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Effect of Crop Rotation, Soil Temperature and Soil Moisture on CO_2 Emission Rate in Indo-Gangetic Plains of India

Mamta Srivastava[1], S. D. Sharma[2,*], M. Kudrat[3]

[1]Forest Soil & Land Reclamation Division, Forest Research Institute, Dehradun, 248006, India
[2]Forest Informatics Division, Forest Research Institute, Dehradun, 248006, India
[3]Regional Remote Sensing Centre, North, 4, Kalidas Road, Dehradun, 248001, India

Abstract Carbon dioxide (CO_2) efflux from soil is one of the very important components of global carbon cycle and climate change. Land use and climate are the major factors that influence the rate of CO_2 efflux. The present study was undertaken to evaluate the monthly variation in rate of CO_2 efflux and its correlation with soil temperature and soil moisture in agricultural lands under different crops and crop rotations in part of Indo-Gangetic plain in India. The Indo-Gangetic plain covers 13% geographical area of the country and produces 50% of the total food grain of the country. The agricultural lands are cultivated for variety of crops including, *Oryza sativa* (Paddy), *Triticum aestivum* (Wheat), *Zea mays* (Maize), *Brassica herta* (Mustard), *Trifolium alexamdrinum* (Barseem), *Sorghum bicolor* (Jowar), *Sachharum officinarum* (Sugarcane) and several pulses and vegetables. The average annual CO_2 emission rate ranged between 0.56 g $m^{-2}h^{-1}$ (wheat –fallow- paddy) and 0.75 g $m^{-2}h^{-1}$ (jowar-barseem) with a mean value of 0.64 g $m^{-2}h^{-1}$. The standard deviation varied from 0.06 to 0.25 and the standard error varied from 0.02 to 0.03. Wheat crop combinations (wheat-fallow-paddy, wheat-fallow, wheat-maize, wheat-pulses, wheat-sugarcane, wheat-jowar, and wheat-vegetable) showed relatively lower values of average annual CO_2 emission rate whereas highest emission rates were found in vegetable crops. During monsoon months the rate of CO_2 emission from soil was higher due to favorable moisture and temperature conditions, while in winter the same was observed minimum in all the crops. The study leads to infer that crop, crop rotation and soil temperature and moisture have significant effect on soil CO_2 emission.

Keywords CO_2 Emission, Monthly Variations, Agriculture, Crop Rotation, Indo-Gangetic Plain

1. Introduction

CO_2 efflux from soil generally referred to as CO_2 emission from soil or soil respiration is an important component of the terrestrial carbon budget and is the second largest factor in the flux of carbon between earth and the atmosphere[1, 2, 3]. This is the most representative manifestation of the biological as well as chemical processes in the soil as it produces 75-80 Pg of CO_2 - C annually[4], which is more than 10 times of the current rate of fossil fuel burning[5]. This phenomenon indicates that nearly 10% of atmospheric CO_2 cycles through soils each year[4]. Although lot of work on CO_2 emission or soil respiration has been carried out all over the globe[6, 4, 7, 8] but the work on CO_2 emission from the soils of Indo-Gangetic plain of India is scanty. It is, therefore, imperative to have an accurate measurement and thorough understanding of the seasonal variation in CO_2 efflux and the effect of agricultural crop on CO_2 emission.

In view of the above, an attempt has been made to evaluate influence of soil temperature and moisture and the crop rotation on monthly variations in CO_2 emission rate in the Indo-Gangetic plain which produces about 50% food grain of the country[9].

2. Materials and Methods

2.1. Study Area

The study was conducted in a part of Indo-Gangetic plains in the 5 districts of Uttar Pradesh and one district of Uttarakhand state of India. The study area extends over 16044.9 km^2 and covers the districts of Ghaziabad, Baghpat, Meerut, Muzzaffarnagar, Saharanpur and Haridwar. It lies between 28°40' N to 30° 21'N Latitude and 77° 07' E to 78° 14' E Longitude with a general elevation of 230m above msl. The climate of the study area is predominantly subtropical and the annual rainfall varies between 600–1000 mm. About 90% of the rainfall occurs during the southwest monsoon, lasting from June to September. The mean annual tempera-

* Corresponding author:
sharmasd@icfre.org (S. D. Sharma)
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ture varies between 22 and 29°C and the monthly temperature ranges from 8-10°C in December-January to 38-40°C during May-June. The summer season is very hot and persists from April to August. The winter falls around Mid-November and continues till February end.

The Psamments and Ustorthents of the Entisol order, Haplustepts of Inceptisols order and Haplustalfs of the Alfisol order occur as the main great group of soil and the agriculture is practiced in 24 out of the total 25 soil associations occurring in the area. The soils in general are deep and well drained. The texture of the soil varies widely between sand to fine loam. The soil reaction is near neutral to alkali and the pH varies from 7.4 to 7.9. The slopes are very gentle with slight to moderate erosion and flooding. Except the Siwalik hill, the area is plain and comprises piedmonts and recent and old alluvial plain.

2.2. Site Selection

The sites were selected on the basis of soil association[10] as well as agricultural crop /crop rotation of the area. The soil map prepared and published by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP 1999) Nagpur, was adopted as base map. Several kinds of crop rotations including paddy-vegetable, sugarcane-wheat, sugarcane-sugarcane, wheat-vegetable, wheat-pulses, wheat-fallow, jowar-barseem, maize-mustard, mustard-vegetable and maize-wheat are practiced. In order to include all the variations in terms of soil associations and crop rotations, the study was conducted in all the 24 soil associations. In all 53 sites were selected and at each site the measurements were recorded in 3 replications. The coordinates of each sample location were recorded with the help of mobile Global Position System (GPS).

2.3. Field and Laboratory Estimations

The measurement of CO_2 emission and soil temperature was carried out at an interval of one month, at each of the 53 sites for a period of 2 years from May 2007 to April 2009. The closed chamber, most popular and widely used method, for measuring CO_2 efflux from soil[11] was adapted. The measurements were made by PSP soil respiration system (EGM-4 CO_2 Analyser). The EGM-4 CO_2, a portable battery operated unit, is a non-dispersive infrared gas analyser that features an "Auto-Zero" facility. It permits instantaneous measurements of CO_2 concentrations. Soil temperature was also recorded at 5 cm soil depth, each month for a period of two years, by Soil Temperature Probe which is in-built with soil PSP respiration system.

Surface soil samples, 0-15 cm deep, were collected from each of the 53 selected sites at an interval of one month for a period of 24 months for estimation of moisture by gravimetric method[12].

3. Results and Discussion

The influence of crops and crop rotations and the soil moisture and temperature on CO_2 emission rate is presented below:

3.1. Effect of Crop and Crop Rotation on CO_2 Emission Rate

Among the various crops and crop rotations, the fodder crop (jowar-barseem) emitted highest amount of CO_2 (0.75 g $m^{-2}h^{-1}$) followed by vegetable grown sites either as vegetables alone (0.72 g $m^{-2}h^{-1}$) or vegetables in rotation with mustard (0.72 g $m^{-2}h^{-1}$) and wheat (0.71 g $m^{-2}h^{-1}$). Since these crops are irrigated twice a month, the moisture seems to be responsible for higher CO2 emission. Many workers[13, 14, 15, 8] demonstrated the significantly positive correlation of CO_2 emission rate with soil moisture. The frequent intercultural operation, being practiced in vegetable fields, lead to higher CO_2 emission rate. Intercultural operation has tillage like effect which significantly influences soil respiration rate[16]. Those sites where the lands were left fallow between two crops i.e. wheat-fallow-paddy and wheat-fallow emitted less amounts (0.56 g $m^{-2}h^{-1}$ and 0.57 g $m^{-2}h^{-1}$ respectively) of CO_2. The CO_2 emission rate in sugarcane fields was 0.60 g $m^{-2}h^{-1}$ but it was higher in those fields where sugarcane was removed to grow wheat (0.62 g $m^{-2}h^{-1)}$.

Wheat was found to be the major crop in the study area and it was grown in rotation with paddy, maize, jowar, sugarcane, pulses and vegetables. All wheat rotations showed relatively lower values of average annual CO_2 emission rate (0.56 g $m^{-2}h^{-1}$). The CO_2 emission rate followed the following trend in rotation of wheat with other crops (Figure 1):

Wheat-fallow-paddy < wheat-fallow < wheat-maize < wheat-pulse < wheat-sugarcane < wheat-jowar < wheat-vegetable

The suitable reason for this is not known, however the application of urea and DAP might have resulted in declining CO_2 emission rate. The application of higher nitrogen treatment in soil reduces 14 to 31 percent of soil CO_2 emission rate[17, 18, 19]. The results of the present study are also in agreement with that of Zheng *et.al.*[20] and Iqbal *et.al.*[21].

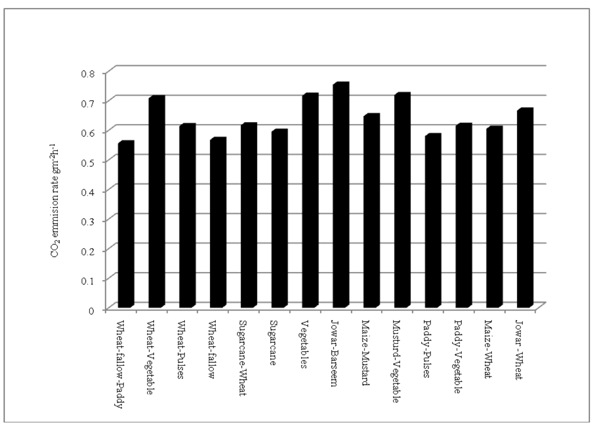

Figure 1. CO_2 emission rates in different crop rotations.

The CO_2 emission rates were significantly different for crop, months of sampling and their interaction (Table 1). Months, species and the interaction between them are significant at $p<0.05$ probability.

Table 1. ANOVA of crops, month of sampling and their interaction

ANOVA						
Source of Variation	*SS*	*df*	*MSS*	*F*	*P-value*	*F crit*
Crop	15.27	9	1.70	182.93	1.77E-128	1.906
Months	6.41	11	0.583	62.825	7.68E-77	1.815
Interaction	28.35	99	0.286	30.869	7.25E-129	1.288
Within	3.34	360	0.009			
Total	53.37	479				

3.2. Effect of Soil Temperature and Moisture on CO_2 Emission Rate

Soil moisture and temperature are the most influencing factors for CO_2 emission from soils[8, 22, 23, 24]. The soil temperature was highest in the month of April (34°C). It remained within a narrow range of 30°C to 31°C from May to August and then declined to 15°C in December. The soil moisture was only 6.02 % in the month of April and it increased to 14.92 % in June and remained between 13.43 and 14.92% during June-September.

The rate of CO_2 emission followed the similar trend and it was maximum (0.75 g m^{-2} h^{-1} to 0.95 g m^{-2} $h^{-1)}$ during monsoon months (June to September) whereas it was lowest in winter months (December-January).Highest rate (0.95 g m^{-2} $h^{-1)}$ was noticed in the month of August followed by 0.93 g m^{-2} h^{-1} in July and 0.82 g $m^{-2}h^{-1}$ in September (Table 2). In the monsoon months both the temperature and soil moisture are favorable for higher CO_2 efflux because of luxuriant growth of soil microbes. The rate of CO_2 emission from soil was lowest in the month of January 0.39 g $m^{-2}h^{-1}$ followed by December 0.40 g $m^{-2}h^{-1}$. Global CO_2 emission has been reported to be minimum during February and maximal during July and August[25] and similar trend has also been observed in grasslands[6].

Table 2. Monthly variations in CO_2 emission rate, soil temperature and soil moisture

Months	CO_2 Emission Rate (g $m^{-2}h^{-1}$)	Temperature (°C)	Moisture (%)
January	0.39	17	11.16
February	0.49	24	9.24
March	0.55	25	8.47
April	0.46	34	6.02
May	0.65	31	8.11
June	0.75	30	14.92
July	0.93	31	13.43
August	0.95	31	13.90
September	0.82	29	14.52
October	0.59	25	11.41
November	0.49	21	12.92
December	0.40	15	10.80
Significance	***	***	***
Level of significance	$p<0.01$	$p<0.01$	$p<0.01$
CD	0.060	0.86	1.29

3.3. Regression Analysis

The following regression equation explains the coefficient of determination between CO_2 emission rate and combined parameters of soil temperature plus soil moisture.

Y = -0.268 + 0.021 Temperature + 0.030 Moisture (R^2 = 0.435)

A significant correlation between CO_2 emission rate and temperature as well as moisture is revealed by the correlation matrix of CO_2 emission rate and soil moisture and soil temperature (Table 3). However, the correlation was less strong (r = 0.35) between CO_2 emission rate and soil moisture than that between CO_2 emission rate and soil temperature (r = 0.55).

Table 3 The correlation matrix of CO_2 emission, soil moisture and soil temperature

	CO_2	Temperature	Moisture
CO_2	1		
Temperature	0.55	1	
Moisture	0.35	-0.033	1

4. Conclusions

The trend of CO_2 emission rate is followed uniformly under all the land uses and soil associations i.e. maximum during monsoon and minimum during winter period. The monthly CO_2 emission showed wide variations. Highest rate was noticed in the month of August followed by July and September and it was lowest in the month of January followed by December. Soil moisture and temperature are the most influencing factors for CO_2 emission from soils. During monsoon period both the temperature as well as soil moisture are favourable for higher CO_2 efflux in the study area. Among the various crop rotations, the soils under Jowar-Barseem (fodder crops) had higher rate of CO_2 emission and the soils under vegetables crops showed next higher CO_2 emission rate. Wheat crop combinations (wheat-fallow-paddy, wheat-fallow, wheat-maize, wheat-pulses, wheat-sugarcane, wheat-jowar, and wheat-vegetable) showed relatively lower values of average annual CO_2 emission rate.

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