INTERNATIONAL JOURNAL OF ENVIRONMENT
Volume-3, Issue-3, Jun-Aug 2014 ISSN 2091-2854
Received:7 June *Revised:5 July* *Accepted:20 August*

AN EVALUATION OF SHORT TERM GREENHOUSE GAS EMISSIONS FROM SOIL AND ATMOSPHERE EXCHANGE IN RESPONSE TO CONTROLLING EDAPHIC FACTORS OF EUCALYPTUS PLANTATION, GUJARAT, INDIA

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Abstract

A considerable amount of atmospheric GHG is produced and consumed through soil processes. Soils provide the largest terrestrial store for carbon (C) as well as the largest atmospheric CO_2 sources through autotrophic and heterotrophic organisms. Soils are also the greatest source (~60%) of CH_4 and N_2O through microbially mediated processes of methanogensis, nitrification and denitrification. Short term CO_2, CH_4 and N_2O gas fluxes from soil under a Eucalyptus plantation in central Gujarat, Western India were measured for three month duration (February to April, 2013) at fifteen days interval using closed static chamber technique and gas chromatography method. Simultaneously soils were analyzed at 0.0-10, 10-20, and 20-30 cm depth for pH, conductivity, organic carbon, nitrogen, phosphate, sulphate to correlate with gas emissions. The results showed that the soil in our study was a sink of atmospheric CO_2, CH_4 and N_2O which the flux varied from -65.27 to 14.6, -0.005 to 0.07 and -0.03 to 0.33 mg m^{-2} h^{-1}respectively. CO_2 emissions were found maximum as compared to other two gases. Variations in soil N_2O emissions could be primarily explained by litter C:N ratio and soil total N stock. Differences in soil CH_4 uptake could be mostly attributed to the soil CO_2 flux and water filled pore space (WFPS). Soil C:N ratio could largely account for variations in soil CO_2 emissions. A strong positive relationship existed between CH_4 flux and soil temperature. The N_2O flux correlated with WFPS and the global warming potential of N_2O is highest compared to other two principal gases.

Keywords: greenhouse gases, fluxes, eucalyptus plantation, global warming potential, soil nutrients

Introduction

Gas exchange between soils and the atmosphere is an important contributing factor to global climate change due to increasing release of greenhouse gases (GHG). The most important individual GHG is CO_2, but substantial contributions to global warming are also made by CH_4, and N_2O. Soils can store and release considerable quantities of carbon through natural processes including litter deposition, decomposition and root respiration. Whereas, forest soils and wetland sediments have been identified as a significant sinks for atmospheric CH_4, about 3–9% of the global atmospheric CH_4 sinks. Soils have also been identified to be significant sources for N trace gases, accounting for 60% of the total annual N_2O emissions. (Nirmal kumar et al., 2012). In the present study an attempt has been made to investigate the concentration, fluxes, emissions, global warming potential of important greenhouse gases like CO_2, CH_4 and N_2O in relation to edaphic factors of Eucalyptus grandis plantation, in Gujarat, India.

The enhanced production and reduced consumption of naturally occurring greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), are responsible for approximately 90% of the global warming and climate change phenomenon (Solomon et al., 2007). Among them the most important individual greenhouse gas is carbon dioxide, but substantial contributions to global warming are also made by methane and nitrous oxide. Soils can store and release considerable quantities of carbon through natural processes including litter deposition, decomposition, microbial and root respiration (Drewitt et al., 2002). Although the atmospheric CH_4 concentration (1.8 ppmv) is much less than that of CO_2 (370 ppmv),however, CH_4 is 23 times more effective per molecule as a greenhouse gas than CO_2 in a period of 100 years (Ramaswamy et al., 2001). The CH_4 increase accounts for 20% of the increased greenhouse effect potential of the atmosphere. Likewise, N_2O is a long half-life gas in atmosphere that is 296 times as effective as CO_2 in a period of 100 years as a greenhouse gas and accounts for about 6% of the Greenhouse Effect (Ramaswamy et al., 2001).

Afforestation and reforestation can greatly affect soil GHG fluxes by changing key physical and chemical properties that influence soil nutrient and C cycling and microbial activity (Merino et al., 2004; Kelliher et al., 2006). Tree species are considered to alter soil physical (e.g. moisture and temperature), chemical and biological processes through their root system, crown structure, foliage, leaf structure and litter quality (Ullah et al., 2008). Plantations are becoming a key component of the world's forest resources and playing vital and prominent role in context of overall sustainable forest management. The root systems of plants change the physical, chemical and biological properties of the soil in the zone of contact (Gobran, Gleegg, 1996). The microzones of rhizosphere soil and soil root surface are different from the soil in general by the amount of available nutrients, organic matter, pH, composition of microorganisms and other indicators (Larisa Afanasyeva and Nina Kozhevnikova., 2014). Well-designed, multi-purpose plantations can reduce pressure on natural forests, and restore some ecological services provided by natural forests and mitigate climate change through direct C sequestration (Paquette and Messier 2010). Moreover, Nirmal Kumar and Shailendra Viyol (2008, 2009) examined CH_4 emission in relation to organic carbon, sulphate, and phosphate contents of wetlands and two rice

fields of central Gujarat, India. Dissolved methane fluctuations in relation to hydrochemical parameters in Tapi estuary, Gulf of Cambay, India was investigated by Nirmal Kumar et al., (2010).

Materials and Methods

Study site

This study was carried out in a Eucalyptus plantation, situated at 22°556' N latitude, and 72°95" E longitudein Anand, Central Gujarat, Western India (Fig. 1).The total area of plantation is 8093.8 m^2 and dominated by *Eucalyptus grandis*. Soil under the plantation is sandy loam and litter layer was normally about 2 to 3 cm; humus layer was about 1-2 cm. Meteorological data from Anand Agriculture University, Anand revealed the mean annual maximum and minimum temperature is 42 °C and 26 °C respectively. The mean annual precipitation is 900 mm; mostly occur in monsoon season (July to October). The average relative air humidity is about 30 %.

Soil CO_2, CH_4 and N_2O measurement

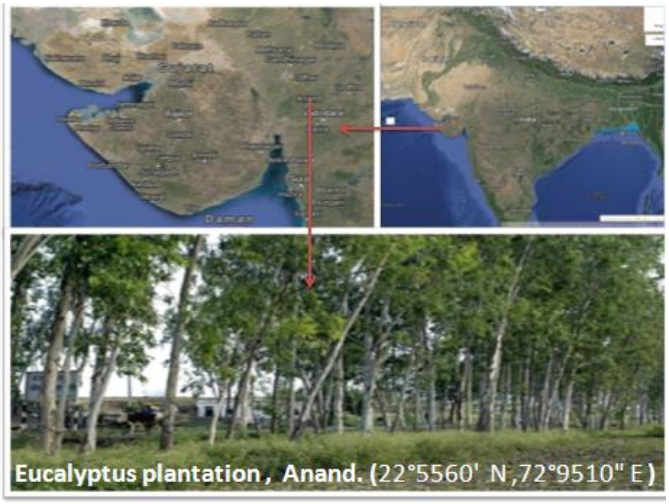


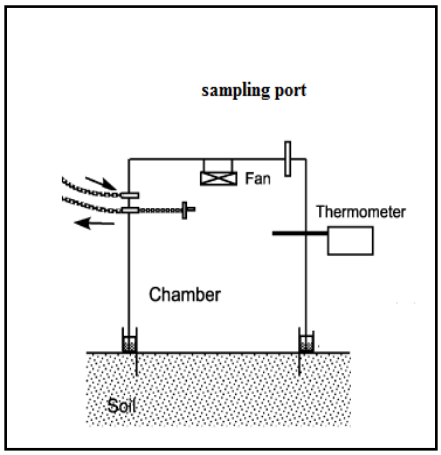
Figure 1. Study area shows the Eucalyptus plantation in Anand, Gujarat, Western India

Soil CO_2, CH_4 and N_2O gas concentrations were measured using the static chamber and gas chromatography techniques. Static chamber was established in plot and fabricated with non-reactive materials PVC (Brechet et al. 2009).

Chambers with the size of 100 cm-diameter ring were anchored 5 cm into soil. During flux measurement 25-cm-high chamber top was attached to the ring and a fan (about 8 cm in diameter) was installed on the top wall of each chamber to ensure proper mixing of the air when collected (Mo et al. 2008) (Fig. 2).

Air was sampled from chamber between 11:00 to 2:00 h at each sampling date because of maximum GHGs emission measured in this period. Concentrations of soil CO_2, CH_4 and N_2O were measured 15 days interval during the experimental period from February to April, 2013 because of the emissions of GHGs from soil – atmospheric interchange would higher due to

moderate climatic conditions as compared to other months of the year (Tang et al. 2006 and Warner et al 2007).



a. Design of Sampler

b. Mixing Fan fixing in Sampler

c. On-Site Fixing of Sampler

d. Withdraw of Gases by Syringe

STATIC CHAMBER GHG SAMPLING METHOD

e. Injecting Gases into Vial

Figure 2. On-Site Soil-Atmosphere Exchange of GHG Emission by Static chamber sampling method

Gas samples were collected with 100 ml plastic syringes attached with three-way stopcock at 0, 60, 120 and 180 min intervals after chamber closure and collected samples over the atmospheric pressure in to glass vials of 30 ml with butyl rubber stoppers which had been evacuated beforehand. The first 100 ml gas was abandoned, because it might contain the gas taken at the latest sampling. N_2O, CH_4 and CO_2 concentrations in the samples were analyzed within 48 h using gas chromatography (Perkin Elmer Auto system Gas Chromatograph). The gas chromatography was equipped with an electron capture detector ECD for N_2O analysis and a flame ionization detector (FID) for CH_4 and CO_2analysis .Gas fluxes are calculated from linear

$$F = \rho \frac{V}{A} \frac{P}{P_0} \frac{T_0}{T} \frac{dC_t}{dt}$$

regressions of concentrations inside the chambers against the closure time according to the following equation:

where, F is CO2, CH_4 and N_2O gas flux (mg/m^2/h)), ρ is gas density at the test temperature (mg/m^3), V is chamber volume available (m^3), A is bottom area of the chamber (m^2), P is atmospheric pressure in the field (hPa), P_0 is atmospheric pressure under standard conditions (hPa), T_0 is absolute air temperature under standard conditions (25°C), T is absolute air temperature in chamber at the time of sampling (°C), C_t is concentration of mixed volume ratios of gases in chamber at time t (10−6).

GHGs emission (t/year) measured by following equation

GHGs (CH_4, CO_2, N_2O) emission (t/year) =Area of land (m^2) × Average daily CH_4, CO_2, N_2O Emission rate Mg/m^2/year × Conversion factor t/mg (10^{-9}) × Molecular/ Atomic ratio (Global Environment Division, 1998) .

Global warming potential calculated by GHGs (CH_4, CO_2, N_2O) emission multiplied by global warming potential for hundred years of CO_2, CH_4, and N_2O is 1, 21 and 310 respectively.

The Greenhouse Gas budget provides an estimate of the net budget of CO_2, CH_4, and N_2O based on the Global Warming Potential (GWP) of each gas. GWP is the contribution that a gas makes to the greenhouse effect according to its capacity to absorb radiation and its residence time in the atmosphere. Each mean day budget of each gas was calculated from the below given formula and expressed in terms of 'carbon dioxide equivalents' (CO_2 eq):

$$CO_{2eq} = (N_2O \times 310) + (CH_4 \times 21) + (CO_2 \times 1)$$

Micro-environmental data measurements

Air temperature at 1.5 m above ground was measured simultaneously. Soil temperature and moisture at 5 cm below soil surface were monitored at each chamber. Soil temperature was measured using a digital thermometer. Soil moisture was measured by gravimetric method. Soil moisture values were converted in to water filled pore space (WFPS) by the following formula:

$$\mathrm{WFPS}[\%] = \frac{\mathrm{Vol}[\%]}{1 - \frac{\mathrm{bd}[\mathrm{g\ cm^{-3}}]}{2.65[\mathrm{g\ cm^{-3}}]}}$$

Where bd is bulk density, Vol is volumetric water content and 2.65 is density of quartz.

Soil sampling and measurements

Soil samples collected at different depth 0-10, 11-20 and 21-30 cm. A total of six soil cores collected using an 8 cm diameter stainless steel core in each plot. Soil samples were air dried at room temperature (25 °C), then were passes through 2 mm mesh sieve to remove coarse living roots and gravel and ground with a mill before chemical analysis. Meanwhile soils samples were measured for bulk density.

Soil was analyzed for total organic C by Walkley and Black method. Total nitrogen (N) was analyzed using Kjeldahl method. Available phosphorus was estimated by phosphomolybdic blue colorimetric method; sulphate by turbidimetric method and nitrate by colorimetric method using phenol disulphonic acid. Soil pH was measured in a 1 mol L^{-1}KCl solution using a glass electrode. Conductivity was measured by potentiometric method and particle density was estimated by gravimetric method. APHA, (1993) and Maiti, (2003) standard books were followed for all the above parameters.

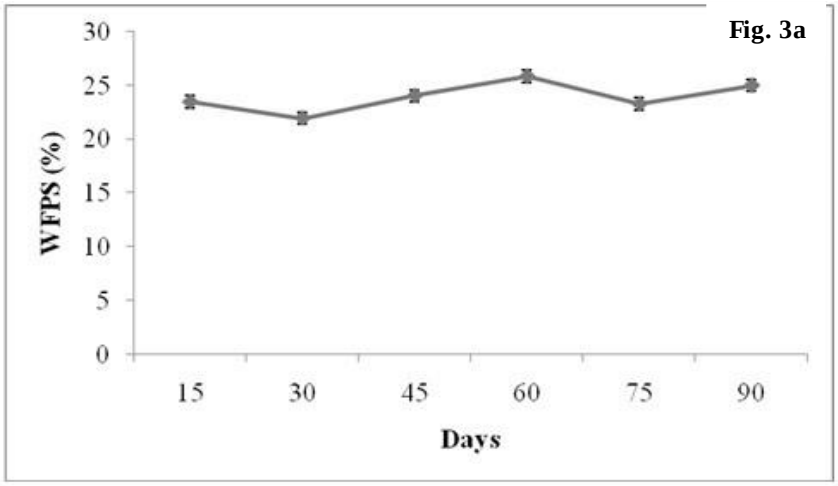
Statistical analysis

In order to examine the relationship between soil parameters and the measured CO_2, CH_4 and N_2O gas fluxes, correlation and linear regression analysis was performed using Sigma Plot 11.0 statistical analysis software.

Results and Discussion

Climatic conditions

Soil temperature and WFPS exhibited the monthly variation in Eucalyptus plantation. The sampling period in February 2013 was a particularly cool-dry season and in April 2013 was a hot-humid season in this study (Fig. 3)



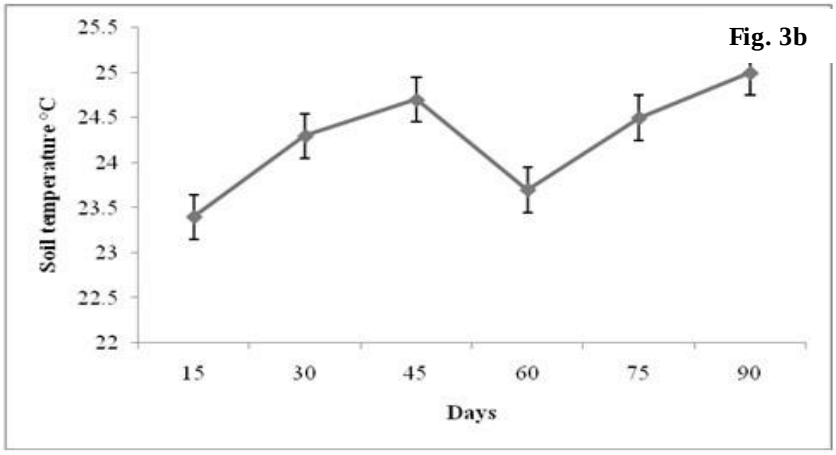


Figure 3(a & b). Seasonal patterns of soil water filled pore space, WFPS (a) and soil temperature (b) measured in the Eucalyptus plantations carried out from February to April, 2013 at every 15 day intervals. Error bars indicate standard error (n=6)

GHGs concentration, flux and emission

Soil CO_2 concentration fluctuated from 190 to 869.5 ppmv in times and days interval during the experiment for February- April, 2013.The maximum concentration was found during 12:00 to 1:00 period.Fluctuations in CO_2 concentration was observed in all the subsequent intervals, perhaps it was due to hot humid temperature (Fig. 4a). CH_4 concentration ranged from 0.59 to 2.14 ppmv with the highest value reported in noon period. (Fig.4b). Similarly N_2O concentration observed between 15.29 to 136.69 ppmv with the maximum during 1:00 to 2:00period. The fluctuation was noticed pretty clear and distinct as the time interval increased (Fig 4c). Statistical significant differences were set with P values < 0.05 between the times and days interval of GHGs concentrations.

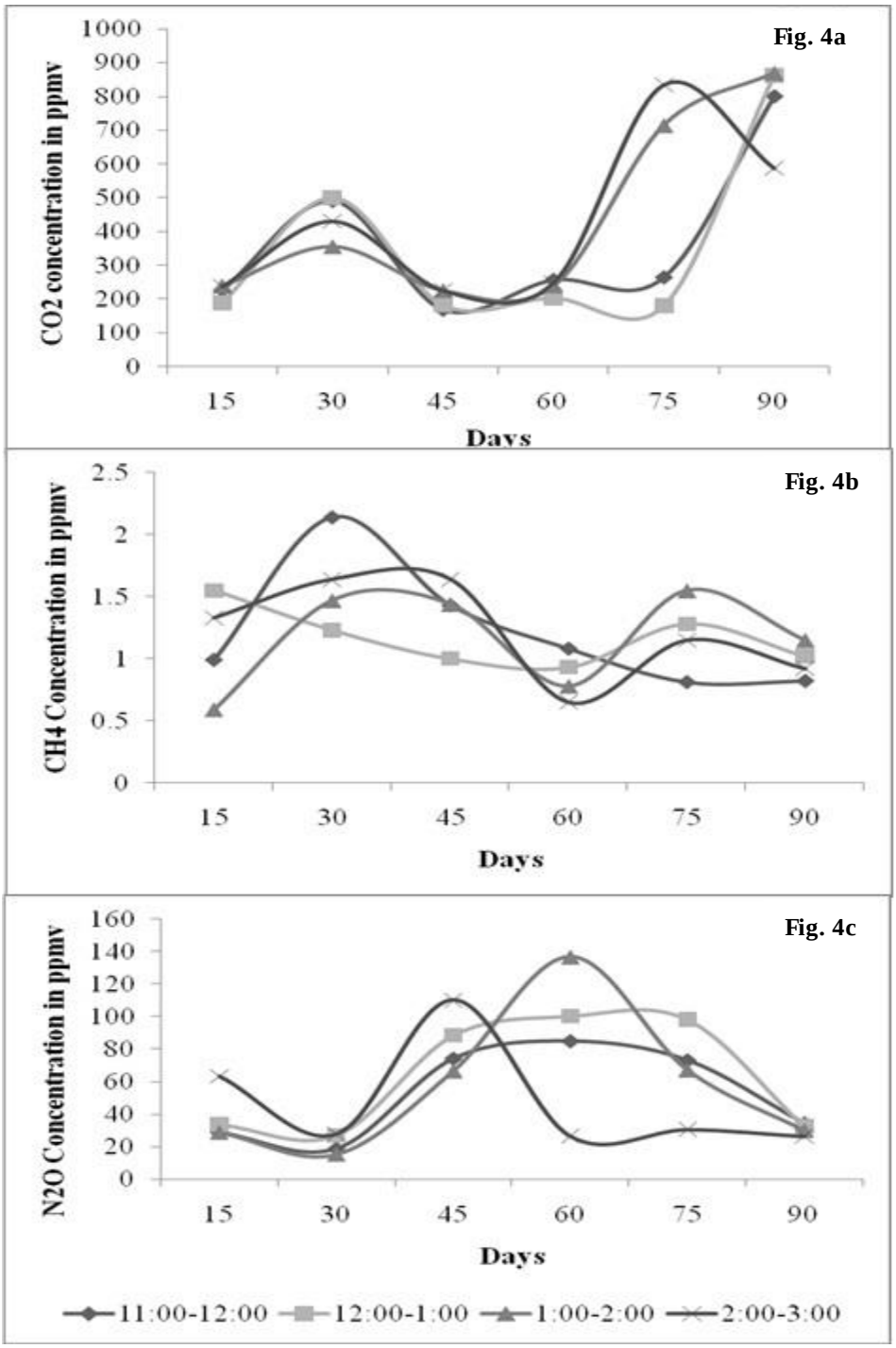


Figure 4 (a, b, c) GHGs concentration in Eucalyptus plantation in times and days interval a. CO_2, b. CH_4, c. N_2O, carried out from February to April,2013 at every 15 day intervals

Soil CO_2, CH_4 and N_2O fluxes varied from -65.27 to 14.6, -0.005 to 0.07 and -0.03 to 0.33 mg m^{-2} h^{-1}respectively (Fig 5 a, b & c).Highest value of the CO_2 flux was registered in fifth interval specifically during 2:00 p.m. to 3:00 p.m. (Fig. 5a). The greater value of methane

concentration was registered during the second trip between 2:00 p.m. to 3:00 p.m. The CH_4 flux fluctuates diurnally and uptake was recorded maximum in fourth interval (Fig. 5b). The maximum value of N_2O flux was observed during the third and fourth trip between 2:00 p.m. to 3:00 p.m. N_2O flux reduces at 1:00 to 2:00 p.m. but observed in all intervals. The soil is consuming atmospheric N_2Omaximum in third interval during 1:00 to 3:00 p.m. (Fig. 5c).

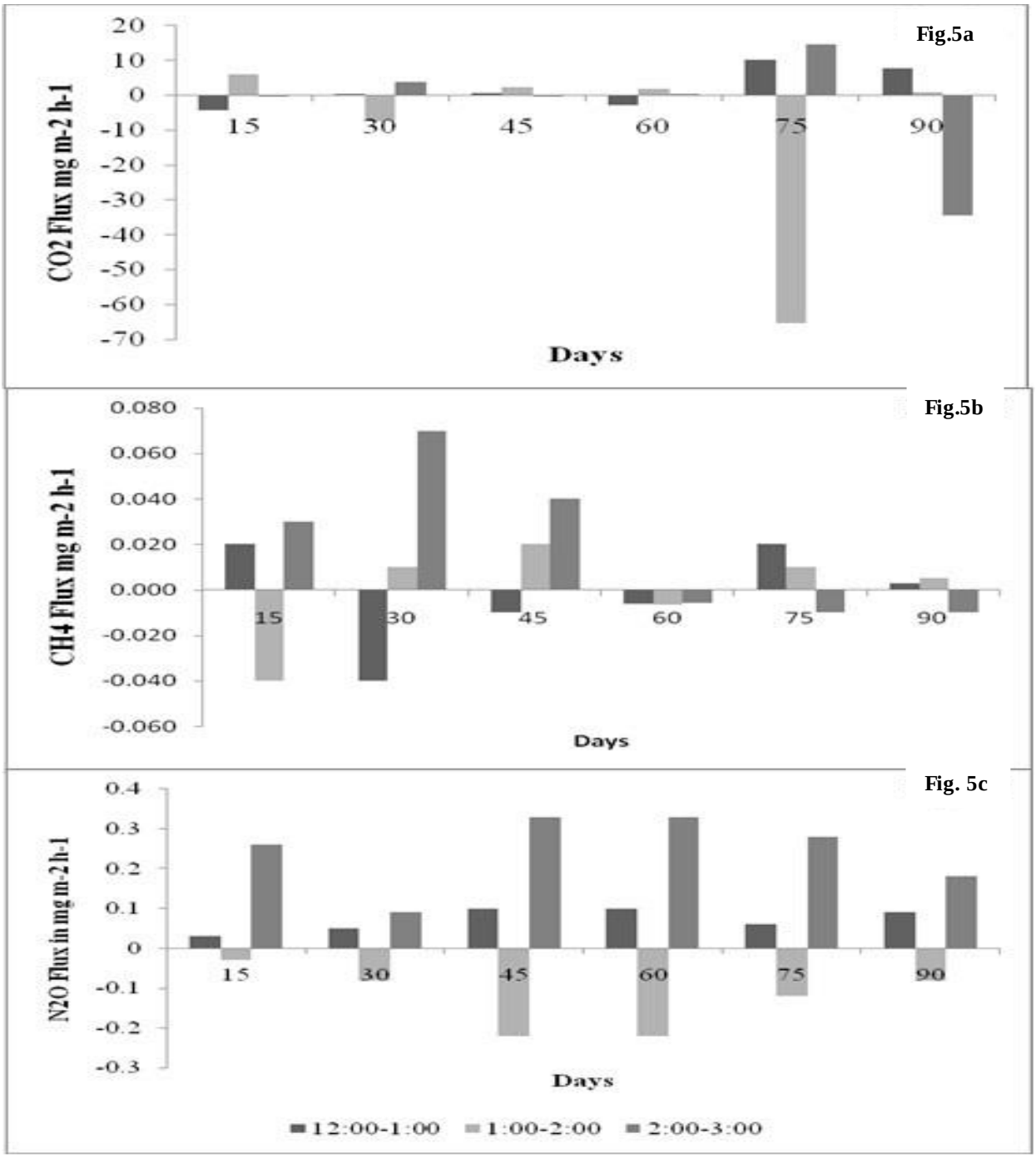


Figure 5 (a,b,c) GHGs flux in Eucalyptus plantation in times and days interval a. CO_2, b. CH_4, c. N_2O, carried out from February to April, 2013 at every 15 day intervals

The negative values of GHGs flux indicate the consumption of gas by the soil while positive results indicate GHGs release through the soil. Soil $CO_2$and N_2O flux positively related to WFPS, whereas CH_4 flux positively related to soil temperature. CH_4 uptake reduced with increased WFPS in plantation (Fig. 6).

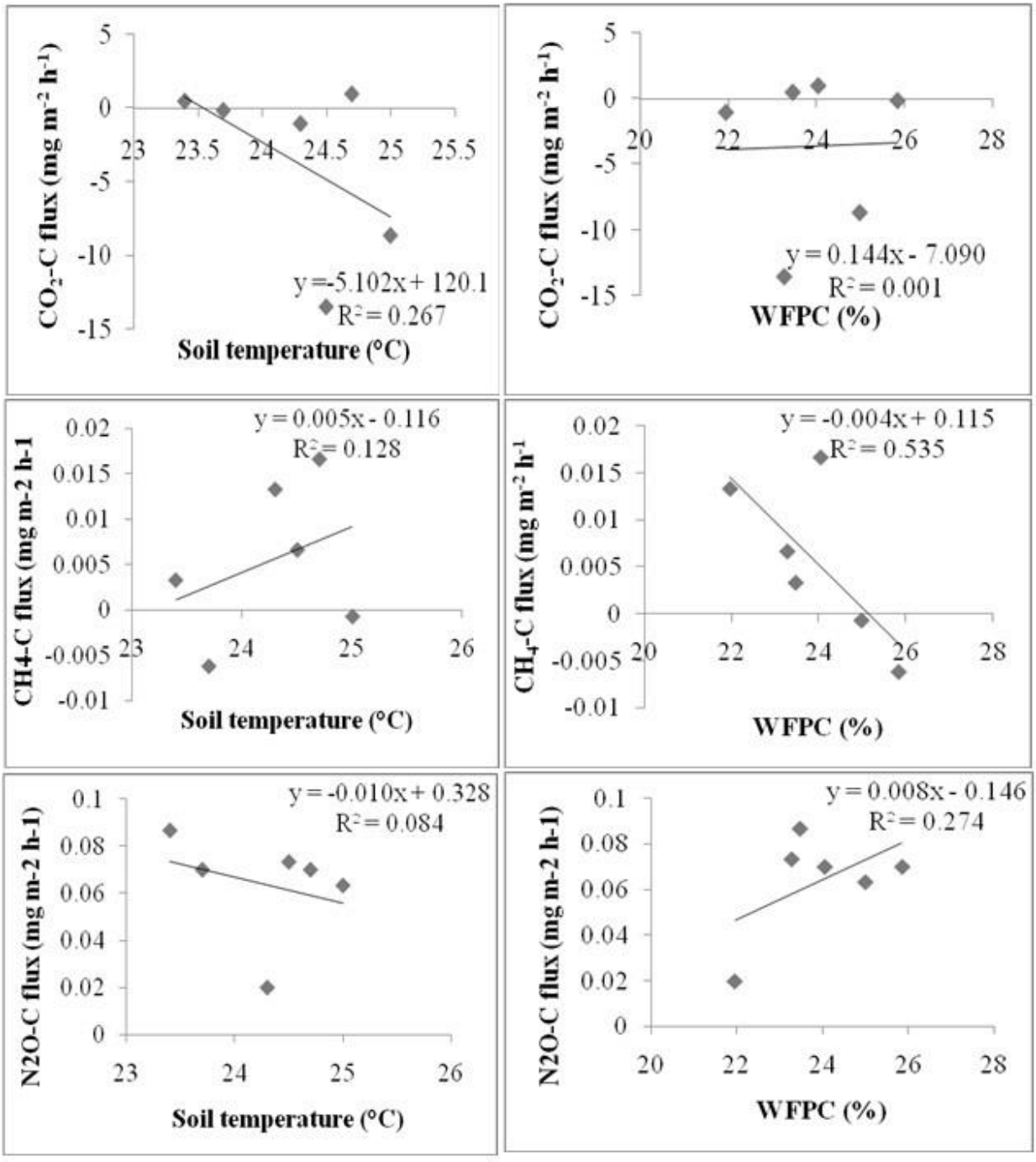


Figure 6. Relationships between soil N_2O, CH_4, and CO_2 fluxes, and soil temperature and soil water filled pore space (WFPS) in the Eucalyptus plantation carried out from February to April, 2013

CO_2 emissions were found maximum when compared to other gases $CH_4$and N_2O (Fig. 7).On the other side, the global warming potential is greater to N2O as compared with CO2 and CH4 (Fig.8), whereas CO2 equivalent is higher during third trip than other trips but negative CO2 equivalent registered during second trip (fig.9).

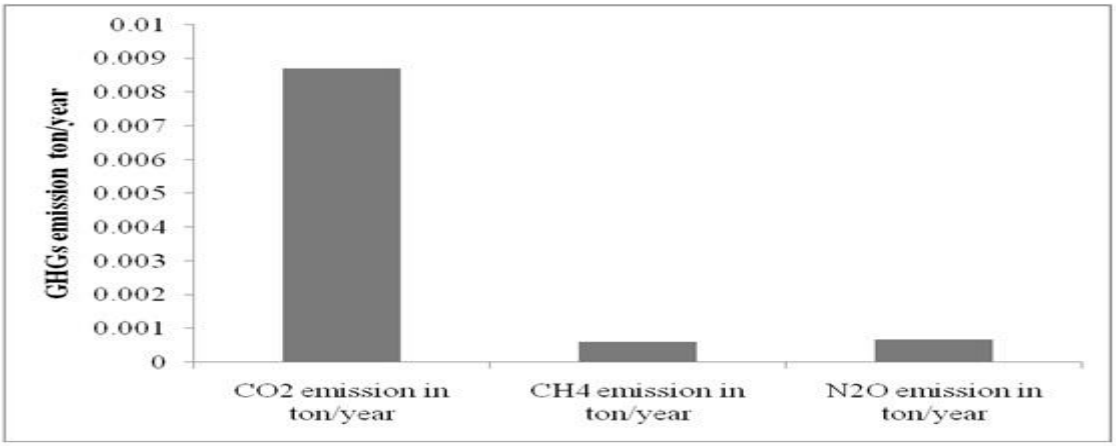


Figure 7. GHGs emission (ton/year) in Eucalyptus Plantation

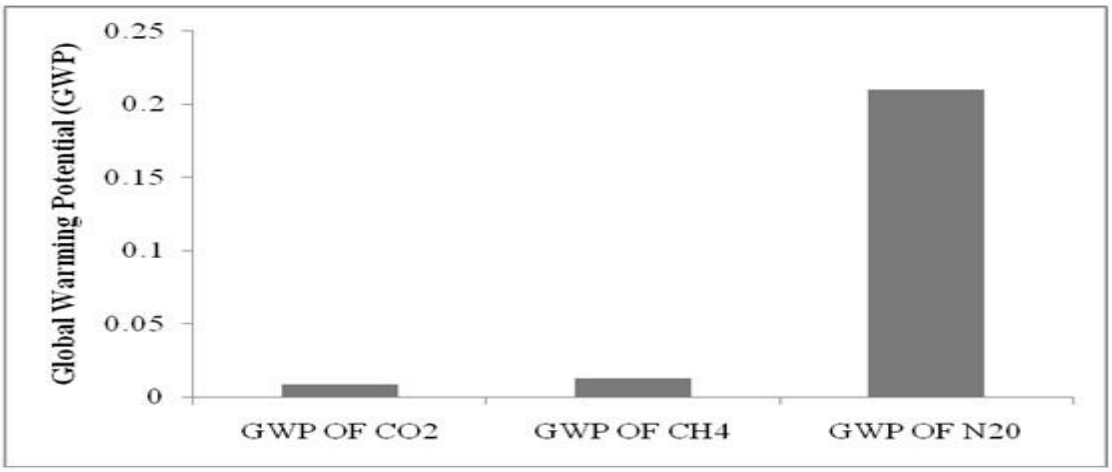


Figure 8. Global Warming Potential (GWP) in Eucalyptus Plantation

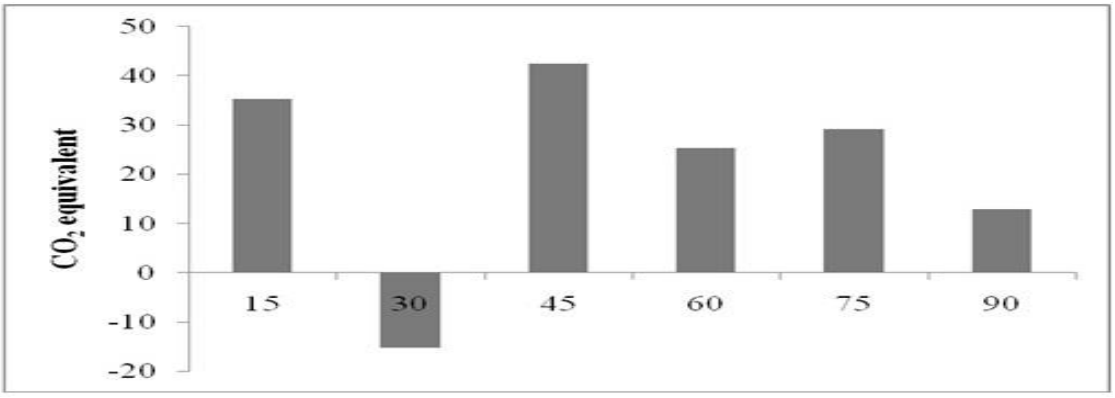


Figure 9. GHGs budget in Eucalyptus Plantation carried out from February to April, 2013 at every 15 day intervals

GHG flux correlated with edaphic factors of soil was shown in Table 1. Soil C: N ratio negatively correlated with CO_2 and CH_4 flux but positively correlated with N_2O flux. WFPS was positively correlated with CO_2 and CH_4 flux and negatively correlated with N_2O flux. Similar results also substantiated by Liu et al. (2008) from soils of different land-use types in a hilly area of South China.

Table 1. Correlation between GHG flux and edaphic factor of soil in Eucalyptus Plantation

Table 1 Correlation between GHG flux and edaphic factor of soil in Eucalyptus Plantation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Soil bulk density	1	0.16	0.86*	0.89*	-0.09	-0.86*	-0.67	-0.93*	-0.78	-0.66	0.23	-0.64	0.04*	0.17	-0.37
Soil conductivity		1	0.12	-0.01	0.79*	0.09	-0.82*	-0.03	0.16	-0.76*	-0.60	-0.43	-0.09	0.94*	-0.48
Soil WFPC			1	0.97*	-0.34	-0.86*	-0.57	-0.83*	-0.95*	-0.63*	0.21	-0.33	0.12*	0.25*	0.12*
Soil Particle Density				1	-0.44	-0.87*	-0.47	-0.82*	-0.97*	-0.56	0.42	-0.38	-0.01	0.07	-0.13
Soil pH					1	0.31	-0.54	0.12	0.60	-0.36	-0.76	-0.36	0.11	0.67	-0.47
Soil organic C						1	0.37	0.95*	0.84*	0.33	-0.29	0.19	-0.38*	-0.03*	0.37*
Soil total N							1	0.53	0.30	0.95*	0.38*	0.73	0.04*	-0.79*	0.45*
Soil C:N								1	0.75*	0.45	-0.12	0.41	-0.38*	-0.12*	0.35*
NH4+-N content									1	0.41	-0.46	0.18	-0.04	0.02	-0.007
NO3--N content										1	0.21	0.74	0.25	-0.72	0.30
Soil total sulphate											1	0.02	-0.49	-0.69	0.001
Soil available P												1	0.41*	-0.23	0.21*
CO_2 Flux													1	0.16*	-0.08
CH_4 Flux														1	-0.39
N_2O Flux															1

* $P < 0.005$

Soil-atmosphere CO_2 exchange

The soil CO_2 mean emission rate of 19.54 mg C m^{-2} h^{-1} measured in present study is similar to that measured in temperate forests (Wang et al. 2006), subtropical forests (Tang et al. 2006), and tropical rain forests (Sotta et al. 2004). Soil CO_2 annual mean emission was lower than in broadleaf plantations (between 56.38 and 72.15 mg C m−2h−1), as observed by Livesley et al. (2009) in coniferous broadleaf forest/plantations. Soil CO_2 emission, could be the result of soil respiration generates mainly from autotrophic (root) and heterotrophic microbial activity (Janssens et al. 2001).The differences in the magnitude of mean soil CO_2emissions might be explained by differences in litter C:N ratio (Epron et al. 2006). Numerous studies emphasized that soil C:N ratio, as a good indicator of substrate quality, was an important factor regulating microbial activity and thus influencing litter decomposition (Hättenschwiler et al. 2005). The soil C:N ratio in the Eucaluptus plantation was higher in 0-10 cm depth (Table 2), indicating high microbial activity and thus heterotrophic respiration may be lower in the 11-20 and 21-30 cm depth. The temporal variations in soil CO_2 emissions influenced by soil temperature and moisture (Figs. 4 and 5), indicating that soil temperature and moisture exert the significant effects on the temporal variations of soil CO_2 emissions. Our results are also supported by the previous studies in tropical forests carried out by Bhatiya et al. (2004).

Soil-atmosphere CH_4 exchange

CH_4 measurements indicated a consistent net soil consumption of CH_4 (i.e. negative CH_4 flux) in plantation (Fig.5b). The highest soil CH_4 uptake rate of −40.12 μg C $m^{-2}h^{-1}$ measured is similar to that measured in other forests like Eastern Amazonia, European Beech and Norway Spruce and South Eastern Australia (Borken and Beese 2006; Fest et al. 2009), but less than that measured in more productive natural forest systems (Merino et al. 2004; Werner et al. 2007). Soil-atmosphere CH_4 exchange is the result of simultaneously occurring production and consumption processes controlled by CH_4- producing methanogens operating at anaerobic conditions and CH_4-consuming methanotrophs in soils that depends on oxygen as a terminal electron acceptor (Topp and Pattey, 1997). Activity and population size of these microbes are dependent on a multitude of soil factors like soil temperature, moisture, pH, substrate availability, and aeration of soil profile (Reay and Nedwell, 2004; Werner et al. 2007). Thus, these parameters were performed in a multiple linear regression analysis to access the importance of different factors for explaining the variations in soil CH_4 uptake in the plantation.(Table 3).The temporal variations in soil CH_4 fluxes displayed dependency on soil WFPS (Figs. 4 and 5) but negatively related to soil moisture. Similar observations were also made by Castro et al. (2000); Verchot et al. (2000). Moreover, CH_4 uptake is dominated by aeration of the soil profile (Khalil and Baggs, 2005).

Table 2. Physico-chemical properties of the soils (0–30 cm depth) in Eucalyptus Plantation (n=6)

Parameters	Depth		
	0-10	10-20	20-30
Soil bulk density (g cm^{-3})	0.82±0.01	0.88±0.01	0.91±0.02
Soil conductivity (µ mho /cm)	1.09±0.03	1.15±0.02	1.14±0.04
Soil WFPC (%)	21.96±1.03	23.47±1.13	25.84±1.08
Soil Particle Density	2.15±0.08	3.48±0.12	5.07±0.06
Soil pH	7.16±0.02	7.21±0.01	7.11±0.01
Soil organic C (Mg ha^{-1})	44.93±0.54	32.54±0.48	27.22±0.59
Soil total N (Mg ha^{-1})	3.79±0.09	3.21±0.04	2.99±0.08
Soil C:N	11.85±0.5	10.14±0.4	9.10±0.7
NH_4^+-N content (mg kg^{-1})	5.20±0.05	4.84±0.13	4.12±0.18
NO_3^--N content (mg kg^{-1})	2.34±0.03	1.87±0.09	1.51±0.01
Soil total sulphate (mg kg^{-1})	1.25±0.01	1.28±0.07	1.31±0.03
Soil available phosphorus (mg kg-1)	0.12±0.02	0.09±0.01	0.08±0.01

Table 3. Results of multiple linear regression analysis of biogeochemical parameters and annual mean GHG flux in Eucalyptus Plantation (n=6)

Parameters	Models
	CO_2 flux (mg C m^{-2} h^{-1}) (Y_1)
Soil C:N ratio (X_1)	$Y_1 = -40.726 + 3.969\ X_1$, $R^2 = 0.551$, $P < 0.001$
	CH_4 Flux (mg C m^{-2} h^{-1}) (Y_2)
Mean CO2 flux (mg C m-2 h-1) (X_2)	$Y_2 = 0.0091\ X_2 + 0.171\ X_3 - 4.04$, $R_2 = 0.826$, $P < 0.01$

Mean WFPS (%) (X_3)	
	N_2O (mg N m^{-2} h^{-1}) (Y_3)
Soil C:N ratio (X_4)	Y_3 = -0.0096 X_4 + 0.051 X_5 + 0.01. R^2 = 0.466, P< 0.001
Soil total N (Mg ha-1) (X_5)	

Soil-atmosphere N_2O exchange

The mean soil N_2O emission 1.52 mg N $m^{-2}h^{-1}$ measured in plantation which agrees with the estimates from other forest studies (Castaldi et al. 2006; Livesley et al. 2009), but is less than that measured in some moist tropical or boreal forests (Hall et al. 2004; Werner et al. 2007). Moreover, our results revealed the soil N_2O emission is predominantly controlled by soil pH (Stevens et al. 1997), soil moisture (Merino et al. 2004), soil C and N stocks (Li et al. 2005), soil inorganic N contents (Merino et al. 2004) and C:N ratio of litter and soil (Werner et al. 2007). The N_2O flux in forest soils has been shown to correlate with gross nitrification rates (Ambus et al. 2006) and soil C:N ratio, as that greatly determines soil nitrification activity (Erickson et al. 2002). The importance of soil N_2O emissions among the plantations is in agreement with previous observations by Regina et al. (1996) in boreal soils and Zhang et al. (2008a) in subtropical forests. The temporal variations in soil N_2O emissions were attributed to those in soil temperature and moisture (Figs. 4, and 5). Similar results were reported in other subtropical forests (Tang et al. 2006; Liu et al. 2008). It has been reported that N_2O production by nitrification and denitrification could increase strongly with the increasing soil temperature and moisture in temperate forests (Borken and Beese 2006) and subtropical forests (Tang et al. 2006; Liu et al. 2008).

Global Warming potential (GWP)

The overall balance between the net exchange of CO_2, CH_4, and N_2O constitutes the net global warming potential (GWP) of any terrestrial ecosystem. Storage of atmospheric CO_2 into stable organic carbon pools in the soil can sequester CO_2. The results reveal that global warming potential of N_2O is highest compared to other two principal gases. However, the negligible portion of GWP was encountered for methane (Fig. 8). Adviento et al., (2007) also found similar result of global warming potential.

GHG budget

Greenhouse gas budget was calculated in terms of CO_2 equivalent. Total budget of the study time was found 129.9 CO_2 equivalents. Maximum budget was found in the third interval and minimum budget was found in second interval, which was very negligible (Fig 9). Among all the three gases, N_2O is the largest contributor to the global atmospheric greenhouse gas budget mainly via microbial process of nitrification and denitrification (Werner et al. 2007).

Conclusion

In this study we estimated short term diurnal CO_2, CH_4 and N_2O fluxes and interrelationships with the edaphic factors such as temperature and WFPS through simple linear regression statistical analysis. The study confirmed that soil temperature was an important factor influencing soil CH_4 flux while WFPS was identified as a key factor regulating CO_2 and N_2O emission.

Acknowledgement

Authors are highly thankful to Gujarat Council of Science and Technology (Gujcost), Gandhinagar for financial assistance and also thankful to Sophisticated Instrumentation Center for Advanced Research and Testing (SICART), Vallabh Vidyanagar, Gujarat for analysis of gas samples.

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