SOIL NUTRIENT STATUS AND GREENHOUSE GAS EMISSION IN MAJOR AGROFORESTRY SYSTEMS OF SOUTH INDIA

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Abstract - Agro forestry systems play a predominant role in the global carbon cycle by restoring carbon stock in the ecosystem and reducing greenhouse gas (GHGs) emissions from soil. The impact of major plantation agroforestry systems in South India viz. rubber, tea, coffee and cardamom on soil nutrient availability and GHG emission was investigated. Representative soil samples were collected and analysed for total and available nutrients, CEC and pH.For examining temporal and seasonal changes in soil respiration (R_s), insitu carbon dioxide (CO_2) flux rate in each system was recorded by using an automated soil respiration analyser. Static closed chamber method was used to measure methane(CH_4) and nitrous oxide(N_2O) emission from agroforestry systems and the collected gas samples were analysed using gas chromatography. Significant difference in soil nutrient status and GHG emission was observed among different agroforestry systems. The high biomass addition, nutrient enrichment of soil through fertilizers and liming materials contributed to significantly high per cent of total carbon (TC), organic carbon (SOC), nitrogen (TN), available calcium (Ca), magnesium (Mg) and pH in coffee agroforestry system. Tea agroforestry system had high per cent of available soil phosphorus (P) and potassium (K). The R_s varied spatially, temporally and seasonally among different systems and was higher in summer season followed by winter. Among the systems studied, the highest rate of R_s was detected in cardamom and coffee system and lowest in rubber. Nitrous oxide (N_2O) and methane (CH_4) gases were undetectable in all agroforestry systems during the period of observation. Significantly positive correlation of R_s with soil temperature was observed in all systems. The lower per cent of the total and available soil nutrients were observed in rubber agroforestry system, which might be due to the lower altitude of the system compared to other systems. The results of the study indicated that the altitude, land use pattern and management practices in agroforestry systems significantly influenced the total and available soil nutrients status and GHG emission from soils.

Index Terms - Agroforestry Systems, GHG Emission, Soil Nutrient Status, Soil Respiration

I. INTRODUCTION

Reducing emission of greenhouse gases (GHGs) from agricultural landscapes is one of the strategies to mitigate the threat of global warming, the most serious environmental issues facing mankind today. Among the GHGs, carbon dioxide (CO_2) is the most dominant gas believed to be causing global warming and accounts for nearly 77 per cent of global total CO_2equivalent GHG emission [1]. According to International energy outlook, EIA 2017 [2], world global CO_2 emissions will increase by 16 per cent between 2015 and 2040. As per the biennial update report (2016)[3], India emitted 2,136.84 million tonnes of CO_2 equivalent greenhouse gases in 2010 and 18 per cent of the total emissions was from agriculture sector. The GHG emissions from agriculture sector in India, the third largest emitter of GHGs in the world, is predicted to rise by 30 per cent over the next three decades [4].

In terrestrial ecosystems, soil is considered as the largest reservoir of carbon and stores more than twice carbon as the atmosphere and thrice as vegetation. A slight variation in soil organic carbon (SOC) storage could greatly affect concentration of CO_2 in the atmosphere. Anthropogenic activities in the terrestrial ecosystems are one of the major reasons for CO_2emission.TheCO_2 exchange between land and atmosphere is mostly mediated by soil respiration (CO_2 flux), generated from respiration of plant roots, the rhizosphere, microbes and fauna which is estimated to be 80 Pg C $year^{-1}$[5]. In different ecosystems, the rate of soil respiration is controlled by biotic and abiotic factors of which soil temperature and soil moisture are considered as the most important parameters. The rate of soil respiration is also determined by the quantity and quality of organic substrates, the efficiency and population dynamics of various soil microbes, and the physico-chemical properties of soil including moisture, temperature, oxygen, pH, and redox potential [6].

Soil respiration differs among ecosystems and the variation is associated with changes in vegetation type and land management practices. Enhancing organic carbon content in the soil is one of the most effective and economical approaches to reduce the increasing concentrations of CO_2 in the atmosphere[7]. The biomass turnover acts as a natural input-output system of nutrients in any ecosystem, where the biomass added and its decomposition regulate nutrient cycling, soil fertility and productivity of the system [8]. Land management practices are the most dominant driver of global climate change in terms of their impacts on terrestrial ecosystems [9],but the sign and magnitude of the effects of land management practices are highly uncertain [10].

Agroforestry provides different land use options to increase productivity and create environmental and socio economic benefits. The state of Kerala in India with many woody perennial-based land use practices is often named as the "Mecca" of agroforestry [11]. Most of the practices are traditionally evolved over centuries of cultural and biological transformations. The perennial plantation agriculture is the chief land use activity in Kerala and rubber, tea, coffee and cardamom are the major plantation sectors in this respect. Majority of these plantations were established initially in forest cleared lands rich in organic matter and plant nutrients and later on the cultivation of these crops were extended to marginal lands. The agro-climatic requirements of these plantation crops are different and are cultivated in diverse soil types [12]. Different land use patterns have different net primary production, root distribution, and litter quality and quantity and these factors affect the soil organic carbon (SOC) dynamics [13]. The differences in agro climatic conditions and agro management practices among different land use patterns influence their impacts on soil and environment. For developing the best management practices and prediction tools for reducing GHGs emission from agroforestry systems better understanding of the role of agroforestry systems on soil nutrient availability and GHGs emission from soil is essential. Hence a study was undertaken to estimate the impacts of major agroforestry systems on soil nutrient availability and greenhouse gas emission from soil.

II. MATERIALS AND METHODS

Experimental sites

This experiment was conducted during 201-15 in the major agroforestry systems of Kerala, South India viz. rubber, coffee, cardamom and tea agroforestry systems. Coffee, tea and cardamom plantations were located within a few km radius of the AVT tea plantations, Vandiperiyar, Idukki (9° 34' 7.19" N latitudeand77° 05' 15.60" E longitudes and altitude 836 m above MSL) and rubber plantation was located at Mundakayam (9^0 30' N latitude and 76^0 53' E longitude and altitude 78 m above MSL.), the doorway to the high ranges of southern Kerala. The study transect comes under a humid tropical climatic regime with warm moist summer (March-May) and winter (Nov-Dec) with rainy season during June to October. The observations were recorded during the month of December (winter) and March (summer) and the seasonal weather conditions of the experimental sites are given in Table1.

Parameters	Agroforestry Systems	
	Rubber	Tea, coffee and cardamom
Winter(December)		
Maximum temperature (^{0}C)	34	30
Minimum temperature (^{0}C)	22	18
Average temperature (^{0}C)	30	25
Rainfall (mm)	70	61.19
No. of rainy days	20	17
Summer (March)		
Maximum temperature (^{0}C)	39	36
Minimum temperature (^{0}C)	25	19
Average temperature (^{0}C)	33	30
Rainfall (mm)	62.31	2.32
No. of rainy days	22	4

Table 1. Seasonal weather conditions of the experimental sites

The agroforestry systems with detailed management history were chosen for this study.

Agroforestry systems

Cardamom (Elletteria cardamomum):The cardamom plants were 8 years of age and was cultivated as a rained crop. The planting density of cardamom was 2000 plants per hectare and fast growing shade trees were also planted in the system for shade regulation .All agro management practices were done as per the recommendations of Spices Board, India.

Coffee var.Robusta(Coffea canephora): The age of the plantation was 30 years and the planting density was 1600 plants / ha. Shade trees were established to provide shade. General cultural operations were done as per the recommendations of Coffee Board, India.

Tea (Camellia sinensis) :Tea was planted in double hedge system and the planting density was 13200/ha. Siver Oak (Grevillea robusta)was established for shade regulation. All agro management practices were followed as per the recommendation of Tea board, India.

Rubber (Hevea brasiliensis) :The rubber plantation was 13 years of age in the third cycle of cultivation. The planting density was 450/ ha and the cover crop, Mucuna bracteata was established during the initial years. Fertilizers application and all cultural operation were done as per the recommendation of Rubber Board, India.

Soil sample collection and analysis

From each agroforesrty systems 10 random soil samples were collected at a depth of 0-30 cm from the inter row areas of lants for chemical analysis. The field moist samples were brought to the laboratory and was sieved Jackson(1973),available phosphorous by the chloromolybdic stannous chloride reduction method using the Bray II extractant , available potassium using a flame photometer and available calcium and magnesium by ammonium acetate extraction followed by subsequent determination by

an atomic absorption spectrophotometer (Avanta – GBC Scientific Equipment Company Ltd ,Australia). through a 2mm sieve and analysed for pH (1: 2.5 soil – water ratio), total carbon and nitrogen using an automated CHNS analyser(CHNS, LECO), organic carbon by Walkley and Black's method as described by

Insitu measurement of fluxes from soil

Soil respiration / CO_2 flux from soil was measured during winter (December) and summer (March) months at morning (7.30-8.30 am) and noon (2-3 pm) hours for three days from each agroforestry system by using an automated soil respiration analyser(ADC BioScientific ACE system,model E-B95-ACE). The soil temperature was measured at a depth of 5cm and soil moisture was determined gravimetrically near the sampling point in each measurement.

Static closed chambers were used to measure CH_4 and N_2O emissions from soils. In each agroforestry system three replicated chambers was placed in the morning hours and gas samples were collected in the evening hours using a syringe equipped with a 3-way stopcock. CH_4 and N_2O present in the in the collected gas samples were analysed using gas chromatography (Clarus 5980 perkinelmer).

Statistical analysis

The data were subjected to one way analysis of variance (ANOVA) using SPSS and significant differences were reported at $P< 0.05$. Correlation coefficient was performed in order to find out the relationship between soil respirations, soil temperature and soil moisture in the agroforesty systems.

III. RESULTS AND DISCUSSION

Effect of agroforestry systems on soil properties

Soil reaction (pH)

Soil pH is a measure of the acidity or basicity of a soil and it affects the availability of nutrients to plants. Significantly higher soil pH was observed in coffee system compared to tea and rubber and was on par with cardamom system (Table 2.). The higher acidification of soil under tea and rubber was due to the high quantity nitrogen fertilizer application in tea and leguminous cover crop (Mucuna bracteata) establishment in rubber during immature phase. The nitrogen fertilizer application in mature tea is usually based on the estimated crop yield and the quantity of N applied was substantially higher (300kgN/ha/year) compared to coffee system (80 kgN/ha/year). In rubber system even though the quantity of N fertilizer application was very less (30 kg N /ha/year) the establishment of cover crop in the inter rows of rubber might have significantly reduced soil pH [14]. The acidification of soil by nitrogen fixing leguminous crops is due to the imbalance in the uptake of cations over anions by nitrogen fixing leguminous crops [15].

Agroforestry systems	TC (%)	SOC (%)	TN (%)	Available nutrients (kg/ha)				pH	C:N
				P	K	Ca	Mg		
Rubber	2.15	2.02	0.19	46.8	184	593.2	48.2	4.73	11.31
Coffee	5.36	4.98	0.46	15	239.8	1528	344.6	4.78	11.65
Tea	4.53	4.25	0.34	131.8	648.2	770	157.2	4.67	13.32
Cardamom	4.68	4.51	0.31	103.5	259.6	835.6	144.6	5.1	15.09
SE	0.109	0.223	0.031	10.27	11.03	29.74	10.43	0.238	0.718
CD	0.15	0.30	0.04	13.78	14.79	39.88	13.99	0.32	0.96

Table 2.soil fertility status of different agroforestry systems

Total carbon (TC), total nitrogen (TN) and Soil organic carbon (SOC)

There is considerable variation in TC,TN and Organic carbon (OC) per cent in soils of different agroforestry systems. Higher biomass production in coffee agroforestry system was associated with significantly higher per cent of TC, TN and OC in coffee soil compared to soils in all other systems. Among the systems, these three parameters were lowest in rubber. The changes in TC and SOC among different agro forestry systems can be expected due to the differences in the addition of organic matter inputs and agro management practices followed in each system. Coffee system showed more than 26 per cent of TC compared to other systems. In coffee system, annual litter addition through leaves, small twigs and parts of pruned litter from coffee plant and litter from shade trees is estimated to be 17.4 t/ha/yr [16] which was several fold higher than that of cardamom (5.5 t/ha/yr) [17], tea and rubber system (6 t/ha/yr) [18]. Soil organic matter (SOM) acts as a storehouse and supplier of N to plant roots and microorganisms and almost 95 per cent of the TN in soil is closely associated with SOM [19]**.** The variations in biomass addition may be attributed to variation in TN in soils. Even though the litter addition in rubber system is similar to other systems except coffee, significant variation in soil carbon was observed. Altitude of the study sites also might have influenced TC, TN and SOC. Total carbon and SOC contents of soil is

positively correlated with altitude [20]. Rubber is a low altitude crop, mainly grown in tropical low lands below 400 m altitude, where as coffee, tea and cardamom plants are generally grown in higher altitude. The lower soil temperatures and greater soil moisture in high altitude regions retard the decomposition of litter and might have resulted in more TC and SOC in soils.

Available P, K ,Ca and Mg

Significant variations in available P, K, Ca and Mg were observed among different agro forestry systems (Table 2). The available P content in soils ranged from 15 to 131 kgha^{-1}and the highest available P was observed under tea system (131 kg ha^{-1}) followed by cardamom (103kg ha^{-1}), rubber (46kg ha^{-1}) and coffee system (15kg ha^{-1}). In Kerala rock phosphate is the extensively used P source in plantation sector and it has residual effect in soils. Higher application of rock phosphate in tea and cardamom results accumulation of P in soils. Build-up of P in rubber plantation was also reported [21].

Among the different agro forestry systems, significantly lower per cent of available cations (K, Ca and Mg) were observed in rubber. The available K was highest in tea system where as Ca and Mg was highest in coffee system. The highest available K status in tea soil might be due to addition of very high doses of potassium fertilizers (300 kg/ha/year). The high pH observed in coffee system by the application of lime (calcium carbonate $Ca(CO_3)$ / dolomite ($CaMg(CO_3)_2$) and litter addition from coffee plants and shade trees might have resulted high available Ca in coffee soils. In this study, the cation exchange capacity of soils in the systems ranged from 7.16 to 21.93 meq/100g soil. Coffee system recorded high CEC of 21.93 meq/100g soil which indicates a higher capacity of the soil to adsorb and hold cations. High pH and high cation exchange capacity of soil contributed high available Ca in coffee soil.

The lowest per cent of soil available calcium and magnesium was observed in rubber agroforestry system. Substantial quantity of Ca and Mg was removed through biomass at the end of each plantation cycle and might have resulted in the low Ca and Mg content in rubber system. Application of lime /dolomite is not a common practice in rubber plantations.

GHGs emission from agroforestry systems

Nitrous oxide (N_2O) and methane (CH4)

The quantity of N_2O and CH_4 gases emitted from different agroforestry systems were traces or undetectable. The formation of N_2O gas in the soil mainly occurs through nitrification and denitrification processes influenced by soil moisture, temperature, available N content and C:N of soils. Application of nitrogenous fertilizer is the main source of N_2O emissions in agriculture soils. Many researchers reported that N fertilizer induced N_2O emissions from soil is concentrated in the first two weeks after the fertilizer application [22] and the N_2O emission disappear within two months after the N application [23]. In this study the quantity and time of fertilizer application was different in different ecosystems and we have attempted to compare the emissions in ecosystems and in two seasons. The results clearly indicated that there is no continuous emission of N_2O in agroforestry systems throughout the year.

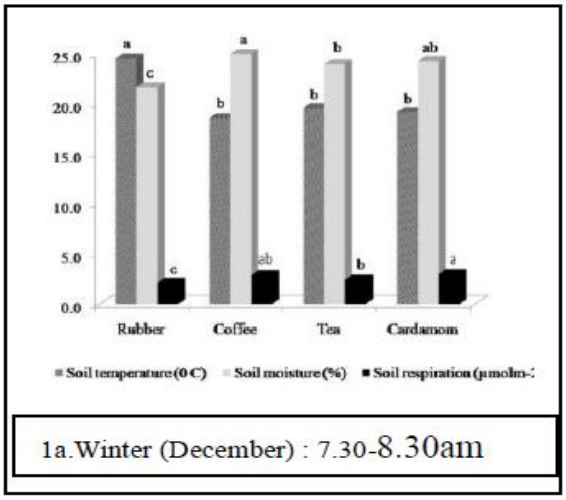
Generally agroforestry systems require less quantity of fertilizers as a result of leaf litter inputs and less N_2O loss from the systems. Trees with deep root system can assimilate residual nitrate left from nitrogen fertilizer applications, which inhibit denitrification in the soil , thus reducing N_2O emissions[24].

Methane production in soils varies with soil moisture, temperature and above-ground biomass and soil properties. In agriculture soils, the production of methane takes place strictly in anaerobic conditions primarily by the activity of methanogenic bacteria living under anaerobic soil conditions at low redox potentials of less than –200mV [25]. Well-aerated soils can actually consume CH_4 from the atmosphere, especially those soils with high surface soil organic matter content under conservation agricultural systems [26]. Many researchers observed periodic emission of methane from upland soils and its production is localised in organic horizons and waterlogged zones. In this study we measured seasonal variation of methane emission during winter and summer season. In agroforestry systems anaerobic soil conditions can be expected during rainy seasons only. This might be the reason for undetectable quantity of methane gas in this study. The data indicated that continuous emission of CH_4 is not present in agroforestry systems throughout the year.

Soil respiration (R_s)

Biomass addition and Co_2 emission

Significant spatial and temporal variability in rate of soil respiration (R_s) /CO_2 flux was observed among different agroforestry systems (Fig.1)



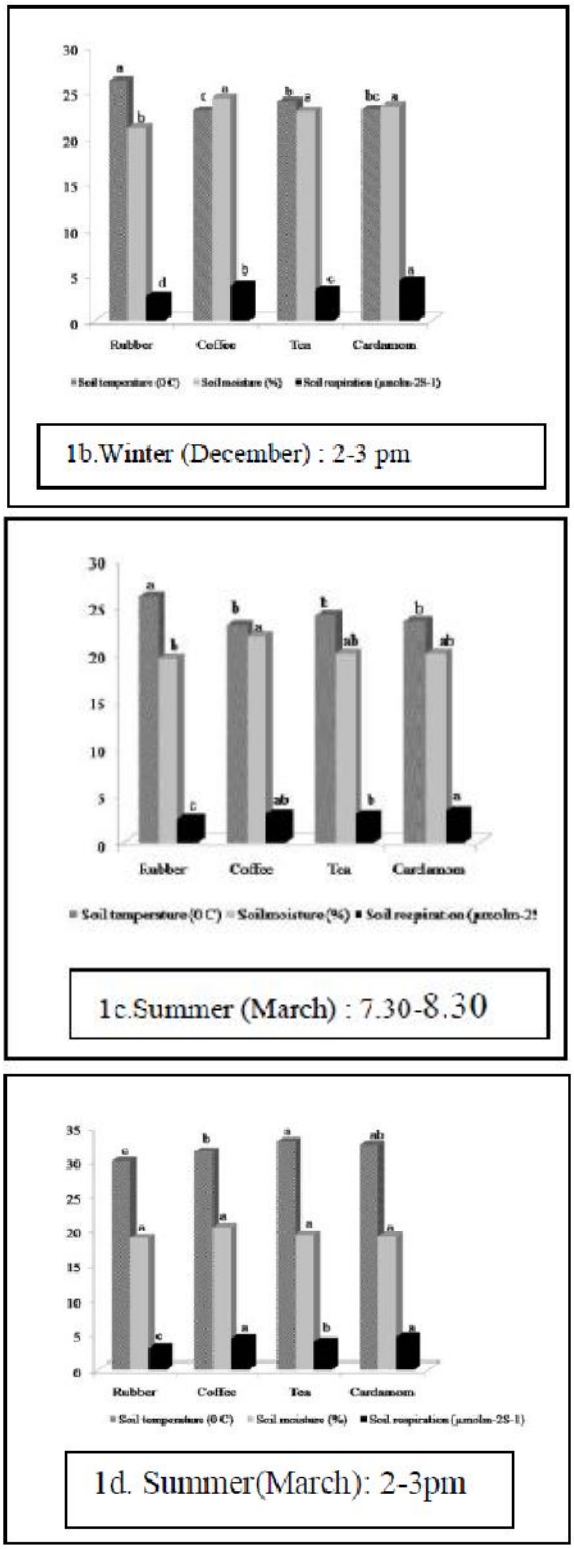


Figure 1. Soil respiration, Soil temperature and soil moisture status of different Agroforestry systems

In winter (December) season during morning (7.30-8.30 am) and noon hours (2-3 pm) the CO_2 emission from the agroforestry systems ranged from 2.16- 3.11 $\mu molm^{-2}S^{-1}$ and 2.64 to 4.55 $\mu molm^{-2}S^{-1}$ respectively. In the morning hours comparatively higher rate of R_s was observed in cardamom (3.01$\mu molm^{-2}S^{-1}$) and coffee systems (2.88 $\mu molm^{-2}S^{-1}$) and the lowest was observed in rubber system (2.16 $\mu molm^{-2}S^{-1}$). During noon time an increase in R_s was detected in all agroforestry systems and significant difference was observed among systems. The rate of R_s was in the following order, cardamom (4.32$\mu molm^{-2}S^{-1}$) > coffee (3.81 $\mu molm^{-2}S^{-1}$) > tea (3.27$\mu molm^{-2}S^{-1}$) > rubber (2.64 $\mu molm^{-2}S^{-1}$). The cardamom agroforestry system recorded the high R_s at both time in winter season, which was 30- 40 per cent more compared to rubber.

During summer month (March) also significantly higher rate of R_s was observed in cardamom and coffee systems during morning and noon hours and the lowest rate was observed in rubber system (Fig. 1c. & 1.d). Soil respiration rate showed a variation in both seasons in all the four systems and the high R s rate was detected in summer season followed by winter.

Soil respiration rate varies spatially, temporally and seasonally and may be influenced by a range of biological, chemical and physiological soil properties and is directly related to the amount of organic residues and fertilizer and manure added to the soils. The accumulation of soil organic matter is a function of the amount of inputs received by soil in the past and the rate at which the biomass input decays. Among the systems studied, more than thrice the quantity of the biomass was added in coffee (17.4 t/ha/yr) system compared to cardamom (5.5t/ha/yr)[27]. Even though the biomass addition was the highest in coffee system high rate of R_s was observed in cardamom. The soil disturbing agro management practices contributed 36.6 to 40.8 per cent of the annual soil cumulative CO_2 emission [28]. The cultural operations like forking, mulching and earthing up in cardamom soils enhances decay or decomposition of soil organic matter and resulted in the significant soil CO_2 emission.

Correlation of Co_2 emission with soil temperature and moisture

Soil temperature and soil moisture are key determinants of R_s. Correlation of R_s with soil temperature and soil moisture is presented in Table 3. During summer, R_s showed a significantly positive relationship with soil temperature and a negative relationship with soil moisture. Among the systems studied R_s in all systems were significantly and positively correlated with soil temperature. With respect to soil moisture, coffee and tea system showed a significantly negative correlation with R_s.

The rate of R_s was recorded to be higher in the month of March in both morning and noon hours in all agroforestry systems. The relatively high soil temperature (30-32^{0}C) experienced during summer months coupled with availability of sufficient soil moisture (18.74 - 20.39 %) might have enhanced the decomposition of plant litter in all systems by the increased activity of the micro flora and fauna in soils, there by increasing the rate of R_s. Soil moisture

content less than 10 per cent seriously affect the activity of soil micro organisms [29]. The rate of R_s was recorded to be low in the month of December in both morning and noon hours which may be due to the lower soil temperature (18.6-24.34^{0}C) which reduces the microbial activity and decomposition of SOM thus leading to low carbon dioxide emission. The precipitation received in the study sites (Table1) contributed to enough moisture in soil during summer months. Precipitation is an important factor influencing R_s variability in soil and immediately after the rainfall events in summer months there was a significant increase the soil respiration rate [30].

Seasons/systems	Soil temperature	Soil moisture
Winter	0.095	0.0702
Summer	0.846**	-0.76*
Rubber	0.649**	-0.38
Coffee	0.756**	0.66*
Tea	0.889**	-0.73*
Cardamon	0.619**	0.377

Table 3. Correlation of soil respiration with soil temperature and soil moisture in different seasons and agro forestry systems

CONCLUSION

The study revealed that the altitude, land use pattern and management practices in agroforestry systems significantly influenced the total and available soil nutrients, and GHGs emission from soils. Among the systems, significantly high per cent of total carbon (TC), organic carbon (SOC), nitrogen (TN), available calcium (Ca), magnesium(Mg) and pH in soils was in coffee agroforestry system where as the available soil P and K was highest in tea. The rate of R_s varied among different systems and was recorded to be higher in summer season compared to winter season. Among the systems studied, the highest rate of R_s was detected in cardamom and coffee systems and lowest in rubber. Continuous emission of nitrous oxide (N2O) and methane (CH_4) gases was not observed in different agroforestry systems. Soil moisture and soil temperatures are correlated with soil respiration. Significant and positive correlation of R_s with soil temperature was observed in all systems. The lower per cent of the total and available soil nutrients were observed in rubber agro forestry system, which might be due to the lower altitude of the system compared to other systems.

Agroforestry system offers promising prospects for mitigating GHGs emission from soils by litter addition, soil and land use management and carbon sequestration. Higher soil organic matter and less soil disturbance contributed to high soil carbon storage. In future, more attention should be given to identify or develop more climate change compatible land management practices that are enhanced or maintained SOC and offset GHGs emissions from agroforestry systems to mitigate the climate change.

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