__Original Research Article__

"Influence of land uses on soil carbon mineralization in selected agro-ecological units of south Kerala"

ABSTRACT

Soilisamajorreservoirofterrestrialcarbonanditplaysanimportantroleintheglobalcarbon cycle.The soil organic carbon (SOC) is the fundamental factor for sustainable agriculture because of the ability in maintaining the soil fertility which is critical to soil productivity. Soilcarbon pool has gained paramount importance in the recent decadesowing to the alarming issues of climate change and global warming.Land use change was found to have a larger net effect on SOC storage than projected climate change.Depending on the land use management practices, soils can be a net sink or source for CO_2. In this regard the present study was carried out to assess the impact of different land uses on carbon storage and mineralization in soils selectedagro-ecological units of south Kerala.The agro-ecological units (AEUs) of south Kerala namely, southern coastal plain (AEU 1), Onattukara sandy plain (AEU 3), southern laterites (AEU 8), south central laterites (AEU 9) and southern and central foothills (AEU 12) were selected. In each AEU, different agricultural land use categories as described by IPCC for the carbon inventory such as, garden land (coconut), wet land (rice), fallow (uncultivated) and plantation (rubber) were also selected for the study. The potential for carbon mineralization in soil was assessed by evaluating factors such as Total organic carbon, mineralizable carbon, particulate organic carbon, global warming potential, carbon distribution, and turnover. The total organic carbon and particulate organic carbon were higher in rubber land use and AEU 12.The mineralizable C content in soil varied from 1.40 to 3.45, 1.18 to 3.41, 1.04 to 3.04, 1.23 to 3.35 and 1.01 to 3.02 mg g^{-1} in AEU 1, 3, 8, 9 and 12 respectively. The highest value was observed from AEU 1 and rice land use. Similar trend was obtained for global warming potential of soils based on CO_2 evolution which varied from 31.82 to 78.41, 26.89 to 79.02, 22.89 to 69.02, 28.03 to 76.06 and 22.96 to 68.64 in AEU 1, 3, 8, 9 and 12 respectively. The C proportion and turnover rates were in the range of 0.25 to 0.77 and 0.04 to 0.17 respectively. The C proportion was the highest in AEU 12 and rubber land use whereas the C turnover was the highest in AEU 1 and rice land use.

Keywords- Land use, agro-ecological units, potential carbon mineralization, global warming potential, carbon proportion, carbon turnover

1. Introduction

Soil serves as a significant repository of carbon within terrestrial ecosystems and holds a pivotal position in the overall global carbon cycle.Approximately 2500 Pg of carbon is stored in the soil, composed of 1550 Pg as organic carbon (SOC) and 950 Pg as inorganic carbon (SIC) within the top 1 meter of the soil profile (Lal, 2004). According to a recent global assessment, soils within the 0-30 cm depth hold an estimated 680 Pg of SOC stock, playing a crucial role in soil biodiversity, nutrient regulation, management of greenhouse gases, and maintaining water balance (Ahirwal et al., 2022).TheSOC plays a major role in improving soil fertility, increasing cation exchange capacity of soil, enhancing water holding capacity, promoting soil aggregation and maintaining soil flora and fauna. It helps to increase the diversity of various soil microbes, which play an important role in maintaining soil quality and functionality (Mc Bratney *et al*., 2014).

Increasing atmosphericconcentration of green houseespecially CO_2 is an importantissueofthetwenty firstcentury.Atmospheric CO_2 concentration has reached 400 ppm in 2013 (Lal *et al*., 2015). Soil carbon sequestration is a promising strategy for the mitigation of global climate change by preventing building up of atmospheric CO_2.Anyattempttoenrichthesoilreservoirthroughsequestration of C will help to offset atmospheric CO_2 concentration and helps to abate global warming to a greaterextent.Changes in land use and land cover significantly impact the SOC pool. This is primarily due to variations in the rates of input (such as plant litter) and output (like SOC mineralization) of soil organic matter (SOM) resulting from alterations in plant communities and land management practices (Poeplau and Don, 2013).Improper land use practices can result in the depletion of SOC, contributing to a decline in soil quality. Additionally, this depletion can lead to the release of carbon emissions into the atmosphere.. A global assessment of SOC revealed a total loss of 116 Pg of carbon within the 2 meter depth of soil due to agricultural land use changes spanning 1200 years (Sanderman et al., 2017).Land use management practices affects the rate of soil C mineralization (Ren et al., 2018). Thus by affecting soil carbon storage, changes in land use have a significant impact on global CO_2 emission and land use changes are regarded as the second source of GHG emission after fossil fuels (Zhong et al., 2019).

Agro-ecological units (AEUs) are broad spatial divisions based on climate variability, land forms and soils. The FAO introduced agro-ecological delineations, emphasizing similar agro-climatic parameters, to identify agriculturally promising areas ideal for specific crops or combinations thereof. This approach aims to maximize production potential for optimal agricultural outcomes.AEUs with different land uses have typical signature on soil organic carbon pools and its storage in different soil layers with unique recalcitrant, lability and carbon management index. There are twenty threeAEUs in Kerala. In this context the present study was proposed to assess the impact of different land uses on carbon mineralization potential in soils of selected AEUs of south Kerala.The main objectives of the study were to determine the mineralizable C content, global warming potential, total organic carbon, particulate organic carbon, carbon turnover and carbon proportion in soils of selected AEUs under different land use categories in order to determine the source/ sink capacity of the selected land uses and their vulnerability status.

2. MATERIAL AND METHODS

2.1.1. Study area and soil sampling

The agro-ecological units (AEUs) of south Kerala namely, southern coastal plain (AEU 1), Onattukara sandy plain (AEU 3), southern laterites (AEU 8), south central laterites (AEU 9) and southern and central foothills (AEU 12) were selected. In each AEU, different agricultural land use

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categories as described by IPCC for the carbon inventory such as, garden land (coconut), wet land (rice), fallow (uncultivated) and plantation (rubber) were also selected for the study.Survey was conducted in the selected AEUs and land uses, and identified locations for soil sampling.Three sites were selected randomly from each land use representing each AEU and considered as replications for the study. Soil samples were collected from various locations including Thuravoor, Nedumpaikulam, Kundra and Magalapuram in AEU 1, Bharanikkavu, Mynagappalli and Karunagappali in AEU 3, Ookkod, Kalliyoor, Venganoor, Balaramapuram and Perumkadavila in AEU 8, Karavaram, Pooyappalli and Madappalli in AEU 9, and Karyom, Thalavoor, Altharamoodu, Kuttikkadu, and Vellarada in AEU 12.Geo referenced soil samples were collected from 0 to 25 cm depth and the samples were stored in plastic covers and labelled. Soil sampling was done during February to March, 2020 and November, 2020 to February, 2021.The soil samples were shade dried, powdered, sieved through a 2 mm sieve and stored in a moisture free environment for laboratory analysis.The location map of sampling sites in the AEUs selected for the study is depicted in figure 1.

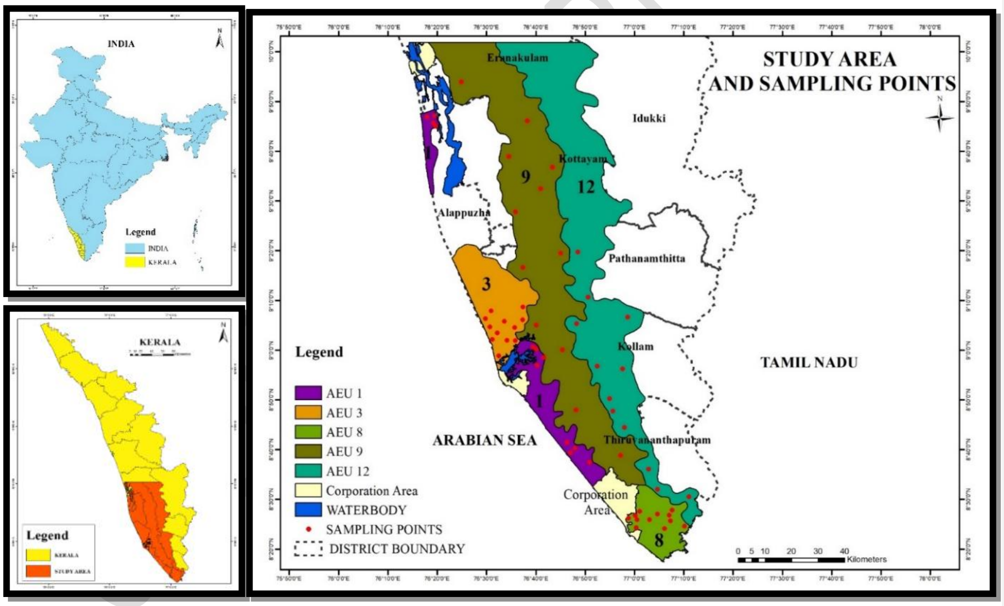

Fig. 1 Location map of study area and sampling points

2.1.2 Soil Analysis

2.1.2.1 Total organic carbon

Total organic carbon (TOC) content in the samples was determined by weight loss on ignition method (FAI, 2017).

2.1.2.2 Particulate organic carbon

The assessment of particulate organic carbon (POC) utilized the sodium hexametaphosphate dissolution method outlined by Camberdella and Elliott (1992). This involved dispersing ten grams of air-dried soil in 30 ml of a 0.5% sodium hexametaphosphate solution, agitating the mixture for 15 hours on a reciprocal shaker. Subsequently, the dispersed soil sample was filtered through a 53 µm sieve. The retained material on the sieve underwent multiple rinses with water, after which it was collected, dried at 50°C in a hot air oven, and analyzed for carbon content using the wet oxidation method by Walkley and Black (1934).

2.1.2.3 Mineralizable carbon

Mineralizable carbon was determined by CO_2 evolution method following laboratory incubation study as outlined by Ladd *et al*. (1995). Hundred gram soil sample was taken in a conical flasks. The moisture content of the sample was maintained at field capacity throughout the incubation period. The CO_2 evolved were trapped in vials containing 0.1 N NaOH, which were hung inside the conical flask using a thread and the flask was sealed tightly using a rubber stopper to prevent any CO_2 loss. The CO_2 absorbed by NaOH was precipitated using $BaCl_2$ and estimated by titrating against 0.1 N HCl using phenolphthalein as indicator. The CO_2 measurement was made on daily basis during the initial period and the interval was fixed based on the evolution and the subsequent measurements were continued up to 50 days depending on the amount of CO_2 evolved.

2.1.2.4 Global warming potential

The global warming potential (GWP) of soils under various land uses was assessed by considering the amount of CO_2 released during the incubation experiment(Ladd *et al*., 1995). According to IPCC(2001), GWP of 1 µmol CO_2 was assumed to be 1 and GWP of selected land use was calculated as described by Cai (1999). The GWP value is unit-less.

$$GWP(CO_2) = [m(CO_2)/44)] \times 1,$$ where 'm' is the mass of the gas

2.1.2.5 Carbon proportion and turnover

Carbon proportion and turnover was worked out by the method given by Chacko *et al.* (2014). The carbon proportion was computed by the ratio of particulate organic carbon (POC) to total organic carbon (TOC). Carbon turnover was computed by the ratio of C mineralization to TOC.

2.1.3 Statistical Analysis

The data generated were subjected to statistical analysis using GRAPES software(Gopinath et al.,,2020). The statistical design followed was two way ANOVA.

3. Results and discussion

3.1 Total organic carbon

The primary elements influencing the dynamics of TOC in soil encompass land uses, climatic conditions, soil types, vegetation and management practices. In the present investigation, the TOC content varied from 1.27 to 3.56 per cent in different AEUs under various land use systems (Table 1). Among the different AEUs, TOC content followed the order AEU 9 (2.53 %)> AEU 12

(2.46 %)> AEU 8 (2.45 %)> AEU 3 (2.24 %)> AEU 1 (2.09 %) and in land uses it varied in the order rubber (3.18 %)>coconut (2.56 %)> rice (2.16 %)> uncultivated land (1.52 %). The TOC build up in soil under any land uses or soil types is the balance the carbon input (litter, crop residue, root exudation & manure) and output (respiration, oxidation, leaching & erosion losses). In all the AEUs higher TOC was registered from rubber land use.The elevated organic carbon levels found in rubber plantations in this study might be attributed to high level of organic residue input in the form of leaf litter, root biomass and exudation, and its recalcitrant nature that slows down the rate of microbial decomposition. The results are in conformity with the findings of Mandal et al. (2020). Lesser TOC content in other land use types implies the considerable depletion of SOC through the nature of crops and its management practices. This happens particularly in areas subjected to intensive cultivation, leading to disruptions in soil structure and increased exposure of soil carbon fractions to oxidation.Similar results were obtained by Hussain et al. (2019) who reported that the absence of organic matter integration into the soil, the removal of crop residues, and the use of traditional tillage techniques in agricultural production systems can result in a reduction of carbon content in the soil and tillage accelerates the oxidation of organic carbon by disrupting the soil structure, thereby exposing the organic matter to soil microorganisms.

Table 1. Effect of agricultural land uses on total organic carbon (%) content in soil

AEUs (A)	Land use (L)				Mean
	Coconut	Rice	Rubber	Uncultivated land	
AEU 1	2.32^{fg}	1.98^{h}	2.80^{cd}	1.27^{j}	2.09^{C}
AEU 3	2.54^{def}	1.97^{h}	2.89^{c}	1.56^{i}	2.24^{B}
AEU 8	2.64^{cde}	2.23^{gh}	3.46^{a}	1.47^{ij}	2.45^{A}
AEU 9	2.79^{cd}	2.51^{ef}	3.18^{b}	1.63^{i}	2.53^{A}
AEU 12	2.51^{ef}	2.08^{gh}	3.56^{a}	1.68^{i}	2.46^{A}
Mean	2.56^{B}	2.16^{C}	3.18^{A}	1.52^{D}	
	A	L	A x L		
S.E(m)	0.046	0.041	0.093		
CD (P= 0.05)	0.132	0.118	0.265		

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3.2 Particulate organic carbon

Particulate organic carbon (POC) is a stable C fraction as it is physically protected within the aggregates and is the most contributing factor to TOC content in soil.The POC fraction varied significantly among different systems and is depicted in figure 2. Among the land uses rubber land use recorded the highest POC (2.07 %) which was found to be significantly superior to coconut (1.57 %) and rice (1.13 %) whereas uncultivated land recorded the lowest POC (0.61 %). With respect to different AEUs, the highest value was observed for AEU 12 (1.74 %) followed by AEU 9 (1.66 %), AEU 8 (1.33 %) and AEU 3 (1.24 %) which were differed significantly and the lowest value was recorded for AEU 1 (0.75 %). It is also revealed that in all AEUs rubber land use recorded higher POC compared to other land uses.The high POC value under rubber land use might be due to high biomass input and minimum soil disturbances and soil aggregation in the land use. Land management practices involving minimal soil disturbance can result in POC accumulation whereas intense cultivation practices reduces the concentration particularly in the surface soil layers. Hence POC is a sensitive indicator of land use management practices in soil. Also lignins and tannins from decomposition of litter from rubber plantations enhances soil aggregation and POC is physically protected within the aggregates.The results are in line with the findings of Kalambukattu et al. (2013).

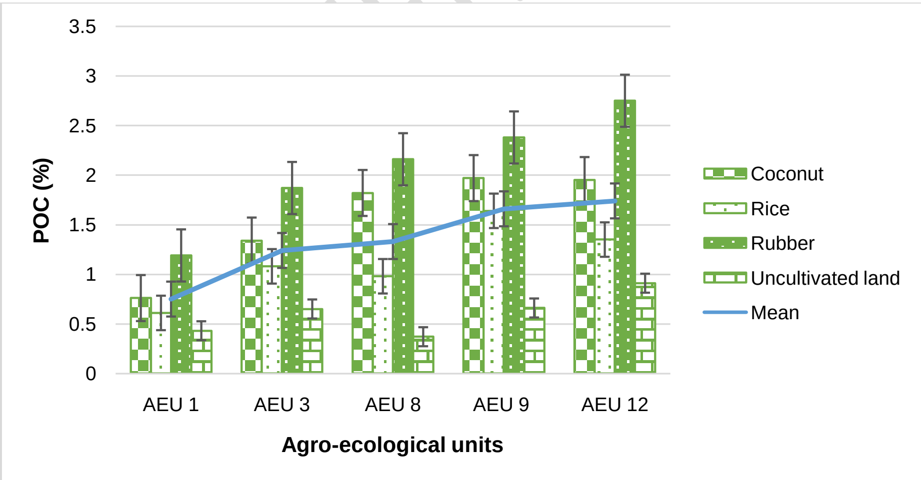

Fig. 2. Effect of agricultural land uses on particulate organic carbon (%) in soil

3.3 Mineralizable carbon

The results of cumulative amount of C mineralized for 50 days of incubation in soils of different agro-ecological units under different land use systems is given in table 3.The mineralizable C content varied between 1.40 to 3.45 mg g^{-1}, 1.18 to 3.41 mg g^{-1}, 1.04 to 3.04 mg g^{-1}, 1.23 to 3.35 mg g^{-1} and 1.01 to 3.02 mg g^{-1} in AEUs 1, 3, 8, 9 and 12. The higher amount of mineralizable carbon in AEU 1 in might be attributed to the sandy nature of the soil which possess low sequestration capacity for carbon that augmented mineralization of carbon. AEU 12 recorded the lowest mineralizable carbon content which enhanced the SOC storage in the system. While comparing the mean value of cumulative mineralizable carbon in different land uses, the highest value was observed in rice land use (3.25 mg g^{-1}), which was found to be significantly different from coconut (2.36 mg g^{-1}) and rubber (1.74 mg g^{-1}) and the lowest value registered in uncultivated land (1.17 mg g^{-1}).The increased carbon mineralization observed in rice land use may be linked to the extensive tillage practices that disrupt soil aggregation and promote faster mineralization as reported by Chacko et al. (2014). Among the land uses uncultivated land showed lowest mineralizable carbon which could be due to reduced soil disturbance that lowers carbon mineralization. The results are similar with the findings of Gladis et al. (2020).

Table 2. Cumulative mineralizable carbon (mg g^{-1}) in soils of different AEUs under various agricultural land use systems for 50 days

AEUs (A)	Land use (L)				Mean
	Coconut	Rice	Rubber	Uncultivated land	
AEU 1	2.61^{c}	3.45^{a}	1.98^{f}	1.40^{i}	2.36^{A}
AEU 3	2.67^{c}	3.41^{a}	1.98^{f}	1.18^{j}	2.31^{A}
AEU 8	2.32^{d}	3.04^{b}	1.41^{i}	1.04^{k}	1.95^{C}
AEU 9	2.16^{e}	3.35^{a}	1.73^{g}	1.23^{j}	2.12^{B}
AEU 12	2.06^{ef}	3.02^{b}	1.58^{h}	1.01^{k}	1.92^{C}
Mean	2.36^{B}	3.25^{A}	1.74^{C}	1.17^{D}	
	A	L	A x L		
S.E(m)	0.023	0.020	0.045		
CD (0.05)	0.065	0.058	0.130		

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3.4 Global warming potential

Soil carbon mineralization directly impacts the potential release of CO_2, which, in turn, contributes to and influences global warming. Different land uses have varying ability to store and release carbon. The CO_2 production and GWP of soils of various AEUs and land uses followed the same trend of mineralizable carbon. The GWP of various AEUs ranged in the descending order AEU 1> AEU 3> AEU 9> AEU 8> AEU 12 and land uses in the order rice> coconut> rubber > uncultivated land (Figure 3). In all the AEUs, the highest value of GWP was noticed in rice which is attributed to the higher carbon dioxide evolution from soil due to the rapid mineralization of organic matter facilitated by intense tillage practices contributes to the higher GWP (74.03). The results were in agreement with the findings of Sreekanth et al . (2013) and Chacko et al. (2014).

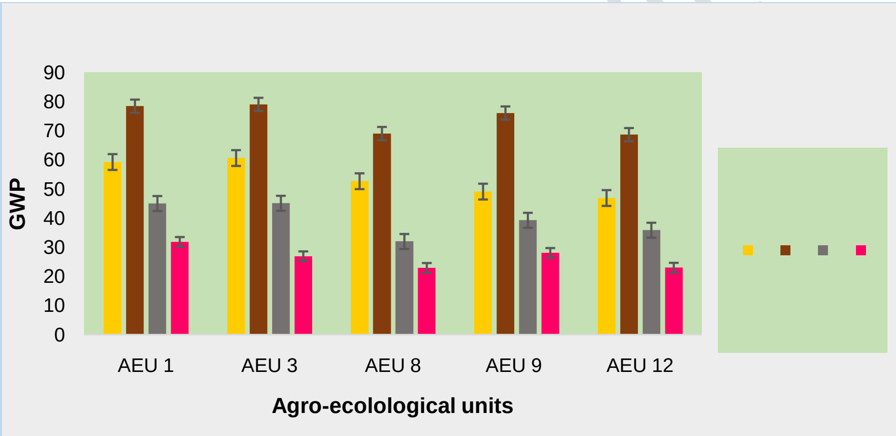

Fig.3 Global warming potential of soils in different AEUs under various agricultural land use systems

3.5 Carbon proportion

The ratio of particulate organic carbon to total organic carbon (POC/TOC) represents carbon proportion in soil. The sink capacity of soil for carbon storage can be represented by soil carbon proportion (Fig. 34). Highest POC/TOC was observed in AEU 12 (0.70) and rubber land use (0.64) which indicate the potential of these systems to store carbon and acts as C sink. The physiography, climatic conditions, vegetation, soil type and management practices might have contributed to the higher carbon proportion in the systems (Chacko et al., 2014; Gladis et al., 2020).

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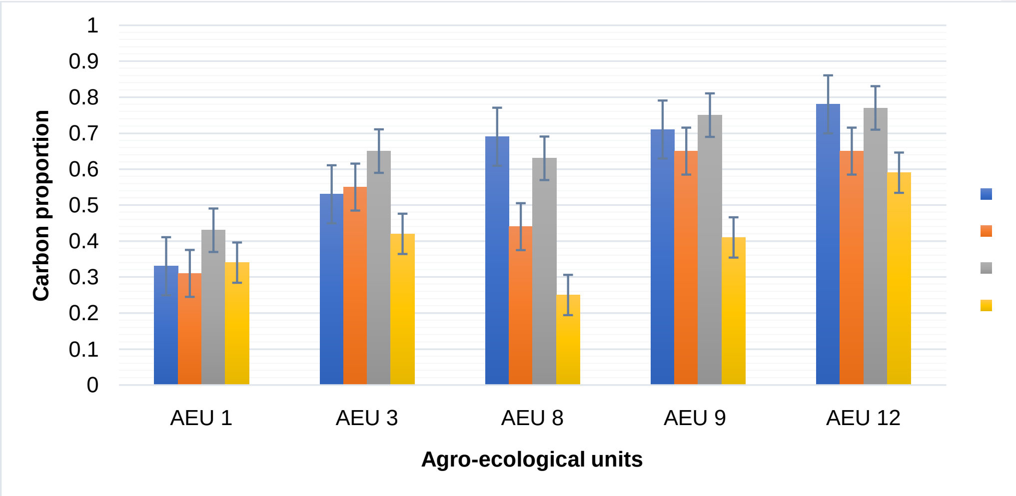

Fig.4 Carbon proportion in soils of different AEUs under various agricultural land use systems

3.6 Carbon turnover

The mineralizable carbon content in TOC (mineralizable C/TOC) represents the carbon turnover in soil. The source capacity can be represented by potential carbon mineralization and carbon turnover rate (Fig.5). Highest C turnover was observed in AEU 1 (0.12) and rice land use (0.15) which might be due to more carbon mineralization prevailing in the systems. The highest C turnover indicate the vulnerability to release C from the soil indicating it as a potential C source as reported by Chacko et al. (2014). Intensive puddling and tillage methods employed in rice cultivation result in the disruption of soil structure, ultimately causing decomposition and mineralization of organic matter in the soil. This makes the land use system more vulnerable as a potential carbon source. The results were comparable with the findings of Paramesh et al. (2022).

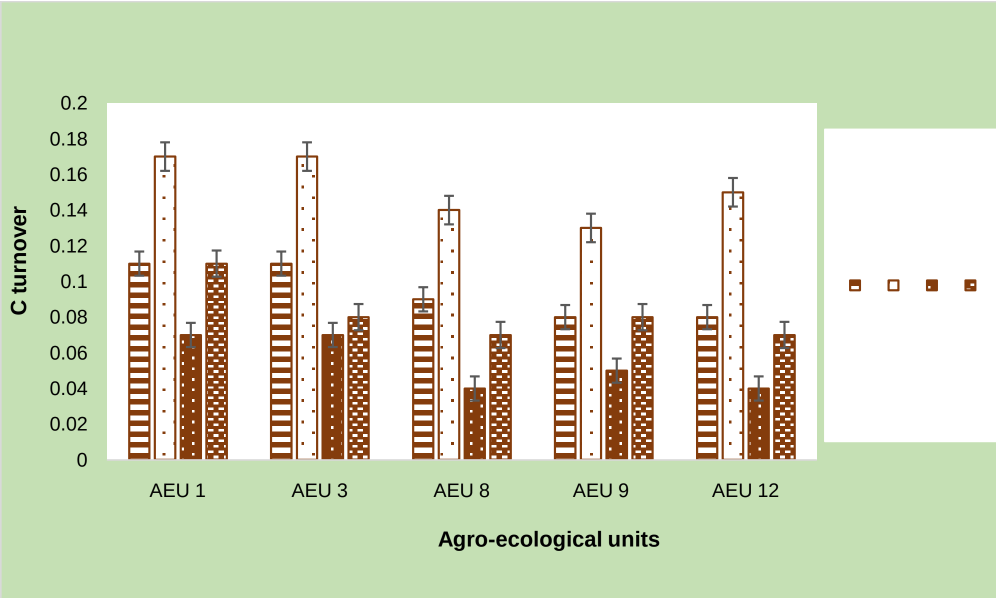

Fig.5 Carbonturnover in soils of different AEUs under various agricultural land use systems

4.Conclusion

Higher levels of TOC,POC, and carbon proportion were notably found in rubber cultivation areas, particularly within AEU 12. This suggests a conducive environment for accumulating organic carbon in the soil. Consequently, it hints at the potential for soil in these systems to act as a significant carbon sink. Among the different land uses, the highest values for mineralizable carbon, GWP and carbon turnover were recorded in the rice land use specifically in AEU 1.The highest carbon turnover signifies the susceptibility of the soil to release carbon, indicating its potential as a carbon source. In rice cultivation, the use of intensive puddling and tillage methods disrupts soil structure, leading to the decomposition and mineralization of organic matter. This renders the land use system more vulnerable as a potential carbon source atmospheric carbon dioxide.

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