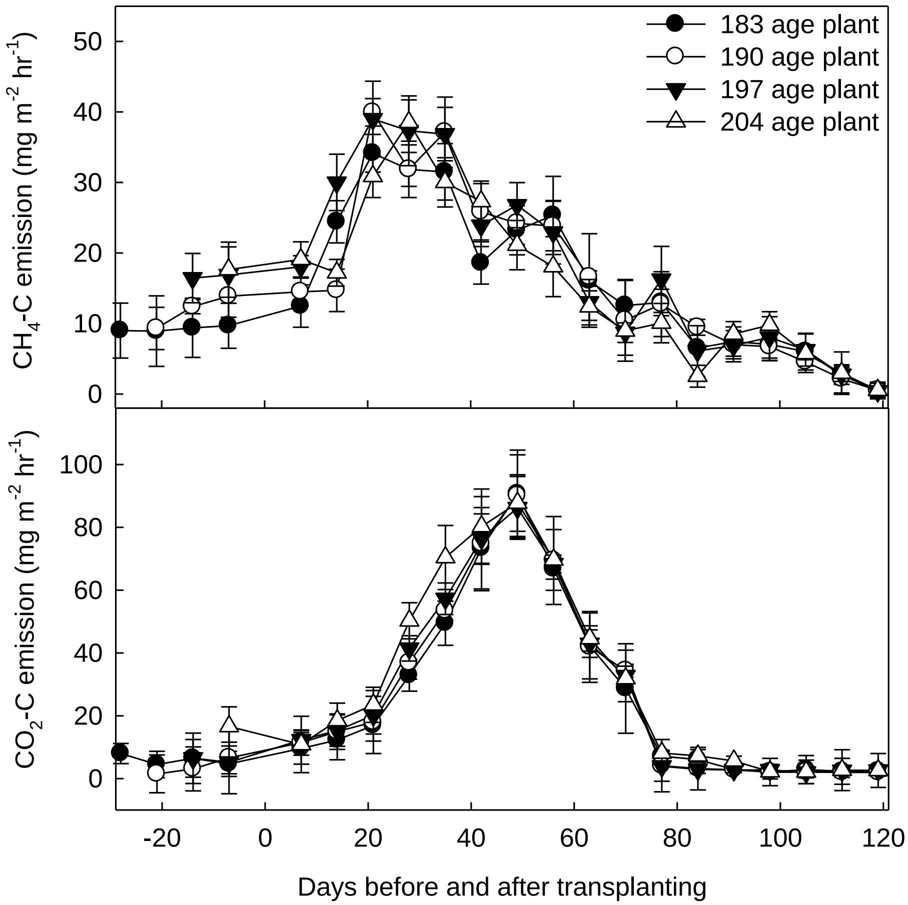

Figure 3. Emission fluxes of CH_4-C , and CO_2-C from soil as affected by age (days) of incorporated biomass.

Table 2. Soil respiration during rice cultivation as affected by age of incorporated barley and hairy vetch biomass.

Parameter	Age (days)				
	183	**190**	**197**	**204**	**LSD 0.05**
Mean respiration rate					
CH_4-C (mg m^{-2} day^{-1})	407	401	388	369	6.99
CO_2 -C (mg m^{-2} day^{-1})	654	654	682	736	6.20
CH_4-C+CO_2-C (g m^{-2} day^{-1})	1.06	1.05	1.07	1.11	0.23
Seasonal respiration (kg ha^{-1})					
CH_4-C	488	482	467	443	4.64
CO_2-C	793	797	814	898	2.82
CH_4-C+CO_2-C	1281	1279	1280	1341	1.91

Carbohydrate concentrations also changed following similar patterns of CO_2 emission rates, but the highest concentration was observed around 60 DAT (Figures 2 and 3). The post harvest soil analysis showed higher total organic carbon, N, available P and porosity in 204 day-old biomass incorporated plot than others (Table 4).

DISCUSSION

The production of methane from organic matter takes place when Eh value goes below -200 Mv. Most readily available organic carbon sources are utilized by the methanogens and thus methane is produced as a by-

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Seasonal respiration (kg ha^{-1})					
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CH_4-C+CO_2-C	1281	1279	1280	1341	1.91

Table 3. Relationship of soil respiration with cover crop biomass composition

Compound	Nitrogen	Cellulose	Lignin	Protein	Ash	CH_4-C	CO_2-C
CH_4-C + CO_2-C	0.347^{ns}	0.852***	0.573*	0.625**	0.625**	-0.881***	0.974***
CO_2-C	0.473^{ns}	0.935***	0.686**	0.735**	0.759**	-0.940***	
CH_4-C	0.612*	0.961***	0.787**	0.800**	0.842***		

^{ns}Not significant; and *, ** and *** Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.

Table 4. Post harvest soil properties as affected by age of incorporated barley and hairy vetch biomass.

Parameter	Age (days)				
	183	190	197	204	$LSD_{0.05}$
pH	7.44	6.99	7.25	7.29	0.89
Total organic matter (g kg^{-1})	20.90	21.53	21.02	21.72	0.18
Total N (g kg^{-1})	1.70	1.72	1.70	1.76	0.34
Available P (mg kg^{-1})	58	62	77	82	1.5
Porosity (%)	47.92	50.94	50.94	53.21	0.15

product as follows. This means composition of substrates (Le Mer and Roger, 2001) play an important role in methane production.

$$C_6H_{12}O_6 \rightarrow 3\ CO_2 + 3CH_4 + \text{energy}$$

Aged cover crop plants were responsible for higher seasonal soil respiration rates might be because of plant composition, especially higher contents of cellulose, lignin, protein, ADF and ash. There was higher inorganic and organic components with aged plants compared to immatured ones (Table 1), but total respiration was less with young plants than the aged ones due to lower amount of CO_2-C emission (Haque et al., 2015b). The rate of CO_2-C respiration was comparatively low at initial rice growth stage and then increased significantly with age of plants upto 60 DAT (Figure 3), which might have influenced total soil respiration. At this stage CH_4-C respiration was more because of increased methagen activity. Gunnarsson and Marstorp (2002) also found that low cellulose containing materials release more C than higher cellulose containing substrates. This C increased methanogen activity and produce higher amounts of CH_4-C at the initial rice growth stage. Moreover, higher cellulose and lignin contents slow down decomposition rates (Melillo et al., 1982; Tian et al., 1992; Gunnarsson and Marstorp, 2002) and thus CH_4-C respiration was less with 204 day-old incorporated biomass (Table 2). Although total DOC and carbohydrate play an important role in CH_4-C emission from flooded rice fields, no significant differences were observed in the present investigation (Figure 2). Organic and inorganic components of cover crop plants varied significantly depending on their age before incorporation (Table 1) and thus influenced physio-chemical properties of soil that ultimately resulted in increased CH_4-C and CO_2-C respiration (Table 2).

The incorporation of aged cover crop biomass decreases C source for methanogens (Vigil and Kissel, 1991) under anaerobic conditions and thus less CH_4-C respiration was recorded. Total soil respiration was significantly different between 204 and 197 day-old plants. Although there was no significant difference in soil respiration with 183, 190 and 197 day-old plants, biomass productivity and plant compositions were higher with 197 day-old ones. It means that cultivation of mixed barley and hairy vetch for 197 days before incorporation can be used to reduce soil respiration.

Conclusion

Inorganic and organic compositions of cover crop plants increase with aging, which in turn might inecrease soil N and C contents following incorporation. Although total soil respiration was low with incorporated young plants having less lignin, cellulose, protein, and ash content, total biomass production was also low compared to aged cover crop. Since the viability of a technology depends of economy and easy handling, addition of 3 t ha^{-1} biomass from young plants would require more production area that might not be acceptable to most of the farmers. Therefore, cultivation of cover crop for about 197 days can be a better option for enhancing biomass productivity and control of soil respiration from paddy soil.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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