Soil Carbon Stock and Pools in Acid Sulphate Soils of Kerala

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RG and KRD during MSc in Soil Science and Agricultural Chemistry. Authors BJ and BA managed the analyses of the study. Author MRR managed the literature searches and correction of the manuscript. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

A study was conducted to assess the soil carbon storage as different soil carbon pools in acid sulphate soils of Kuttanad, Kerala under different land uses and mapping of carbon stock using GIS. Surface soil samples (0-15 cm) were collected from three agricultural land use systems namely rice, coconut and rice-fish from six acid sulphate soil series viz. Ambalapuzha, Purakkad, Thakazhi, Thuravur, Thottapalli and Kallara and were analysed for soil carbon pools like organic carbon, labile carbon, water soluble carbon, particulate organic carbon, microbial biomass carbon and mineralizable carbon using standard procedures .The carbon stock in soil was also computed and mapped using Arc GIS software. The highest organic carbon content of 9.38% was recorded in Kallara series under rice land use. The water soluble carbon ranged from 44.38 to 208.68 mg kg^{-1}. Labile carbon in soil varied form 4.36 mg g^{-1} to 13.06 mg g^{-1}. Particulate organic carbon was the highest in rice land use in Kallara series (7.23%). The mineralizable carbon ranged from 2.17 mg kg^{-1} to 2.91 mg g^{-1}. The microbial biomass carbon varied between 71 mg kg^{-1} and 488 mg kg^{-1}. The humic acid content varied from 0.20% to 6.09% and the fulvic acid content ranged from 0.09% to 20.10%. The active and passive carbon pools and their contribution to total soil carbon pool was the highest in Kallara series. Among the different land uses, coconut had the highest active pool, while rice land use recorded the highest passive pool of carbon. The soil organic carbon stock (115.96 Mg

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ha^{-1}) and carbon pool index (2.10) were the highest in Kallara series. The proportion of POC to SOC was the highest in Kallara series (0.62) under rice land use indicating it as a potential carbon sink. The carbon turnover rate was found to be the highest in Thottapalli series (1.15) under coconut land use indicating it as a potential carbon source.

1. INTRODUCTION

Soil is the largest reservoir of terrestrial carbon and its major contribution is from soil organic matter. The global soil carbon pool of 2500 Gt includes almost 1550 Gt of soil organic carbon and 950 Gt of soil inorganic carbon [1]. The carbon stored in soils is thrice higher than that in above ground biomass and twice higher than that in the atmosphere [2]. The soil organic carbon pool is more reactive, highly dynamic and a strong determinant of soil quality. Total organic carbon pool in soils of India is estimated at 9.55 Gt at 0.3 m depth and 30 Gt at 1.5 cm depth [3]. Soil organic carbon is an indicator of soil quality and environmental stability [4]. Build-up of each ton of soil organic matter removes 3.667 tons of carbon dioxide from the atmosphere [5]. Different land uses have varying ability to store soil organic carbon and have strong impact on soil carbon pools which decides whether the soil is a net sink or source of CO_2. Wetlands are the effective carbon sinks because of low rate of organic matter decomposition due to standing water conditions. The increase in carbon sequestration have a positive effect in increasing soil fertility, crop productivity, long term sustainability and ultimately in reducing greenhouse effect. The change in land use induced significant losses of soil and particulate organic carbon [6]. Major soil carbon sequestration parameters like particulate organic carbon, soil organic carbon, microbial biomass carbon and aggregate formation were found to be higher in wetland soil and has the potential to combat global warming without compromising productivity [7]. Carbon (C) fluxes are largely controlled by the small but highly bio-reactive, labile pools in terrestrial soils, while long-term C storage is determined by the long-lived recalcitrant fractions [8]. The understanding of the different soil C pools and processes are of vital importance before the implementation of agro-ecological management practices, as it determines the success of SOC management [9].

In India, around 0.293 M ha of land is under acid sulphate soils [10]. In Kerala, Kuttanad is known to be the rice bowl of the state which include 50,000 ha of rice fields, out of which 15,000 ha

belongs to acid sulphate soils (Typic Sulfaquent) [11]. The lower pH of the kari soils of Kuttanad is due to the acid sulphate nature of the soil and the presence of un decomposed organic matter in the form of wood fossils. They are dark brown to black in colour, rich in organic carbon, sandy to clayey in texture, with random deposits of lime shells and humus. These soils serve as a carbon sink due to its specific wetland characteristics. Improvement of soil organic carbon pool will result in augmentation of soil quality and agronomic productivity per unit area. Estimation of soil carbon pools in major soil series of Kuttanad under different agricultural land use systems will help to identify the carbon fractions dominant in different land uses and will help to prioritize land use systems for carbon sequestration.

2. MATERIALS AND METHODS

A study was conducted in acid sulphate soils of Kuttanad, Kerala to assess the soil carbon stock and pools. It extends between 9^0 8´ and 9^0 52´ N latitudes and 76^0 19´ and 76^0 44´ E longitudes and lies at 0.6 to 2.2 m below MSL. It experiences humid tropical climate, with the temperature ranging from 21 °C to 36 °C and annual rainfall of 3000 mm. The total geographic area of the region is 854 km^2. The soils of Kuttanad are typical water logged soils and generally fall under the acid saline group, where about 15,000 ha belongs to acid sulphate soils. The six acid sulphate soil series delineated from Kuttanad namely Ambalapuzha, Purakkad, Thakazhi, Thuravur, Thottapalli and Kallara and three agricultural land use systems prevailing in Kuttanad like rice, coconut and rice-fish were selected for the study. Surface soil samples from 0-15 cm depth were collected from different series of acid sulphate soil under different land use systems. Sampling depth of 15 cm was selected because of the presence of hard pan of clay below the plough sole of 15 cm depth in this soil.

The soils of the study area belong to the order Typic Sulfaquent [11], textural class sandy loam to clay, bulk density 1.21 Mg m^{-3}, cation exchange capacity 45.50 c mol(+) kg^{-1} and

exchangeable acidity 9.38 c mol kg^{-1}. The soil samples were analysed for carbon pools namely soil organic carbon (Walkley and Black wet oxidation method), labile carbon (Potassium permanganate oxidation method), water soluble carbon (water dissolution and wet oxidation method), particulate organic carbon (sodium hexa-meta phosphate dissolution method) and mineralizable carbon (CO_2 evolution method following laboratory incubation study in aerobic condition) and microbial biomass carbon (Chloroform fumigation - extraction technique) following standard procedures. Carbon stock in soil was calculated by the equation SOC (%) x BD (Mg m^{3}) x depth (cm) and mapped using Arc GIS software. The active and passive pools of carbon was apportioned by modified Walkley and Black titration method. Humic and fulvic acid content were determined by alkali extraction followed by acid precipitation method. Carbon Pool Index was computed by the formula, CPI = Total Organic Carbon (TOC) in sample soil/ TOC in reference soil, which represents the loss of carbon from pools. The carbon proportion was computed by the ratio of particulate organic carbon (POC)/ soil organic carbon (SOC) which represents the carbon sink. Carbon turnover was computed by the ratio of C mineralization (MC)/ C storage (SOC) which represents the carbon source. The data obtained were analysed statistically using analysis of variance for completely randomized design using SAS package.

Random sampling technique was followed for the selection of sampling sites and representative geo referenced surface soil samples were collected from 56 sites representing different soil series and land uses. The geographical coordinates viz., latitude and longitude of the locations were recorded using GPS and the location map of study area was prepared. The spatial distribution of carbon stock in surface soil was mapped using Arc GIS software version 10.3 by assigning carbon values in attribute table to each soil series and land use.

3. RESULTS AND DISCUSSION

3.1 Total Organic Carbon Content

In acid sulphate soil, the highest mean total organic carbon was observed in Kallara series (8.89%) which may be attributed to input of carbon through litter fall and greater root biomass and to the chemical stabilization of organic carbon in soil matrix. The lowest organic carbon content of 1.97% was noticed in Thottapalli series under coconut land use which could be due to low organic matter input coupled by reduced physical protection of SOC as a result of oxidation of soil organic matter. Among the various land use systems, rice land use system registered the highest value of 4.69% which was on par with rice - fish (4.41%). The interaction effect of soil series and land use system revealed that the highest total organic carbon of 9.38% was observed in Kallara series under rice land use system. Carbon accumulation in soil is highly correlated to the productivity of the recovering vegetation, physical and chemical conditions in the soil, past history of soil organic carbon inputs and physical disturbances. This may have contributed to the variation in carbon content among the soil series [12]. The highest SOC accumulation was reported from rice fallow system [13]. In paddy soil, the organic amendments and rice residues (stubbles and roots) are the main carbon sources. The presence of this decomposable organic matter under submerged condition might have resulted in the increase in soil organic carbon in paddy soil.

3.2 Water Soluble Carbon

Water soluble carbon is the mobile and reactive soil carbon source and it is the sensible indicator of soil organic matter quality. These pools are vigorously cycled and easily decomposed by micro-organisms and serves as energy source. Water soluble carbon content in soil ranged between 44.38 (Thottapalli series, Coconut) and 208.68 mg kg^{-1} (Kallara series, Rice).The highest mean for water soluble carbon was observed in Kallara series (185.84 mg kg^{-1}) which was on par with Thuravur series (169.45 mg kg^{-1}). With respect to land uses, rice –fish (115.65 mg kg^{-1}) and rice (106.78 mg kg^{-1}) land use systems recorded higher water soluble carbon in soil. Kallara series and rice – fish land use system registered comparatively higher clay and total organic carbon content. As small sized soil particles have higher sorptive potential, soils rich in clay content have higher water soluble carbon and the carbon fractions that eluted down the soil profile would have got sorbed on the clay surface. The highest contribution of water soluble carbon towards the total organic carbon was observed from Thuravur series in rice-fish land use system. This is attributed to the mobile and reactive nature of water soluble carbon in aquatic ecosystems [14].
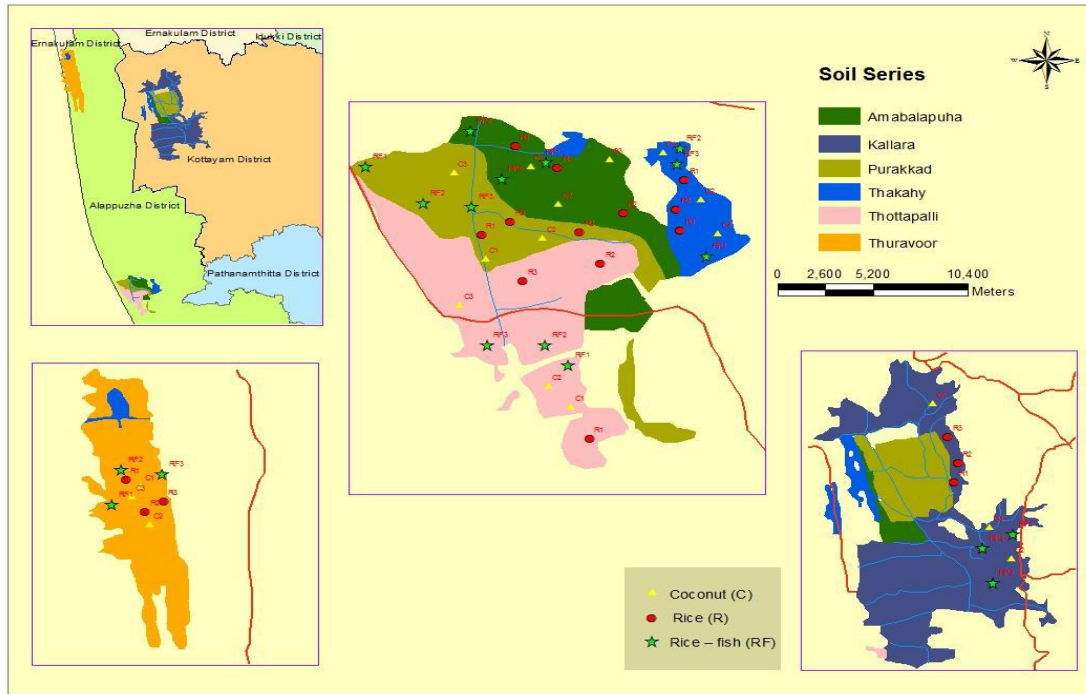
Fig. 1. Location map of study area

Table 1. Total organic carbon content (%) of acid sulphate soils of Kerala

Soil series (S)	Agricultural land use systems (L)			Mean
	L_1 – Rice	L_2- Coconut	L_3 - Rice – fish	
S_1 – Ambalapuzha	3.34	3.17	3.51	3.34
S_2 – Purakkad	2.84	3.47	3.23	3.18
S_3 – Thakazhi	3.44	2.89	6.21	4.18
S_4 – Thuravur	6.58	2.50	2.11	3.73
S_5 – Thottapalli	2.59	1.97	2.80	2.46
S_6 – Kallara	9.38	8.67	8.61	8.89
Mean	4.69	3.78	4.41	
	S	L	S × L	
S.E (m)	0.283	0.200	0.490	
CD (0.05)	0.574	0.406	0.994	

Table 2. Water soluble carbon (mg kg^{-1}) of acid sulphate soils of Kerala

Soil series (S)	Agricultural land use systems (L)			Mean
	L_1 – Rice	L_2 – Coconut	L_3 - Rice – fish	
S_1 – Ambalapuzha	72.19	59.15	117.77	83.04
S_2 – Purakkad	56.57	56.57	86.05	66.40
S_3 – Thakazhi	51.81	62.09	104.12	72.67
S_4 – Thuravur	201.9	126.98	179.47	169.45
S_5 – Thottapalli	49.52	44.38	60.24	51.38
S_6 – Kallara	208.68	202.60	146.25	185.84
Mean	106.78	91.96	115.65	
	S	L	S × L	
S.E (m)	9.904	7.003	17.154	
CD (0.05)	20.089	14.205	34.794	

Table 3. Labile carbon (mg g^{-1}) of acid sulphate soils of Kerala

Soil series (S)	Agricultural land use systems (L)			Mean
	L$_1$ – Rice	L$_2$–Coconut	L$_3$ - Rice – fish	
S$_1$ - Ambalapuzha	5.60	4.64	7.94	6.06
S$_2$ – Purakkad	5.33	4.76	8.62	6.24
S$_3$ – Thakazhi	9.70	9.59	5.85	8.38
S$_4$ – Thuravur	11.24	10.19	9.05	10.16
S$_5$ – Thottapalli	4.89	5.05	4.36	4.77
S$_6$ – Kallara	13.06	12.55	11.09	12.23
Mean	8.30	7.80	7.82	
	S	L	S × L	
S.E (m)	0.253	0.179	0.438	
CD (0.05)	0.512	0.362	0.888	

3.3 Labile Carbon

A significant difference was observed in the labile carbon content of soil. The highest value recorded was 13.06 mg g^{-1} (Kallara series- rice) and the lowest value 4.36 mg g^{-1} (Thottapalli series - rice-fish). With respect to soil series, Kallara showed the highest mean value of 12.23 mg g^{-1} and Thottapalli series the lowest (4.77 mg g^{-1}). The mean values of labile carbon among the different land use system ranged from 7.8 to 8.3 mg g^{-1}. The highest value was recorded from rice and the lowest value from coconut which was on par with rice – fish (7.82 mg g^{-1})The highest value recorded in Kallara series is attributed to the presence of high organic carbon in this soil as labile fraction of organic carbon were largely dependent on the amount of SOC in the soil. The enhanced protection of SOM by aggregates also resulted in an accumulation of more labile C in this soil .Labile carbon fractions are the active carbon pools and they contribute significantly towards total organic carbon. Higher level of labile carbon indicates greater turnover rate of organic matter and higher availability of nutrients. Labile carbon pool is readily decomposable, easily oxidizable and is sensitive to attack by micro-organisms and is more prone to management induced changes in soil organic carbon. It plays an important role in nutrient cycling in soil and thereby influences soil quality and productivity [15]. Labile fraction of organic carbon were largely dependent on the amount of SOC in the soil.

3.4 Particulate Organic Carbon

Particulate organic carbon fractions are the stable carbon pools and they are the more sensitive indicators of change due to land use and management. The results clearly depicts a significant influence of land use on particulate organic carbon with the content ranging from 0.62 to 7.23 %, where the highest value was recorded from Kallara series under rice based system and the lowest in Thottapalli series under coconut. With respect to soil series, Kallara recorded the highest mean value of 5.54%, which also recorded the highest total organic carbon content. Among the land uses, rice based system had the highest mean value of 2.56% and the lowest value of 1.48% from coconut which was on par with rice – fish (1.62%). A similar finding of POC content in paddy field was obtained [6]. Land use changes affect the soil organic carbon due to the changes in the particulate organic carbon fractions, which confirm the role of this fraction in soil carbon sequestration [16]. Intensive agricultural activities may promote the loss of POC due to the destruction of macro-aggregates thus enabling its decomposition by soil micro-organisms.

3.5 Mineralizable Carbon

The mineralizable carbon content varied between 2.17 to 2.91 mg g^{-1}. Among the different soil series, the maximum mineralizable carbon was recorded from Thottapalli series (2.84 mg g^{-1}) which was on par with Ambalapuzha series (2.74 mg g^{-1}) and the lowest values was recorded in Kallara series (2.39 mg g^{-1}). With respect to different land uses, the maximum value of 2.65 mg g^{-1} was registered from coconut and rice - fish land use system, while the minimum value of 2.54 mg g^{-1} was recorded in rice. The maximum mineralisable carbon content was noticed from Thottapalli series and from coconut land use system. However it recorded the lowest total organic carbon and soil carbon storage. Kallara series and rice land use system recorded the minimum mineralizable carbon, the highest total organic carbon and the maximum storage of soil organic carbon. Thus, mineralizable carbon

is inversely correlated with total organic carbon. Soil carbon mineralization influences the CO_2 production potential [6] and global warming and hence different land use systems have varying ability to store and release carbon [17].
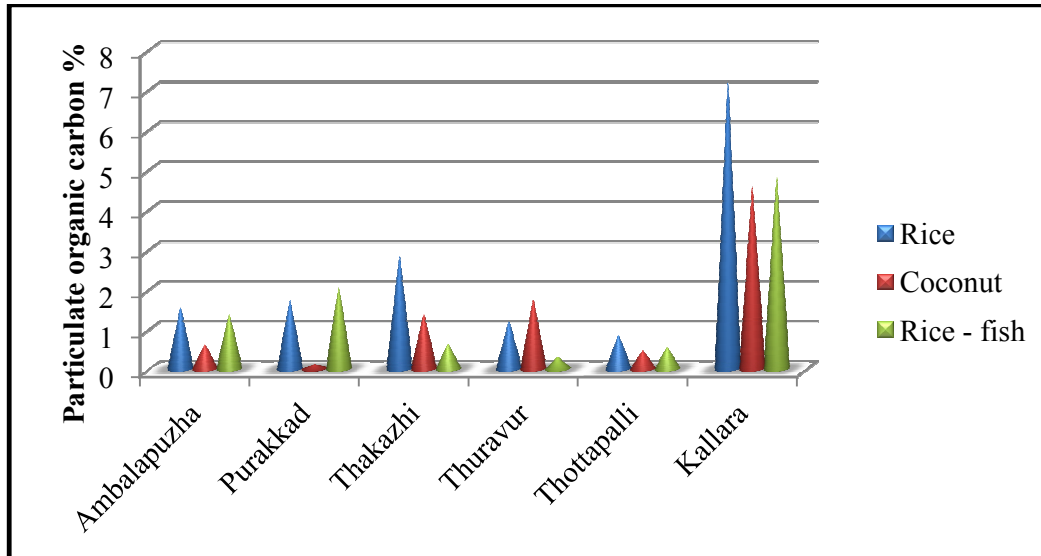

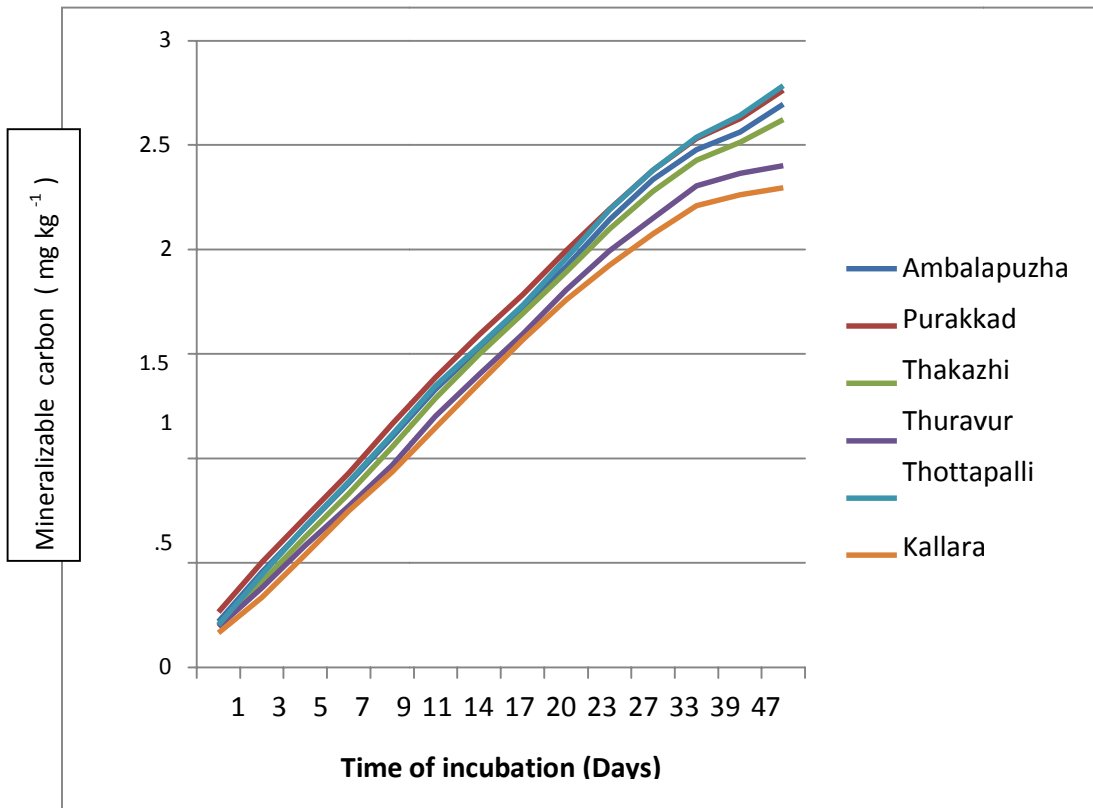**Fig. 2. Particulate organic carbon content (%) of acid sulphate soils of Kerala**

Fig. 3. Mineralizable carbon (mg kg^{-1}) of acid sulphate soils of Kerala

3.6 Microbial Biomass Carbon

The microbial biomass carbon content of acid sulphate soils of Kuttanad varied between 71 mg kg^{-1} and 488 mg kg^{-1}. Among the different soil series, the highest mean value of 394 mg kg^{-1} was noted from Kallara series and the lowest of 125 mg kg^{-1} in Ambalapuzha series which was on par with Thakazhi series (184 mg kg^{-1}). With respect to the different land use systems studied, the maximum value of 315 mg kg^{-1} was observed from rice – fish based system and the minimum value of 225 mg kg^{-1} from coconut which was on par with rice (252 mg kg^{-1}). The microbial biomass carbon is also found to be positively correlated with total organic carbon. Similar results were reported [18]. The soil series and the land use system that recorded the highest microbial biomass carbon have also registered the highest total organic carbon content. Since microbial biomass carbon is the labile pool of soil organic matter, Kallara series had also registered the highest labile carbon while rice – fish land use system had registered the highest water soluble carbon [19].

3.7 Percentage Contribution of Water Soluble, Labile and Particulate Organic Carbon to Total Organic Carbon

The results shown in Table 5 indicated that the percentage contribution of water soluble carbon to total organic carbon was very less and it ranged from 0.17 (Thakazhi) to 0.45% (Thuravur). With respect to the percentage contribution of labile carbon to total organic carbon, the values ranged between 13.76 and 27.24% and the highest contribution was observed from Thuravur series. The particulate organic carbon significantly contributed towards total organic carbon and the value ranged from 25.20 to 62.32% and the highest contribution was noticed from Kallara series. Among the different land uses, the contribution of WSC to TOC was found to be high in rice- fish, LC to TOC in coconut and POC to TOC in rice.

3.8 Distribution of Total Carbon between Active and Passive Pools

Active pool contributes 17 to 48% towards the total organic carbon and the highest contribution was observed in Purakkad series and coconut land use system .The contribution of passive carbon pool towards total organic carbon varied from 51 to 82%. The soil series, Kallara,

Thakazhi and Thuravur series and land use systems rice and rice – fish contributed more passive pool of carbon towards total organic carbon. The source of organic matter in rice and rice – fish land use system is mainly the stubbles left over after the harvest of the paddy crop. This would have contributed to the higher passive pool of carbon. Carbon in the passive pool is inert with a turnover time of 2000 years and hence has a better soil carbon storage. Kallara series and rice land use system recorded the highest passive pool of carbon and hence contribute substantially towards soil carbon storage. Similar results were reported in corn belt agro ecosystem and sodic soil [20,21].

3.9 Humic Acid and Fulvic Acid Fraction

Humic acid content was the highest in Thuravur series and coconut land use system. The highest fulvic acid content was witnessed in Ambalapuzha series and coconut land use system. The fulvic acid concentration is generally higher than humic acid. The ratio of humic acid to fulvic acid varies from 0.11 to 2.06. This ratio was less than 1 in most of the locations and it confirms the predominance of fulvic acid compared to humic acid which indicates the slow rate of decomposition of organic matter or frequent organic addition to the soil [22]. The slow rate of organic matter decomposition in these soils may be as a result of the extremely low pH due to pyrite oxidation and the salinity due to the tidal effect which would have affected the micro-organisms responsible for the mineralization of organic matter. The type of land use influenced the organic matter fractions, which may be due to the micro climate, vegetative canopy and litter input [23].

3.10 Carbon Pool Index

The carbon pool index of the soils varied from 0.47 to 2.19. The highest mean value observed was 2.10 (Kallara series) and the lowest value was 0.58 (Thottapalli series). Rice land use system registered the maximum carbon pool index of 1.10 which was on par with rice-fish (1.05). The lowest value of 0.90 was registered from coconut. Kallara series under rice land use system registered the highest value of 2.19 while Thottapalli series under coconut land use system registered the lowest value of 0.47.The loss of carbon from a soil of small carbon pool is of greater consequence when compared to the loss of same amount of carbon from the soil of large pool size [24].

Table 4. Microbial biomass carbon content (mg kg^{-1}) of acid sulphate soils of Kerala

Soil series (S)	Agricultural land use systems (L)			Mean
	L$_1$ – Rice	L$_2$ – Coconut	L$_3$ - Rice – fish	
S$_1$ - Ambalapuzha	116	71	186	125
S$_2$ – Purakkad	283	276	347	302
S$_3$ – Thakazhi	205	204	143	184
S$_4$ – Thuravur	445	266	275	329
S$_5$ – Thottapalli	72	231	449	251
S$_6$ – Kallara	391	303	488	394
Mean	252	225	315	
	S	L	S × L	
S.E (m)	36.54	25.84	63.29	
CD (0.05)	74.12	52.41	NS	

Table 5. Percentage contribution of water soluble, labile and particulate organic carbon to total organic carbon

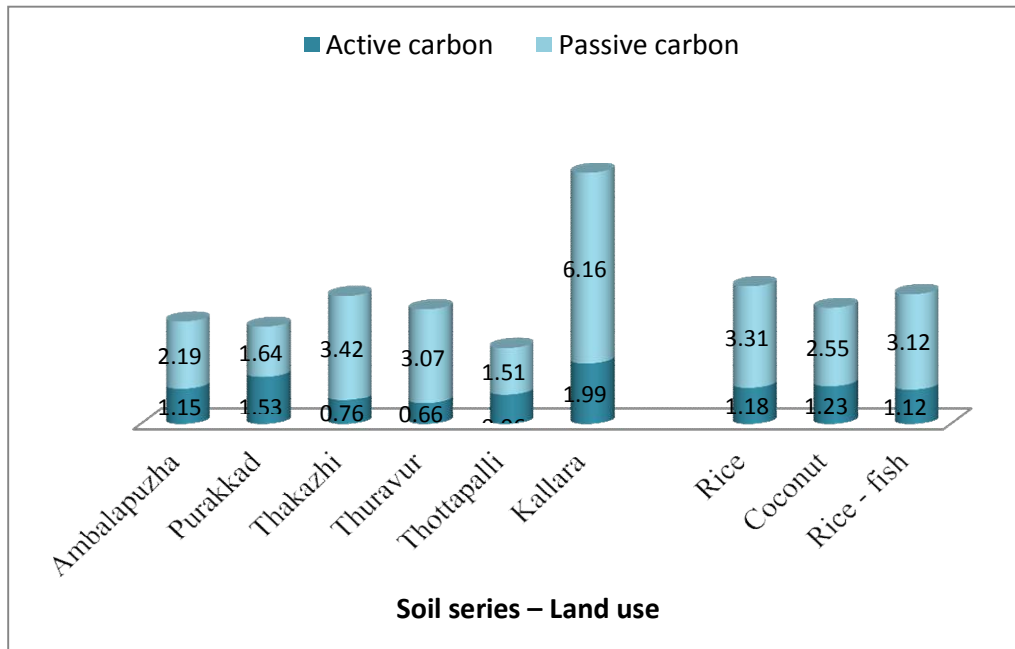| Soil series/ Land use	WSC as % of TOC	LC as % of TOC	POC as % of TOC
Soil series			
S$_1$ – Ambalapuzha	0.25	18.14	35.03
S$_2$ – Purakkad	0.21	19.62	40.57
S$_3$ – Thakazhi	0.17	20.05	38.52
S$_4$ – Thuravur	0.45	27.24	29.22
S$_5$ – Thottapalli	0.21	19.39	25.20
S$_6$ – Kallara	0.21	13.76	62.32
Land use			
L$_1$ – Rice	0.23	17.69	54.58
L$_2$ – Coconut	0.24	20.63	39.15
L$_3$ - Rice – fish	0.26	17.73	36.73

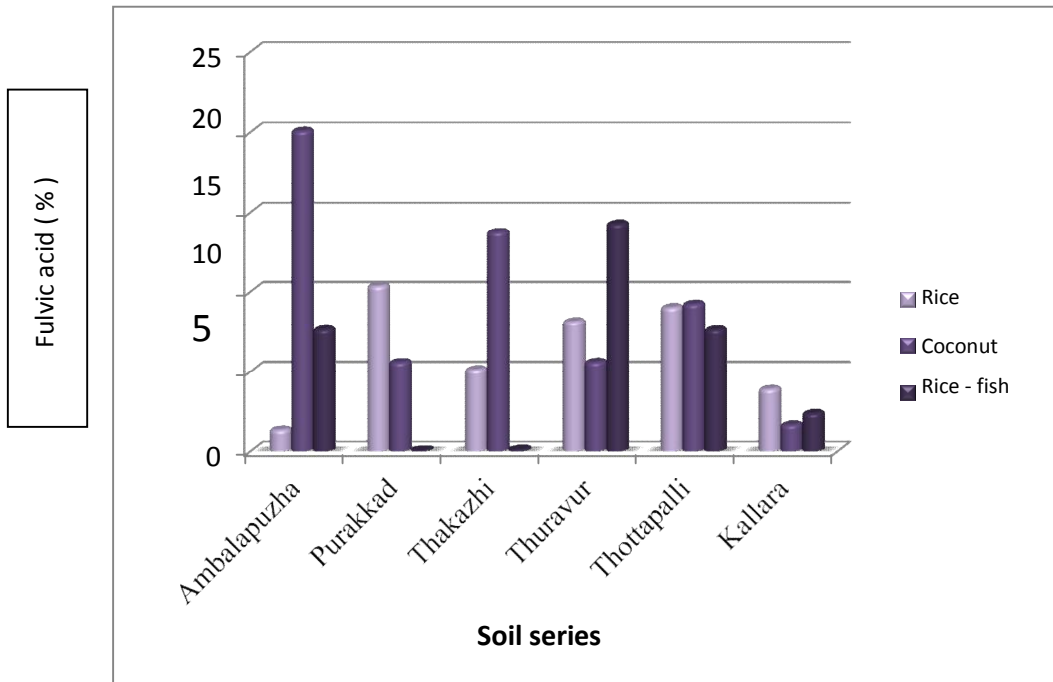**Fig. 4. Distribution of total carbon between active and passive pools**

Fig. 5. Fulvic acid fraction (%) in acid sulphate soils of Kuttanad

Table 6. Humic acid fraction (%) in acid sulphate soils of Kuttanad

Soil series (S)	Agricultural land use systems (L)			Mean
	L_1 – Rice	L_2 - Coconut	L_3 - Rice – fish	
S_1 – Ambalapuzha	1.77	2.83	1.91	2.17
S_2 – Purakkad	1.49	3.33	3.96	2.93
S_3 – Thakazhi	3.11	2.46	0.20	1.92
S_4 – Thuravur	6.09	1.70	1.51	3.10
S_5 – Thottapalli	1.32	2.60	0.81	1.58
S_6 – Kallara	1.79	3.43	2.56	2.59
Mean	2.6	2.72	1.83	
	S	L	S × L	
S.E (m)	0.102	0.072	0.177	
CD (0.05)	0.208	0.147	0.359	

Table 7. Carbon pool index in acid sulphate soils of Kerala

Soil series (S)	Agricultural land use systems (L)			Mean
	L_1 – Rice	L_2 - Coconut	L_3 - Rice – fish	
S_1 - Ambalapuzha	0.78	0.75	0.83	0.79
S_2 – Purakkad	0.66	0.82	0.77	0.75
S_3 – Thakazhi	0.80	0.69	1.47	0.99
S_4 – Thuravur	1.54	0.59	0.50	0.88
S_5 - Thottapalli	0.61	0.47	0.66	0.58
S_6 – Kallara	2.19	2.06	2.04	2.10
Mean	1.10	0.90	1.05	
	S	L	S × L	
S.E (m)	0.066	0.046	0.114	
CD (0.05)	0.133	0.094	0.231	

3.11 Carbon Proportion and Turn Over

The mineralisable fraction of carbon in the soil denotes carbon turn over. Highest carbon turnover was observed from Thottapalli series(1.15) and coconut land use system(0.70), while the lowest carbon turnover was recorded from Kallara series (0.27) and rice land use system (0.54), which also recorded the highest POC/SOC ratio. Chacko et al. [6] had also witnessed the highest POC/SOC ratio from paddy soils. The sink capacity of a soil is determined by the POC/SOC ratio and soil carbon storage, while potential carbon mineralization and carbon turn over indicates the carbon source. The higher POC/ SOC ratio was observed in Kallara series (0.62) and rice land use system (0.54) indicating it as a potential carbon sink. The higher carbon turnover rate was observed in Thottapalli series and coconut land use system indicating it as potential carbon source. These findings are also in line with those reported by Chacko et al. [6].

3.12 Soil Organic Carbon Stock

The highest SOC stock of 115.96 Mg ha^{-1} was observed from Kallara series and the lowest of 32.06 Mg ha^{-1} from Thottapalli series. Rice land use system registered the maximum soil organic carbon stock of 61.28 Mg ha^{-1} which was on par with rice-fish (57.57 Mg ha^{-1}). The organic carbon stock was the lowest in coconut based land use system (49.32 Mg ha^{-1}). The interactions also imposed significant influence on the soil organic carbon stock where in the highest value registered was 122.37 Mg ha^{-1} (Kallara series, Rice) and the lowest value registered was 25.75 Mg ha^{-1} (Thottapalli series, coconut). The soil organic carbon stock was found to be the maximum in Kallara series and rice land use system, which also recorded the highest total organic carbon content. Land use change had significantly influenced the soil organic carbon stock [25]. The higher clay content in these soils also contributed to the higher carbon stock. Slow rate of decomposition of soil organic matter and decreased microbial activity may have resulted in increased carbon stock in these soils. In addition, increased micro aggregate fraction in these soils also provide protection to soil organic matter and decrease carbon loss and thereby augment the soil organic carbon stock [26].

Table 8. Carbon proportion and turn over in acid sulphate soils of Kerala

Soil series/Land use	Carbon proportion (POC/SOC)	Carbon turn over (MC/SOC)
Soil series		
S$_1$ – Ambalapuzha	0.35	0.82
S$_2$ – Purakkad	0.40	0.85
S$_3$ – Thakazhi	0.38	0.63
S$_4$ – Thuravur	0.29	0.64
S$_5$ – Thottapalli	0.25	1.15
S$_6$ – Kallara	0.62	0.27
Land use		
L$_1$ – Rice	0.54	0.54
L$_2$ – Coconut	0.39	0.70
L$_3$ - Rice – fish	0.36	0.60

Table 9. Soil organic carbon stock (Mg ha^{-1}) in acid sulphate soils of Kerala

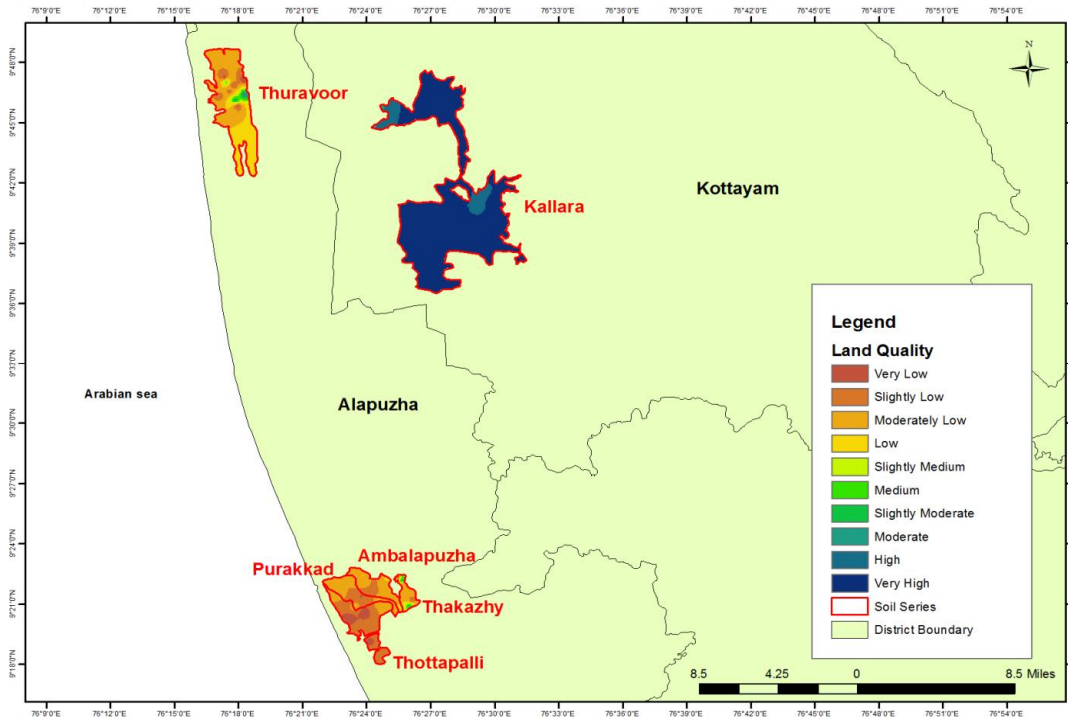| Soil series (S)	Agricultural land use systems (L)			Mean
	L$_1$ – Rice	L$_2$ - Coconut	L$_3$ - Rice – fish	
S$_1$ - Ambalapuzha	43.59	41.32	45.85	43.59
S$_2$ – Purakkad	37.01	45.29	42.11	41.47
S$_3$ – Thakazhi	45.02	37.72	81.00	54.58
S$_4$ – Thuravur	85.82	32.67	27.54	48.67
S$_5$ – Thottapalli	33.84	25.75	36.58	32.06
S$_6$ – Kallara	122.37	113.14	112.36	115.96
Mean	61.28	49.32	57.57	
	S	L	S × L	
S.E (m)	3.693	2.611	6.397	
CD (0.05)	7.491	5.297	12.974	

Fig. 6. Carbon stock map of acid sulphate soils of Kerala

4. CONCLUSION

The results of the present study revealed a significant difference in total organic carbon among soil series and land uses with the maximum value for Riceland use in Kallara series and the minimum value for coconut in Thottapalli series. The highest value of water soluble carbon was observed from rice in Kallara series and the lowest from coconut in Thottapalli series. With respect to labile carbon, the highest value was noted from rice based system in Kallara series and the lowest from rice - fish in Thottapalli series The mean values of particulate organic carbon was the highest in Kallara series under rice and the lowest in Purakkad series under coconut. The mineralizable carbon was found to be the highest in Thottapalli series (Rice - fish) and the lowest in Thuravur series (Rice). The highest active carbon pool was noted from coconut based system in Kallara and the lowest from rice–fish in Thuravur. The passive pools of carbon was highest in rice in Kallara series and the lowest in coconut in Thottapalli series. The organic carbon stock and the carbon pools were the highest in Kallara series of acid sulphate soil. Among the different land uses, rice and rice- fish contributed to maximum soil organic carbon stock and carbon pools showing the prevalence of conducive environment in these ecosystems for the buildup of organic carbon. The proportion of POC to SOC was the highest in Kallara series under rice land use indicating it as a potential carbon sink. The carbon turnover rate was found to be the highest in Thottapalli series under coconut land use indicating it as a potential carbon source. This emphasizes the need to conserve the wetland ecosystems of Kuttanad in Kerala to sequester more carbon into the soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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