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Effect of long-term differential application of inorganic fertilizers and manure on soil CO_2 emissions

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ABSTRACT

Carbon dioxide (CO_2) fluxes from agricultural soils have been considered as one of the important environmental impact issue, due to their role in global warming and also its mitigation by carbon (C) sequestration in soils. Substantial scope of C sequestration with the application of inorganic fertilizers and manures has been reported, but the long-term effects of continuous application need to be critically examined. To study the effect of continuous differential application of NPK fertilizers and farmyard manure (FYM) in maize-wheat cropping system, CO_2 fluxes were measured via closed chambers and gas chromatography in a long-term experiment in progress for the past 42 years. The average daily CO_2 fluxes differed significantly amongst various treatments and were 55, 26 and 92% higher in NPK, N and NPK + FYM treatments over the control in the maize crop season and 43, 8 and 83% in the wheat crop season. Highly significant correlation of CO_2 emissions was found with soil organic carbon and total nitrogen in the maize and the wheat crop seasons. Although, CO_2 emissions were higher from long-term inorganic fertilizers and FYM treatments, still they are environmentally sustainable management practices, as they increased soil fertility and crop yields which consequently resulted in higher atmospheric CO_2 capture by plants and carbon sequestration in soils.

Keywords: fertilization; soil C-forms; soil N-forms; *Zea mays*; *Triticum* spp.

Terrestrial ecosystems are important sink of carbon (C) and could partially offset the increase in atmospheric CO_2 (Smith 1999). Conflicting results were reported about the changes in soil organic carbon (OC) due to use of inorganic fertilizers under intensive agriculture. Application of fertilizers, along with tillage and crop residue management practices, influence emissions of greenhouse gases (GHG) from agricultural soils (Adviento-Borbe et al. 2010, Mbonimpa et al. 2015, Dhadli et al. 2016). Further, cropping systems can influence CO_2 emission by affecting the quality and quantity of C returned to the soil as root biomass or as straw incorporation or mulching (Mapanda et al. 2011, Gong et al. 2012, Ding et al. 2014). Additionally, due to variations in management practices in different cropping systems, soil temperature and water content which directly control CO_2 emission are also influenced (Peng et al. 2011, Allaire et al. 2012, Zhang et al. 2013, Dhadli et al. 2015).

Although CO_2, CH_4 and N_2O emissions from agricultural fields under rice-wheat system in India have been reported from some field studies conducted over short term, information about CO_2 emissions from soils under long-term maize-wheat cropping system is lacking. The objectives of the present study were to study the impact of long-term application of inorganic fertilizers and farmyard manure (FYM) in a maize-wheat cropping system on CO_2 emissions and relationship of CO_2 emissions with various soil C and N (nitrogen) forms.

MATERIAL AND METHODS

An experiment under maize-wheat cropping system in progress since 1971 at the Research Farm, Punjab Agricultural University, Ludhiana, India, was selected to study the effect of long-term differential application of inorganic fertilizers and

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FYM on CO_2 emissions in the maize and the wheat crop seasons. The experimental site is located at 75°47'09''E, 30°54'19''N at an altitude of about 247 m a.s.l. and the climate is subtropical, semiarid, hot and monsoon type with cold winters and hot summers. The soils of the area are developed above the flood plains sediments and are classified as Fluvisol (FL–dr) according to World Reference Base for Soil Resources (WRB) and have loamy sand texture. At the beginning of the experiment in 1971, the initial status of soil organic carbon (SOC), available P and K was 2.2, 6.1 and 58.7 g/kg, respectively. In the maize and the wheat crop seasons, CO_2 fluxes from five treatments: 100% NPK (T_1); 150% NPK (T_2); 100% N (T_3); 100% NPK + FYM (T_4), and control (T_5) were measured to study the effect of long-term application of inorganic fertilizers and FYM on CO_2 emissions. In different treatments, 100% NPK refers to the application of inorganic fertilizers viz., nitrogen (N), phosphorus (P) and potassium (K) at recommended level of 120 kg N + 26.2 kg P + 25.0 kg K/ha to each of maize and wheat crops. In T_3 treatment 100% N refers to the application of fertilizer N only at 120 kg/ha and in the control treatment (T_5) no input has been added in the past 42 years. Urea, single supper phosphate (SSP) and muriate of potash (MOP) were used to supply N, P and K to maize and wheat crops. In T_4, FYM was applied at 10 t/ha (dry weight basis) before sowing of maize, which supplied 3700 kg C, 90 N, 140 kg P and 150 K/ha annually. Fertilizer N was applied in 3 equal doses in maize and 2 equal doses in wheat, while the whole of P and K were applied at sowing. Maize was sown at the end of May 2013 and at sowing 1/3 of N was applied, while remaining N was applied in two equal parts at 21 and 56 days after sowing (DAS). Wheat crop was sown in November 2013 and in all treatments except T_5, half of fertilizer N was applied at sowing and remaining after 30 days. Soil temperature in maize and wheat seasons ranged between 31–39°C and 11–24°C, respectively. Total rainfall received in maize crop season was 662 mm, while total rainfall in wheat crop season was 143 mm. Grain and straw yields were recorded at harvest and straw of both the crops was removed from field.

CO_2 fluxes were measured via closed chambers (10 cm internal diameter and 15 cm height) and gas chromatography. Air samples were collected in triplicate (within a minute) using a 10-mL syringe fitted with a hypodermic needle at 0, 15 and 30 min after chamber closure. The samples were immediately stored in 5-mL pre-evacuated glass vials equipped with a butyl rubber septum. The collected samples were taken to laboratory and CO_2 concentration in the samples was determined on the same day via a gas chromatograph (model 2100 Shimadzu Inc., Kyoto, Japan) equipped with a packed column, a flame ionization detector (FID) and a methanizer having Ni catalyst, 320°C. Daily CO_2 fluxes (CO_2-C kg/ha/day) were calculated from the linear temporal increase in mixing ratio of CO_2 in chamber headspace as elaborated by Parkin et al. (2012). Seasonal total CO_2 emissions (CO_2-C kg/ha) for each of maize and wheat crop seasons were calculated by interpolating flux between two successive measurements.

Surface soil (0–15 cm) samples were collected from different treatments before sowing of maize and wheat crops for the determination of various soil C and N forms. Soil organic carbon was determined by oxidation with potassium dichromate as described in Walkley and Black (1934) method and mineral nitrogen (N_{min}) by rapid titration method of Subbiah and Asija (1965). Total carbon (C_{tot}) and nitrogen (N_{tot}) were determined on CHN analyzer (Elementar Analysesysteme GmbH, Hanau, Germany) equipped with TC detector.

Statistical analysis of the data was performed via SAS 9.3 software (SAS Institute Inc., Cary, USA). A generalized linear mixed model (Glimmix) was used to perform ANOVA to study the significance of treatments as factorial structure, sample collection dates as repeated measures. In addition, an ANOVA was also run out to determine the effects of long-term treatments on various soil C and N forms, using the generalized linear model (GLM) of SAS 9.3 software. Long-term application of fertilizers and manures affected various soil C and N forms, therefore to study the effect of long-term treatments, correlations analysis between various soil C and N forms and CO_2 emissions from different treatments via Proc CORR was conducted.

RESULTS AND DISCUSSION

Crop yields and CO_2 emissions. Long-term application of fertilizers and manures in different treatments has a significant effect on grain and straw yields of both the maize and wheat crops.

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Maize grain yield was highest in T_4 but statistically at par with T_2, and was followed by T_1. Grain yield in T_3 was lower than in T_1 but higher than in T_5. Wheat grain yields were significantly higher in NPK (T_1 and T_2) and FYM (T_4) treatments over N alone (T_3) and were lowest in control (T_5) (Table 1). Maize straw yield was significantly high in T_2, followed by T_4 and minimum in T_5, while the highest wheat biomass yield was observed in T_4 followed by T_2, T_1, T_3 and T_5. This implies that higher application of NPK fertilizer in maize contributed only to biomass production without any gains in grain yields. Continuous application of inorganic fertilizers and manure increased soil fertility, which helped in achieving higher crop yields. Higher dry matter yields indicated more capture of atmospheric CO_2 by plants.

Average of daily CO_2 fluxes during the maize crop season was the highest for T_4, followed by T_1 and T_2 and minimum for T_5 (Table 1). Seasonal total flux for the maize crop season was significantly higher by 26% to 55% in three fertilizer treatments and by 92% in FYM treatment over the control. In the wheat crop season, average of the daily fluxes was the highest for T_4 and lowest for T_5. Seasonal total CO_2 emissions were significantly higher by 43% in T_1 and T_2, 8% in T_3 and 83% in T_4, over T_5. Higher application of fertilizers (150% NPK) in T_2 had no significant effect on CO_2 emissions as compared to recommended level in T_1 (100% NPK), but CO_2 emissions and crop yields were significantly lower in T_3 receiving N fertilizer only. Continued applications of FYM along with NPK fertilizers, resulted in significantly high CO_2 emissions, in both the maize and the wheat crop seasons. An increase in CO_2 emissions with the input of inorganic fertilizers and organic inputs has been reported from many studies (Song and Zhang 2009, Mapanda et al. 2011, Zhang et al. 2013).

Temporal variations in CO_2 fluxes. The daily CO_2 fluxes in the maize crop season ranged from 4.7 to 14.1 kg CO_2-C/ha/day in various treatments (Figure 1). Different long-term treatments, gas sampling dates and their interactions had a significant effect on daily CO_2 fluxes. CO_2 fluxes were comparatively higher at the beginning of maize crop season and thereafter declined sharply till 14 DAS (Figure 1). Significant surge in CO_2 fluxes after the application of N fertilizer on 21 and 56 DAS was registered in all the treatments, except T_5, and depression in fluxes was observed after rainfall associated with drop in soil temperature.

Amongst different treatments, CO_2 fluxes from T_4 treatment remained at significantly higher level throughout the maize crop season, except on 21 DAS, and similarly fluxes in T_1 and T_2 remained significantly higher than T_3 and T_5 till 77 DAS with one exception on 21st day (Figure 1). CO_2 fluxes in T_5 increased slightly between 21 to 49 DAS and declined gradually thereafter. They were at par with T_3 on 42 DAS, but were still significantly lower than T_1, T_2, T_3 and T_4. At the end of season, CO_2 fluxes were still significantly high in T_4, and T_1 was at par with T_2 at lower level, while T_3 was at par with T_5 at the lowest level. It became evident that CO_2 emissions were significantly higher in FYM treatment than in all the other treatments. The effect of fertilizer application on CO_2 fluxes at higher rates (T_2) as compared to recommended

Table 1. Effect of long-term application of inorganic fertilizers and farmyard manure (FYM) on CO_2 emissions and crop yields (t/ha)

	Average of daily flux (CO_2-C kg/ha/day)		Seasonal total emissions (CO_2-C kg/ha)		Grain yield		Straw yield	
	maize	wheat	maize	wheat	maize	wheat	maize	wheat
T_1	9.29^b	5.7^b	898^b	813^b	4.59^{ab}	5.08^a	5.07^c	8.50^a
T_2	9.34^b	5.7^b	903^b	819^b	5.04^a	5.43^a	8.67^a	8.75^a
T_3	7.58^c	4.3^c	735^c	614^c	3.33^{bc}	4.23^b	3.70^d	5.77^b
T_4	11.6^a	7.3^a	1112^a	1040^a	5.91^a	5.75^a	7.17^b	9.79^a
T_5	6.01^d	4.0^d	578^d	563^c	2.25^c	1.72^c	2.99^d	2.87^c

Values followed by the same letters in a column are not significantly different ($P < 0.05$). T_1 – 100% NPK; T_2 – 150% NPK; T_3 – 100% N; T_4 – 100% NPK + FYM; T_5 – control

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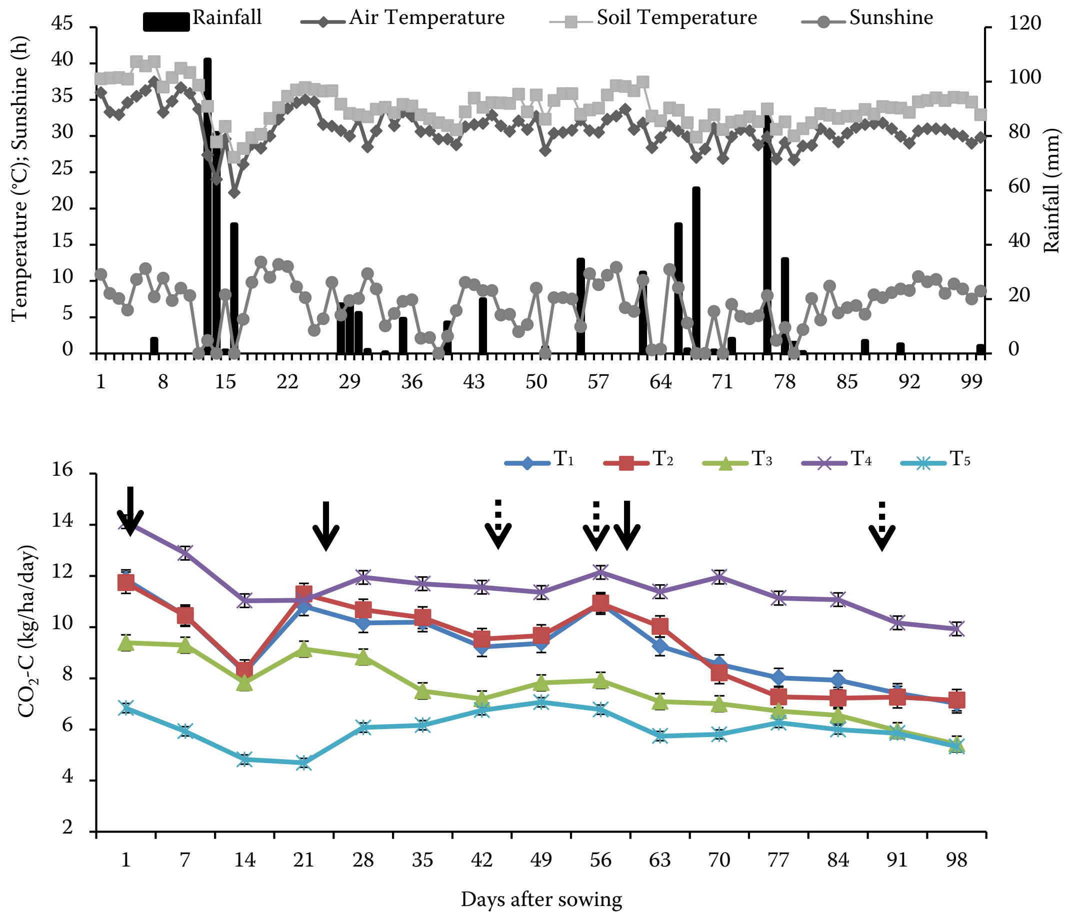

Figure 1. Temporal variations in weather variables and CO_2 fluxes in different treatments in the maize crop seasons (solid arrows indicate N-fertilization and dotted arrows irrigation). T_1 – 100% NPK; T_2 – 150% NPK; T_3 – 100% N; T_4 – 100% NPK + FYM; T_5 – control

level (T_1) was not significant. Application of N alone had some effect on CO_2 fluxes just after the fertilizer application, but generally they declined gradually in season. Another interesting observation was that in control treatment, CO_2 fluxes increased during the middle of season, which coincided with vegetative and flowering stages (Sey et al. 2010, Dhadli et al. 2015). Soil CO_2 fluxes were found associated with soil temperature and soil water content (Adviento-Borbem et al. 2010) and N-fertilization (Zhang et al. 2013).

In the wheat crop season, CO_2 fluxes were also significantly affected by long-term treatments, gas sample collection dates and their interactions. Before the sowing of wheat crop, CO_2 fluxes in various treatments ranged from 4.2 to 7.1 kg CO_2-C/ha/day and were significantly higher in T_4 than other treatments (Figure 2). Just after the sowing and application of basal dose of fertilizer-N, CO_2 emissions increased in all the treatments. Generally throughout the wheat crop season, CO_2 fluxes were significantly high in T_4, followed by T_1 and T_2 at par with each other and then T_3, while in T_5 fluxes remained at constant level. CO_2 fluxes decreased in all the treatments 11 DAS and remained stable up to 27 DAS. After the application of 2nd dose of urea on 37 DAS, fluxes increased significantly in all treatments except T_5. Between 49 DAS and 59 DAS, all season low CO_2 flux was recorded. Thereafter CO_2 fluxes gradually increased in all treatments till 102 DAS, but amazingly in control (T_5) after registering an increase, fluxes attained a plateau between 83 DAS and 93 DAS, and declined thereafter. On 116 day depression in CO_2 fluxes was observed in all treatments except T_4 and thereafter CO_2 emissions also started rising in all the other treatments, but the increase was significant in T_1, T_2 and T_4 only. The depressions

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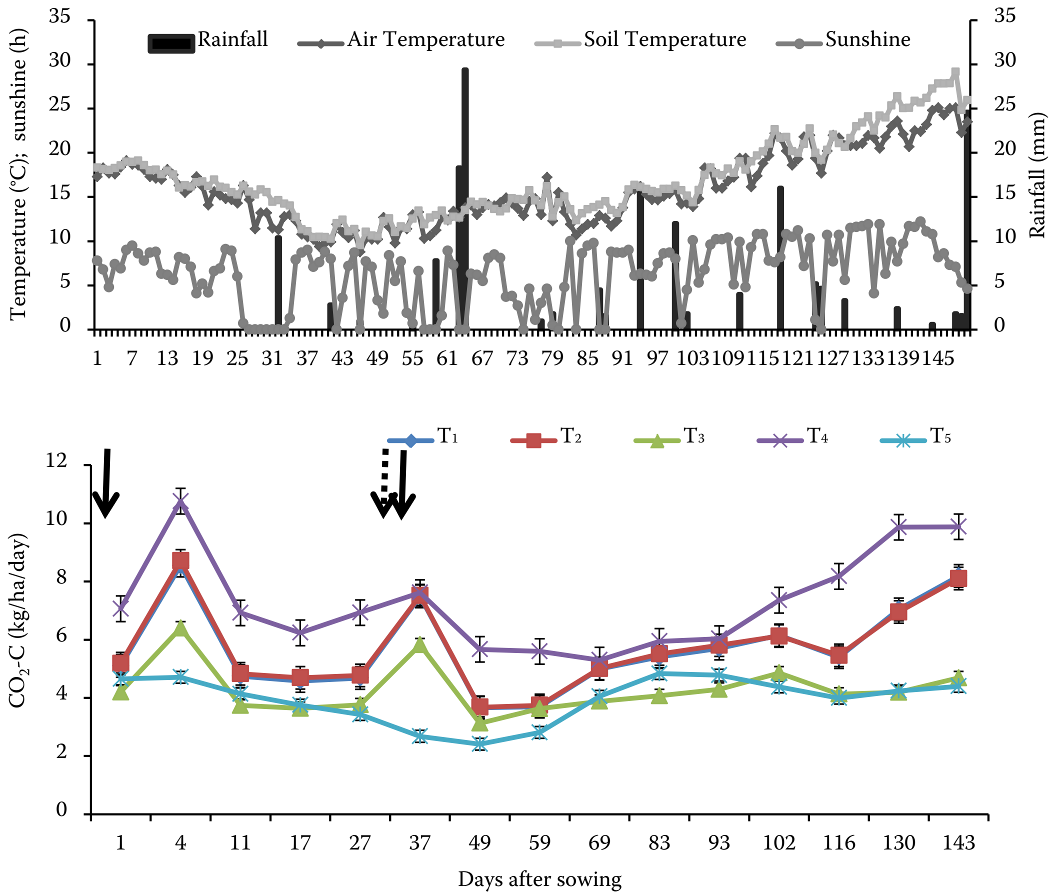

Figure 2. Temporal variations in weather variables and CO_2 fluxes in different treatments in the wheat crop seasons (solid arrows indicate N-fertilization and dotted arrows irrigation). T_1 – 100% NPK; T_2 – 150% NPK; T_3 – 100% N; T_4 – 100% NPK + FYM; T_5 – control

in CO_2 emissions in middle of wheat season coincided with drop in temperature, while towards the end of season soil moisture and temperature together controlled quantum of CO_2 emissions. Rise of flux in T_5 in the middle of season and then drop afterwards could have been the effect of higher root activity resulting in higher root exudation during vegetative and flowering growth stages (Dhadli et al. 2015). It was reported that specific root-derived respiration is higher during early vegetative growth and decline thereafter during reproductive and senescence stages (Fu et al. 2002, Sey et al. 2010, Jans et al. 2010). Further, soil CO_2 emissions have found to be regulated by soil temperature and moisture (Peng et al. 2011, Allaire et al. 2012, Dhadli et al. 2015). Soil moisture coupled with soil temperature and other soil-atmospheric interactions had been found to greatly affect soil CO_2 emissions, and an increase for shorter period after N application was also recorded (Dhadli et al. 2015, Mbonimpa et al. 2015).

Relationship of CO_2 emission with soil C and N status. In the soil samples collected before the sowing of both the maize and wheat crops, SOC and C_{tot} were significantly high in T_4 followed by T_1 and T_2 at par with each other, while T_3 and T_5 were at par at lower level (Table 2). Effect of various long-term treatments was significant on N_{tot} and N_{min} and they were found significantly higher in T_4 and at lowest levels in T_5. Increase in SOC due to continuous cropping with the input of inorganic fertilizers and manures has been reported by Ding et al. (2014). During maize, average and total CO_2 flux have higher significant (P < 0.01) correlation with SOC and N_{tot} as compared to C_{tot} and N_{min} (Table 3). In wheat season, all C and N forms have highly significant correlation with average and total CO_2 emissions, but it was

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Table 2. Effect of long-term application of inorganic fertilizers and farmyard manure (FYM) on soil carbon (C) and nitrogen (N) forms before sowing of maize and wheat crops

	SOC	C_{tot}	N_{min}	N_{tot}
	(g/kg)			
Maize				
T_1	4.2^{b}	4.6^{b}	0.08^{bc}	0.48^{bc}
T_2	4.2^{b}	4.5^{b}	0.09^{ab}	0.52^{b}
T_3	3.3^{c}	3.9^{c}	0.07^{c}	0.44^{c}
T_4	5.3^{a}	6.1^{a}	0.10^{a}	0.60^{a}
T_5	3.0^{c}	3.6^{c}	0.06^{c}	0.39^{d}
Wheat				
T_1	4.0^{b}	4.7^{b}	0.08^{ab}	0.51^{bc}
T_2	4.0^{b}	4.8^{b}	0.09^{ab}	0.52^{b}
T_3	3.3^{c}	3.7^{c}	0.07^{bc}	0.46^{c}
T_4	5.2^{a}	5.9^{a}	0.10^{a}	0.68^{a}
T_5	3.0^{c}	3.6^{c}	0.06^{c}	0.39^{c}

Values followed by the same letters in a column are not significantly different ($P < 0.05$). SOC – soil organic carbon; C_{tot} – total carbon; N_{min} – mineral nitrogen; N_{tot} – total nitrogen; T_1 – 100% NPK; T_2 – 150% NPK; T_3 – 100% N; T_4 – 100% NPK + FYM; T_5 – control

higher with both the soil C forms. Wheat grain and straw yield was found significantly correlated with N_{min}. The highest increase in C_{tot} upon long-term application of FYM followed by balanced NPK fertilizers in a long-term experiment under maize-wheat was recorded in China (Gong et al. 2009). CO_2 emissions were found related to SOC in maize and wheat seasons in a long-term experiment in China (Ding et al. 2007).

As a result of long-term differential application of inorganic fertilizers and FYM in the maize-wheat cropping system, the status of various soil C and N forms in various long-term treatments differed significantly after 42 years, which consequently resulted in significant differences in soil CO_2 emissions and crop yields amongst various long-term treatments. Although CO_2 emissions were higher from NPK fertilizer and FYM treatments, these treatments present status of soil C was significantly higher than the soil C status at the beginning of the experiment and the current status of control treatment. It can be concluded that although long-term application of balanced

Table 3. Correlation of soil carbon (C) and nitrogen (N) forms with CO_2 emissions and crop yields

	SOC	C_{tot}	N_{min}	N_{tot}
Maize				
Average flux	0.99**	0.96*	0.96*	0.98**
Cumulative flux	0.98**	0.96*	0.96*	0.98**
Grain yield	0.96*	0.91*	0.98**	0.97*
Straw yield	0.77	0.66	0.91*	0.82
Wheat				
Average flux	0.99**	1.00**	0.98**	0.98**
Cumulative flux	0.99**	1.00**	0.98**	0.98**
Grain yield	0.84	0.81	0.90*	0.86
Straw yield	0.92*	0.91*	0.96**	0.92*

*$P \leq 0.05$; **$P \leq 0.01$; SOC – soil organic carbon; C_{tot} – total carbon; N_{min} – mineral nitrogen; N_{tot} – total nitrogen

inorganic fertilizers and FYM resulted in higher CO_2 emissions, still they are environmentally sustainable management practices, as they helped in achieving higher yields along with carbon sequestration in plants and soils.

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