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FULL-LENGTH RESEARCH ARTICLE

Greenhouse Gas Fluxes from Sugarcane and Pigeon Pea Cultivated Soils

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Abstract Quantification of greenhouse gas (GHG) emissions from agricultural lands is essential for strategic planning towards GHG efficient development in India. We measured the fluxes of CH_4, N_2O and CO_2 during cultivation of two important crops; sugarcane and pigeon pea following the closed chamber technique. Both the soils acted as net CH_4 sinks, but sources of N_2O and CO_2. Pigeon pea soil acted as a weak sink, removing 0.054 ± 0.002 kg CH_4 ha^{-1} from the atmosphere, while sugarcane soil removed 11.061 ± 0.093 kg CH_4 ha^{-1}. Urea application in sugarcane field increased the fluxes of N_2O, but the total N_2O emission over growth period of sugarcane (355 days) was similar to the total emissions during pigeon pea cultivation (245 days); 2.69 ± 0.09 and 2.07 ± 0.17 kg N_2O ha^{-1}, respectively. CO_2 fluxes from pigeon pea cultivation were higher than sugarcane cultivation. Pigeon pea cultivation was a low input farming, but its global warming potential was higher than that of sugarcane cultivation. This study presents the GHG estimates from cultivation of the two important crops in India for which GHG estimates are lacking.

Keywords Sugarcane · Pigeon pea · Methane · Nitrous oxide · Carbon dioxide · Global warming potential

Introduction

Agriculture sector contributes around 17.6 % to the total annual anthropogenic emissions of greenhouse gases (GHGs) from India [19]. While 1.5 billion ha is already occupied by croplands, rising food demand will further cause expansion and intensification of agricultural fields [36]. In order to achieve the goal of stabilizing GHG emissions while sustaining food production, it is essential to make agricultural practices more GHG efficient. This requires a comprehensive assessment of GHG emissions under different cropping systems and cultivation practices along diverse climatic conditions. Though substantial work has been done on estimation of GHG intensities of crop production worldwide, such estimates are limited only to major crops mainly rice, wheat and maize [16, 23]. Information from other cropping systems is still limited. Croplands are responsible for a major part of anthropogenic emissions of N_2O and to a small degree, CO_2 [23]. In certain cases, however, croplands also act as sinks of atmospheric CH_4 [22, 29]. Better estimates of GHG emissions and mitigation potential of different agricultural systems is, therefore necessary for effective and justifiable planning towards more GHG efficient development and for reducing the overall carbon footprints of food production and distribution systems [26, 29]. These issues hold utmost importance for countries like India, where agriculture is the largest land use and food demand is very high.

In the present study, we attempted to estimate the soil borne fluxes of CH_4, N_2O and CO_2 during sugarcane (*Saccharum officinarum* L.) and pigeon pea (*Cajanus cajan* L.) cultivation and calculated their global warming potential (GWP). We found only few studies over quantification of GHG fluxes from cultivation of sugarcane that include Denmead et al. [5, 7] and Weier [39–41], who estimated fluxes of CH_4 and N_2O from Australian sugarcane fields. These studies

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showed that fluxes of N_2O and CH_4 in sugarcane fields are highly variable and depend on cultivation practice as well as soil quality. Denmead et al. [5] observed that CH_4 emission from sugarcane cultivation on acid sulfate soil was comparable to the values observed from rice fields, and N_2O emission was also higher than average emissions from croplands. But in other studies, soils acted as net sinks with CH_4 consumption rates ranging from 0.02 to 0.42 $\mu g\ m^{-2}\ s^{-1}$ [7, 41].

In India, sugarcane is the sole source of sugar production, the second largest agro-based industry in the country. It also forms the basis of ethanol production, which is being promoted by the Government of India in order to decrease dependence of fuel imports [14]. It is therefore, an important cash crop for farmers. About 2.6 % of India's gross cropped area during 2006–2007 was under sugarcane cultivation [10]. It is a resource intensive crop susceptible to pests, water stress and temperature stress.

Pigeon pea on the other hand is a drought tolerant leguminous crop with a wide range of growth duration ranging from 90 to 300 days which make its cultivation popular in a range of environments and cropping systems. It is cultivated over 3.58 Mha in India [12]. With an average protein content of 20–22 %, it is a traditional and major protein source in Indian diet [34]. Besides, it is also an important fodder crop especially in dry regions. Due to minimal or nearly no input requirement, this is a popular crop among resource poor farmers. For low or no need of N fertilizers, cultivation of leguminous crops helps avoiding emissions related with fertilizer production and application [42], although legume-derived N can also participate in processes leading to N_2O production in soil [31]. Ghosh et al. [13] reported that N_2O emissions from leguminous crops may exceed the emissions from rice and wheat cultivation, thereby highlighting the importance of in situ measurements. A number of studies have been conducted in India to estimate the emission of GHGs from legumes; however, studies that address pigeon pea in this respect are still lacking. Swami et al. [35] estimated the fluxes of CH_4 and N_2O from cultivation of *Vigna radiata* and *Vigna mungo* and observed that during the seasonally integrated CH_4 flux to be 0.009 and $-4.06\ g\ m^{-2}$, respectively. Total N_2O emissions during *V. radiata* and *V. mungo* cultivations were respectively 3.38 and $-7.6\ g\ m^{-2}$. In a pot experiment, Ghosh et al. [13] measurd N_2O emissions from *V. mungo*, *Glycine max*, *Cicer arietinum* and *Lens esculenta*. They observed that emissions of N_2O ranged between 0.45 to 3.84 $kg\ ha^{-1}$.

The present study will contribute to the existing GHG estimates from croplands other than major crops.

Materials and Methods

Agricultural fields under sugarcane and pigeon pea cultivation as per the farmers practice were selected for the study. The sugarcane farm of 1.0 ha area was located at the agricultural research farm of the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. In this field, sugarcane was cultivated continuously since October 2003 The 0.5 ha pigeon pea farm was situated at the Vegetable Research Farm of the Banaras Hindu University, Varanasi. This field was maintained continuously under pigeon pea cultivation since 1995. The experimental soil at both the sites is inceptisol with sandy loam texture. Meteorological conditions during the study period are provided in Fig. 1.

Soil Sampling and Analysis

On each monitoring day, reduction potential (Eh), soil temperature (*T*s) and gravimetric water content (GWC) were estimated. Eh and *T*s were measured using a double junction ORP Tester 10 (Eutech Instruments, Mumbai, India) and mercury thermometer (1/10 °C), respectively. Both the measurements were taken at 10 cm depth at ten randomly selected locations. For GWC estimation, soils from 15 cm depth were collected from four different places randomly in each treatment with the help of an auger. Organic carbon, total nitrogen and available phosphorus in the soil were initially determined in the samples collected on the day of sowing seeds (pigeon pea) or transplantation (sugarcane) and on the date of harvest. For these analyses, samples were collected in the same way as was described for determining GWC at four randomly selected places. The collected soil samples were mixed together to get a composite sample, which was then air dried and ground to pass through 2 mm sieve. Soil organic carbon and total nitrogen were determined following Walkley and Black [38] and micro Kjeldahl digestion method using Gerhardt Automatic N Analyzer (Frankfurt, Germany), respectively. Available phosphorous was extracted following Olsen et al. [27] and estimated by the method of Dickman and Bray [9].

Raising of Crops

For transplanting of sugarcane (*S. officinarum* L. cv. CoS–95255), land was chisel ploughed, followed by planking. Recommended dose of NPK (200 kg N + 60 kg P_2O_5 + 60 kg K_2O) was applied through 15:15:15 NPK complex fertilizer and urea. Stocks were transplanted on 20th March 2009 with 1 m distance between consecutive stocks. At 125 days after transplantation (DAT), the exposed roots of canes were covered with surrounding soil by earthing up. To prevent lodging of the canes, the canes from the individual clumps were tied together with leaves at 160 DAT. Land was irrigated weekly through channel irrigation up to 45 DAT. Afterwards, irrigation was done on monthly basis. Due to earthing up, small furrows and

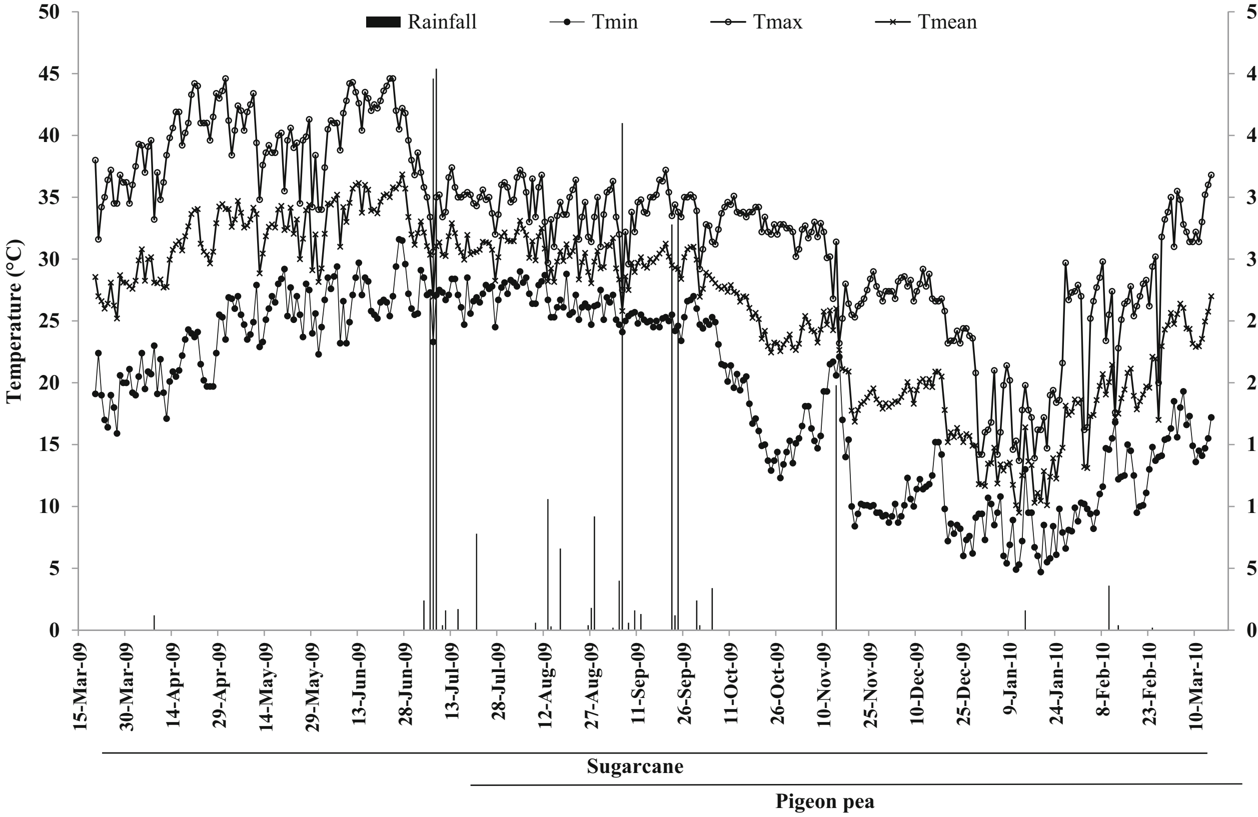

Fig. 1 Meteorological conditions during the study period

ridges formed, but this did not create waterlogged conditions for more than 5–6 h. Mature canes were harvested manually on 10th March, 2010.

Seeds of pigeon pea (*C. cajan*, cv. IPA 203) were sown on 16th July, 2009 on a prepared land which involved chisel ploughing up to 15 cm and planking. Seeds were sown in rows with 40 cm distance between two plants. Row to row space was 50 cm. No fertilizer was applied either at the time of sowing or during the crop growth. The field was rain fed and no irrigation was done during the study period. The crop was harvested on 15th March 2010.

Measurements of Fluxes of CH_4, N_2O and CO_2

Fluxes of CO_2, CH_4 and N_2O from soil were measured since the date of transplantation of sugarcane and sowing of the pigeon pea and continued up to the date of the respective harvestings. Manual closed chamber technique was used for measurement of GHG fluxes [8]. The cylindrical steel chambers (20 cm diameter, 15 cm height) had separable steel bases. The steel bases were permanently installed at ten places selected randomly in each field. The bases were fixed between the plant rows. The chambers were fixed firmly on water filled rim of four bases selected randomly. A battery operated fan was used to ensure uniform mixing of air inside the chamber. Temperature inside the chamber was recorded by the mercury thermometer (1/20 °C) attached with the camber top with its sensor reaching midway of the chamber height. The chamber was provided with one sampling port on the top fitted with non reactive rubber septum which was attached with a moisture trap of $MgCl_2$. The chamber had a vent tube of 3.5 mm diameter and 12 cm length. Samples were drawn for CH_4 and N_2O with 20 ml air tight syringes at 0, 20, 40, 60, 80, 120, 140, 160 and 180 min and transferred immediately into pre-evacuated vacuum tubes of 4 ml capacity (Vacutainer, Becton, Dickinson & Company, New Jersey USA). Concentrations of CH_4 and N_2O in the gas samples were estimated on Gas Chromatograph (CP 3800, Varian, California, USA) the same day. CH_4 was analyzed on flame ionization detector (FID), while electron capture detector (ECD) was used for N_2O. Gases were separated on stainless steel column packed with PORAPAK-Q (50–80 mesh). N_2 at 30 ml min^{-1} was used as the carrier gas. For FID, flow rates of H_2 and zero air were maintained at 30 and 300 ml min^{-1} respectively. Temperature of ECD and FID were maintained at 280 and 250 °C respectively.

The gas chromatograph was calibrated with the gases of known standards obtained from the National Physical Laboratory, New Delhi, India. For CO_2 measurements, a portable CO_2 analyzer (Li-820, LI-COR Biosciences, USA) was connected directly to the chamber for continuous CO_2 measurements at 1 s log time. Change in concentration of the gases was calculated from regression equation between time and concentration of gas inside the chamber taking the readings only up to the linear rate of change of concentration. From this change, flux was calculated according to the formula given by Liu et al. [24].

$$F = (\Delta m/\Delta t)/A,$$

where, $\Delta m/\Delta t$ is the change in mass of the gas inside the chamber with respect to time, A is the area of the soil covered by the chamber (m^2), F is the flux obtained in mass of the gas per unit area per unit time. The method detection limit (MDL) for CH_4 and N_2O were, respectively 0.14 and 0.20 $\mu g\ ml^{-1}$.

Chambers were installed for three hours during daytime (08:30–11:30 AM). An interval of seven days was maintained between successive monitoring dates. Monitoring dates were adjusted to take measurements the next day after rainfall events.

To calculate the cumulative emission or removal of CH_4 and N_2O, area under the curve was calculated assuming that fluxes changed linearly between two successive monitoring dates. GWP of the sugarcane and pigeon pea cultivation were calculated as summation of cumulative CO_2 equivalent (CO_2-e) emissions of CH_4, N_2O and CO_2 using the conversion factors for 100 year time horizon given in [20]. GWP of CH_4 and N_2O are respectively, 25 and 298.

Statistical Analysis

The means and standard errors of different soil parameters and GHG fluxes were calculated. *t* test was conducted to check the differences between mean values of different soil parameters and cumulative emissions. Correlation coefficient between different soil parameters (GWC, T_s and Eh) and fluxes of GHGs (CH_4, N_2O and CO_2) were conducted. All the statistical analyses were performed on SPSS version 10.0, IBM USA.

Results and Discussion

Soil Properties

Soil at both the sites was sandy loam in texture and neutral pH (Table 1). Due to application of inorganic fertilizers during cultivation of sugarcane, total N and available P contents were higher at the site at the time of transplantation of stocks as compared to the levels on respective nutrients in the soil at the time of harvest. In case of pigeon

Table 1 Physico-chemical properties of soil under sugarcane and pigeon pea cultivation

	Sand (%w/w)	Silt (%w/w)	Clay (%w/w)	pH	Dry bulk density (g cm^{-3})	SOC (mg g^{-1})	Total N (μg g^{-1})		Available P (μg g^{-1})	
							Transplanting/sowing	Harvesting	Transplanting/sowing	Harvesting
Sugarcane	58.96	29.04	12.00	7.18 ± 0.07	1.49 ± 0.03	3.81 ± 0.05	49.32*** ± 0.10	15.03 ± 0.10	10.85*** ± 0.03	4.43* ± 0.03
Pigeon pea	59.96	27.04	13.00	7.01 ± 0.01	1.42 ± 0.01	6.21 ± 0.01	35.32** ± 0.10	38.44 ± 0.10	9.23** ± 0.04	7.83 ± 0.01

Values are mean ± 1SE

Level of significance of differences between respective mean values of nutrient contents at the time of sowing and after harvesting according to *t* test: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

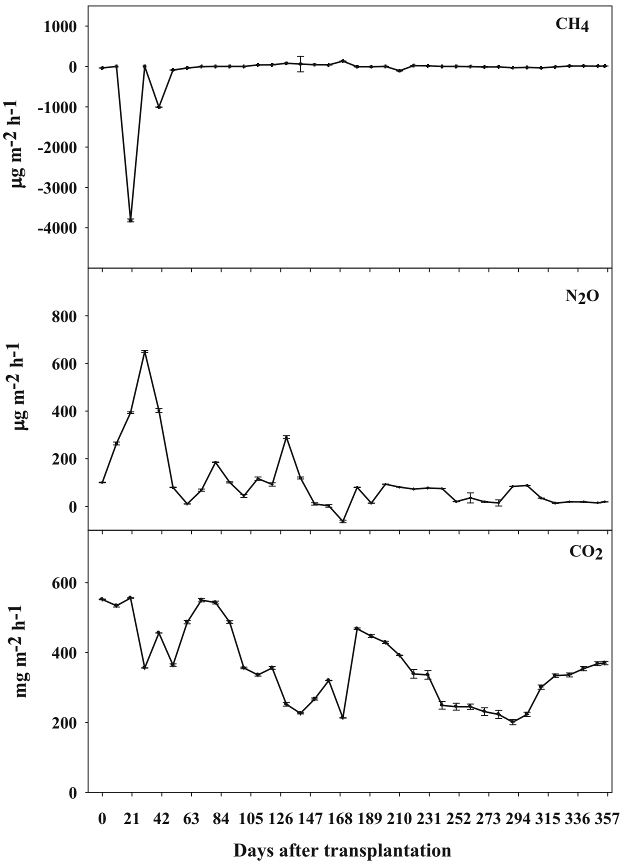

Fig. 2 Fluxes of CH_4, N_2O and CO_2 during cultivation of sugarcane

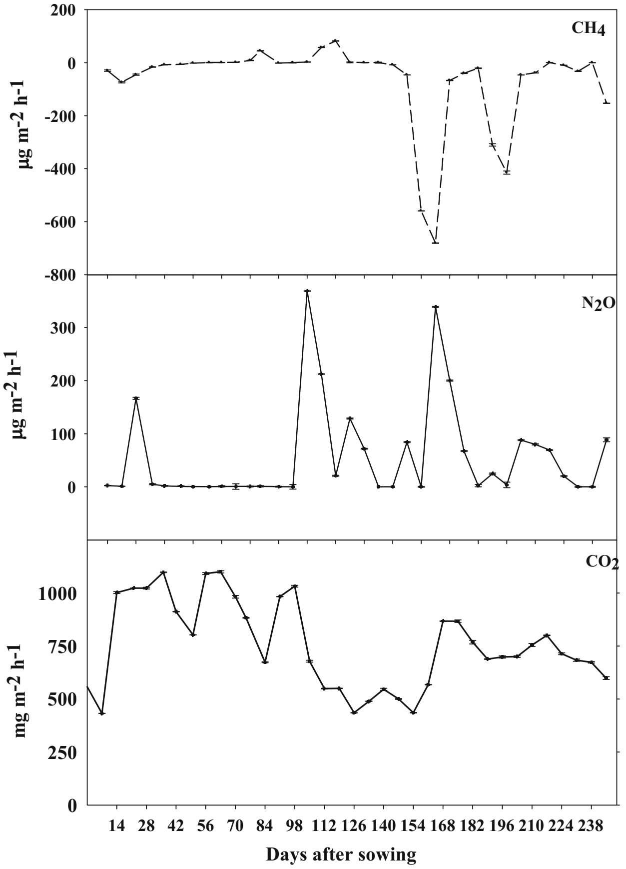

Fig. 3 Fluxes of CH_4, N_2O and CO_2 during cultivation of pigeon pea

pea, similar levels of N was maintained at the time of harvest ad sowing in the pigeon pea field, but P content decreased. Long term cultivation of nitrogen fixing pigeon pea improved the background concentrations of N in soil, which was maintained even after the harvest of the crop. Graham and Vance [15] and Vance [37] observed an improvement in soil P content under cultivation of legumes. Macedo et al. [25] also observed that leguminous trees could efficiently restore the nutrients in degraded soils.

CH_4, N_2O and CO_2 Fluxes

Cultivation of sugarcane as well as pigeon pea acted as net sources of N_2O and CO_2 throughout the monitoring period. In case of CH_4 however, fluxes attained positive and negative values at different stages of crop development (Figs. 2 and 3), both the agricultural soils, however, acted as net sinks of CH_4.

CH_4

During sugarcane cultivation, CH_4 fluxes fluctuated from -3816.7 $\mu gm^{-2}\,h^{-1}$ during early vegetative stages, to 131.1 $\mu gm^{-2}\,h^{-1}$ during late maturity. High negative fluxes of CH_4 were observed up to 40 DAT. Afterwards, nearly zero or very low positive CH_4 fluxes were recorded. In case of pigeon pea, CH_4 fluxes fluctuated between -681.7 and 57.3 $\mu gm^{-2}\,h^{-1}$. Overall, both the soils acted as net sinks of CH_4, sugarcane being a stronger sink than pigeon pea (Figs. 2 and 3). It is well recognized that aerobic soils oxidize CH_4 due to stronger methanotrophy and weak methanogenesis [22]. Eh values observed during the present study (Fig. 4) clearly indicated that soil of both the croplands remained predominantly under oxidized conditions. However, small positive fluxes were also observed which indicated towards dominance of methanogenesis under certain set of conditions.

During sugarcane cultivation, strong negative fluxes continued up to 50 DAT after which fluxes subsided to nearly zero to small positive values. It could be due to reduced compaction in upper layers of soil due to ploughing during land preparation thereby improving exchanges of atmospheric CH_4 in methanotrophically active zone. This is also expected to improve oxygen availability in soil, which is a prerequisite for methanotrophy. Previous researches have demonstrated that in upland soils, compaction may reduce CH_4 oxidation up to 50 % [17]. It is also observed that destruction of microaerophilic niches

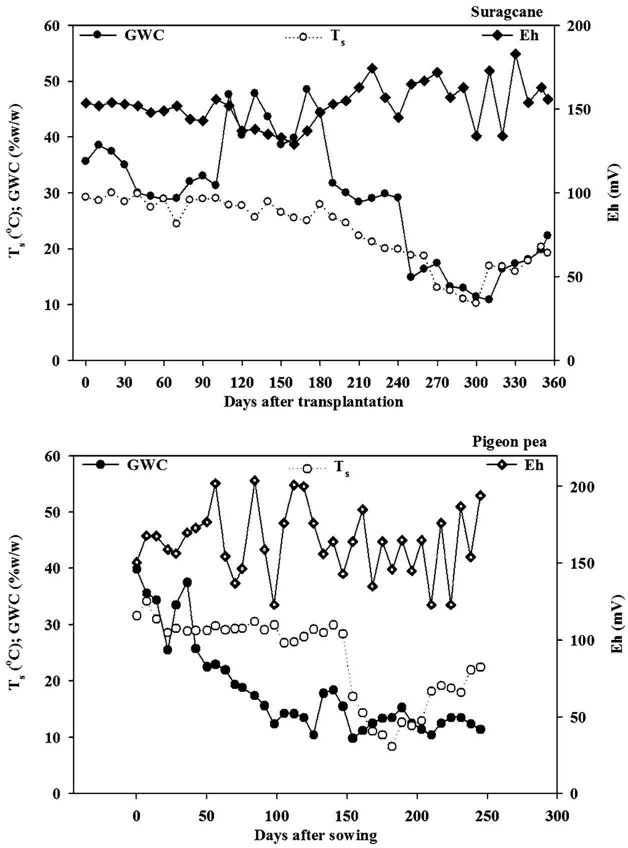

Fig. 4 Soil temperature and gravimetric water content of soil during cultivation of sugarcane can pigeon pea

and disruption in the organic matter enriched layer decrease methanogenesis, thus reducing CH_4 production [18]. After 50 DAT, increase in positive fluxes of CH_4 indicated that methanogeneis became stronger relative to methanotrophy, though Eh values indicated that soil remained dominantly aerobic up to the depth of measurement i.e.10 cm. Positive CH_4 fluxes from aerobic sandy loam soils have also been observed by Pandey et al. [29].

In aerobic soils, CH_4 consumption is a well observed phenomena, but its quantification studies are still very meagre to generate a comprehensive view. Ellert and Janzen [11] calculated an average CH_4 consumption rate of -6 μg m^{-2} h^{-1} in wheat-barley cropping systems in sequences with corn or legumes in Canada under different fertilizer managements.

During pigeon pea cultivation also, the fluxes of CH_4 remained negative up to 42 DAS which could be due to better aeration and CH_4 exchange between atmosphere and soil as a consequence of land preparation. Afterwards fluxes remained very low and generally positive. After 140 DAS, fluxes again became negative and the soil acted as a CH_4 sink up to the harvest.

No significant correlation of CH_4 fluxes with any of the soil property was observed for sugarcane as well as pigeon pea cultivation (Table 2).

N_2O

During sugarcane cultivation, N_2O fluxes varied between 2.07 to 649.8 μgm^{-2} h^{-1}. Highest fluxes were recorded during early vegetative stages up to 28 DAT. Application of nitrogenous fertilizer like urea in the sugarcane field induced the generation of N_2O leading to high emission rates. Denmead et al. [7] also observed high N_2O fluxes after urea application in sugarcane fields, which subsided abruptly after the N in the soil was used up. A significant positive correlation of N_2O fluxes with T_s and GWC in the present study showed that higher temperature and better moisture conditions promoted N_2O emissions. This observation is in agreement with Sahrawat and Keeney [33], though such correlations are usually masked under field conditions [2]. N_2O fluxes were also found to be correlated negatively with CH_4 fluxes. It indicated that the conditions that favored CH_4 emissions during sugarcane cultivation helped limiting N_2O emissions.

On the contrary, no N fertilizer was applied during pigeon pea cultivation, even though N_2O emissions were observed. The rate of emissions, were nevertheless much less than those observed under sugarcane cultivation in which urea was applied. This indicated that pigeon pea which is a leguminous crop, led to lower N loss as N_2O,

Table 2 Correlation coefficients between fluxes of CH_4, N_2O and CO_2 and soil properties

	Sugarcane ($n = 37$)						Pigeon pea ($n = 36$)					
	CH_4	N_2O	CO_2	Eh	GWC	T_s	CH_4	N_2O	CO_2	Eh	GWC	T_s
CH_4	1.00	−0.44**	−0.35*	−0.45	−0.09	−0.23	1.00	−0.25	0.32	−0.04	0.22	0.24
N_2O		1.00	0.31	−0.71	0.30*	0.92**		1.00	0.01	−0.08	−0.26	0.02
CO_2			1.00	−0.07	0.28	0.63**			1.00	−0.21	−0.39*	0.12
Eh				1.00	−0.53**	−0.39*				1.00	0.06	0.01
GWC					1.00	0.82**					1.00	0.50**
T_s						1.00						1.00

Level of significance (2 tailed): * $p < 0.05$; ** $p < 0.01$

while improving N content in the soil. At reproductive stage (after 105 DAS), high fluctuations in N_2O fluxes were observed. It could be due to litter fall on the soil which acted as N source and hence N_2O emissions increased for some brief periods (Fig. 3). Several studies have shown that root exudates from legumes and N rich litter fall on the soil also causes N_2O emissions [42]. Besides, symbiotic N fixing bacteria including *Rhizobia* are also known to produce N_2O through denitrification [32].

CO_2

CO_2 fluxes remained positive throughout the crop duration for both the crops, although there was no particular temporal trend (Figs. 2 and 3). CO_2 fluxes basically represent the soil respiration and hence, are often used as a proxy of microbial activity. CO_2 emissions were generally high during initial growing stages for both the crops and decreased up to the maturity and harvest.

In sugarcane field, CO_2 fluxes ranged from 552.11 mg m^{-2} h^{-1} on the date of transplantation of sugarcane stocks to 201 mg m^{-2} h^{-1} during maturity. Up to 15 DAT, CO_2 fluxes remained the highest. It could be due to the farm activities related with land preparation and transplantation. Ploughing and irrigation are widely reported to increase soil respiration by exposing the organic matter and its availabilities for microbial activities [21]. Fertilizer application also improves microbial activities resulting into the pulses of CO_2 emissions [4]. Correlation analyses also showed strong positive correlation of CO_2 fluxes from sugarcane field with GWC and T_s.

During pigeon pea cultivation, CO_2 fluxes ranged from 432 to 1100.43 mg m^{-2} h^{-1} (Fig. 3). Initial soil disturbance during pigeon pea cultivation may have led to high rates of CO_2 emissions during 7 to 45 DAS. CO_2 fluxes remained highest during the initial vegetative stages of the crop. This period corresponded to rainy season with soil temperatures ranging between 28 to 32 °C. As already discussed that moderate moisture and temperatures lead to high microbial activities; significant positive correlations were obtained between CO_2 fluxes and T_s and GWP in pigeon pea fields. Among the two crops, pigeon pea cultivation emitted CO_2 at a higher rate than sugarcane cultivation.

Cumulative Emissions and Global Warming Potential

Figure 5 presents the net emission or consumption of the three GHGs as CO_2-e during growing period of the two crops. Over the crop growth period, both sugarcane and pigeon pea fields acted as sinks of atmospheric CH_4 but sink strength of sugarcane soil (-11.06 kg CH_4 ha^{-1}) was much stronger than pigeon pea soil (-0.05 kg CH_4 ha^{-1}). Though there was marked difference in fertilizer managements and growing periods of the two crops, there was no significant difference in the cumulative emissions of N_2O. Total N_2O emitted during pigeon pea and sugarcane cultivation were 2.68 and 2.07 kg N_2O ha^{-1}, respectively (Fig. 5). Average cumulative CO_2 emission from pigeon pea was higher than the emission from sugarcane cultivation.

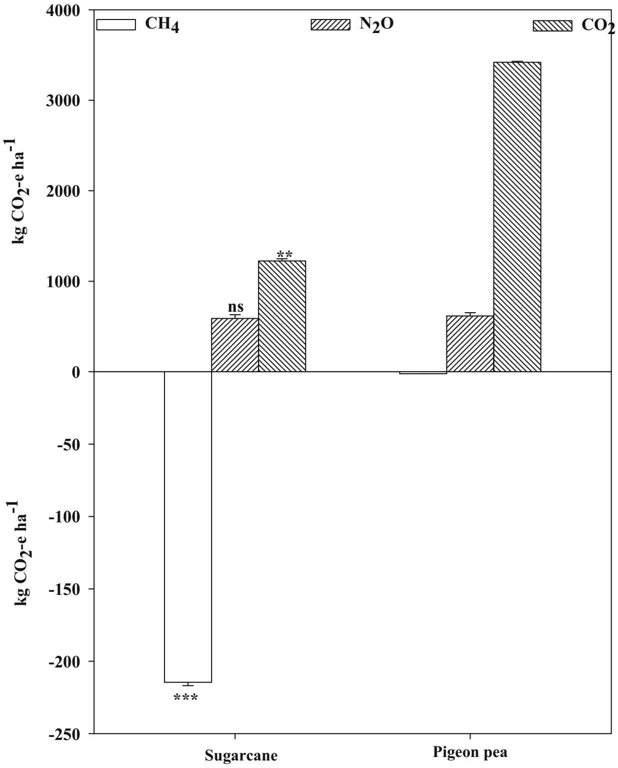

Fig. 5 Cumulative emission of CH_4, N_2O and CO_2 expressed as carbon dioxide equivalent over 100 years time horizon for cultivation of sugarcane and pigeon pea

Comparison of cumulative emissions of GHGs and GWP of sugarcane and pigeon pea cultivation in the present study is made with similar studies conducted for other crops in Table 3.

It is clear that CH_4 is the dominant GHG during rice cultivation, however, in other croplands, where soil conditions are aerobic, N_2O emissions become predominant and soils may even act as a net sink of CH_4. Linquist et al. [36] calculated an average GWP of rice, wheat and maize cultivations, considering CH_4 and N_2O. The highest GWP was of rice cultivation (3757 kg CO_2-e ha^{-1}) and the least for wheat (662 kg CO_2-e ha^{-1}). Considering these two GHGs, the GWP of sugarcane and pigeon pea cultivation in the present study was found to be comparable (respectively 544.50 and 614.44 kg CO_2-e ha^{-1}). However, CO_2 emissions increased the total GWP by an order. The GWP of pigeon pea was more than the GWP of sugarcane cultivation. GWP of sugarcane in our study was lower that calculated by Denmead et al. [5], whereas, GWP of pigeon

Table 3 Emissions of CH_4, N_2O and CO_2 and global warming potential of cultivation of some crops and sugarcane and Pigeon Pea in the present study

	Crop	Region	Soil borne emissions (kg ha^{-1})			GWP (kg CO_2-e ha^{-1})	Reference
			CH_4	N_2O	CO_2		
1	Rice	Global average	3.12×10^3	1.49×10^2	–	3.76×10^3	[23]
2	Rice	India	3.72×10^3	9.28×10^2	3.10×10	1.34×10^3	[28]
3	Rice	India	35.10	1.79	1.58×10^3	3.01×10^3	[3]
4	Wheat	Global average	–	3.39×10^2	–	6.62×10^2	[23]
5	Wheat	India	-6.72×10	5.96	8.78	-6.67×10	[29]
6	Wheat	India	–	2.31	1.92×10^2	2.61×10^3	[3]
7	Maize	Global average	–	4.38×10^2	–	6.68×10^2	[23]
8	Maize	USA	-1.1×10^2	1.17×10^3	–	1.06×10^3	[1]
9	Alfalfa	USA	-6.0×10	5.90×10^2	–	5.30×10^2	[30]
10	Sugarcane	Australia	5.8×10^2	2.15×10^4	3.78×10^4	5.99×10^4	[7]
11	Sugarcane	Australia	$0–5.8 \times 10^3$	$2.30 \times 10^3–2.24 \times 10^4$	$3.50 \times 10^3–8.2 \times 10^3$	$1.05 \times 10^4–3.73 \times 10^4$	[6]
12	Sugarcane	India	-2.76×10^2	8.01×10^2	2.25×10^3	2.77×10^3	Present study
13	Pigeon pea	India	-1.37	6.16×10^2	3.28×10^3	3.90×10^3	Present study

pea was higher than reported by Robertson et al. [30] for another legume, alfalfa. The results highlight the importance of estimating GHG intensities of cropping systems for which such data is still missing.

Conclusions

Soil properties of fields under pigeon pea and sugarcane cultivations were significantly different from each other. Pigeon pea cultivation helped improving soil organic carbon, total nitrogen and available phosphorous despite of the fact that no inorganic fertilizer or manure was applied during its cultivation. This indicated that pigeon pea is a resource conserving crop which can be used to improve soil fertility. Fluxes of CH_4, N_2O and CO_2 during cultivation of sugarcane and pigeon pea also showed marked differences in temporal trends as well as their values. Both the soils acted as net sinks of CH_4, but sugarcane was stronger sink. N_2O fluxes during pigeon pea cultivation were lower than those observed during sugarcane cultivation, but due to its longer growing period, cumulative emissions of both the crops were similar. CO_2 fluxes showed high variations and were relatively much higher from pigeon pea compared to sugarcane field. Higher CO_2 emissions and weak negative CH_4 fluxes led to greater GWP of pigeon pea than sugarcane cultivation. Due to high spatiotemporal variations in GHG fluxes due to crops, crop management and climate, more studies are required; nonetheless, the results obtained in the study clearly convey that absence of data for regionally important crops may be a significant source of uncertainty in national GHG inventories.

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Conflict of interest There was no conflict of interest.

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