EFFECT OF LAND USE CONVERSION ON SOIL CARBON STORAGE IN A TROPICAL GRASSLAND

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ABSTRACT

In the event of climate change and global warming issues, the role of grassland soils needs special emphasis owing to its capacity to store and release carbon. In this regard, the present study discusses variations in soil carbon storage of grassland soils of the Vagamon region, a biodiversity hot spot in the Western Ghat of Kerala, India, under various scenarios of conversion. We address variations in the carbon pool by assessing the parameters soil organic carbon (SOC), particulate organic carbon (POC), potential carbon mineralization (PCM), water stable aggregates (WSA) and the soil protein glomalin in relation to relative land uses changes. The data provide the rates of SOC fluctuations and dynamics and indicate the relative importance of POC, PCM, WSA and glomalin that influence organic carbon sequestration in soil under different land uses. During the study, SOC concentration changed in accordance with land use disturbance and varied in the order: native grassland-(S1) > acacia-(S2) > cardamom-(S3) > open scrub-(S4) > pine-(S5) > tea-(S6) > rubber-(S7) > homestead-(S8). The findings suggest that POC can be considered as a suitable and better indictor towards addressing changes in soil carbon pools, especially for short-term studies, rather than SOC. The study also advocates the importance of native grasslands and their sustainable management in soil carbon storage under climate change scenarios.

Keywords: Soil organic carbon, particulate organic carbon, aggregate stability, glomalin, land use change.

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1. INTRODUCTION

Every soil possesses a limited carbon storage capacity which is a function of the vegetation type, climate, hydrology, topography and nutrient environment that the soil is exposed to [1]. From a global perspective, grasslands store approximately 34% of the global terrestrial stock of carbon while forests store approximately 39% and agro-ecosystems approximately 17 percent [2]. Grasslands are able to sequester about double the quantity of C in the soil in comparison to arable land [3-6]. In the current scenario of climate change, knowledge of grassland soils is the need of the hour because they can act as a carbon source or sink depending on changes in management practices and conversions. Hence, the present study focuses on the implication of land use changes and disturbances on the soil carbon pool of tropical grassland soils. The present study area, Vagamon, is an agro-pastoral ecotone located on the Western Ghats of South India. The region has been identified as a biodiversity hotspot because of its ecological importance supported by grassland and the shola forests. The study hypothesized that the land use change from native grassland would induce a change in the soil C pool by altering the source and sink capacity of the soil. Quantifying the response of terrestrial C, a large proportion of which derives from the soil, is essential for understanding the nature and extent of grassland systems response to global warming. Hence, the objective of this study is to investigate the implications of grassland conversions in the soil C pool – SOC, POC and PCM, aggregate stability, and the soil protein - glomalin of the Vagamon hills, where land use change is progressing rapidly and the risk of soil carbon loss is high.

2. METHODOLOGY

To assess the implications of land use changes and disturbances of the soil carbon pool of grassland Vagamon, a tropical grassland region in Kerala, India (Figure 1) has been selected and a detailed study was conducted during 2012. For the detailed analysis, eight soil samples, which were in the converted or disturbed category, were selected, with an undisturbed grassland site as control. From all these sampling sites triplicate soil samples were taken to the lab for analysis. The details of the study area, sampling sites and lab analysis are given below.

The study plot *'Vagamon'* is located in the Western Ghat region of Kerala, India (9° 34'N latitude and 76°

58'E longitude). Vagamon is identified as a biodiversity hotspot with grasslands or meadows situated at an altitude of 1100 m above mean sea level. The climate is tropical, ranging from 32°C in summer to 16°C in winter and the mean annual precipitation is 376 cm. The soil is fine loamy, mixed, isohyperthermic Oxic Dystrustepts. The soil is very dusky red to dark reddish brown, strongly acid, sandy clay loam to clay loam A horizon and dark reddish brown, very strongly acid, clay loam B horizon. These soils are formed on gneissic rocks on steep to very steeply sloping hill slopes and summits of the Kottayam district, at an elevation of 300 - 900 m above mean sea level.

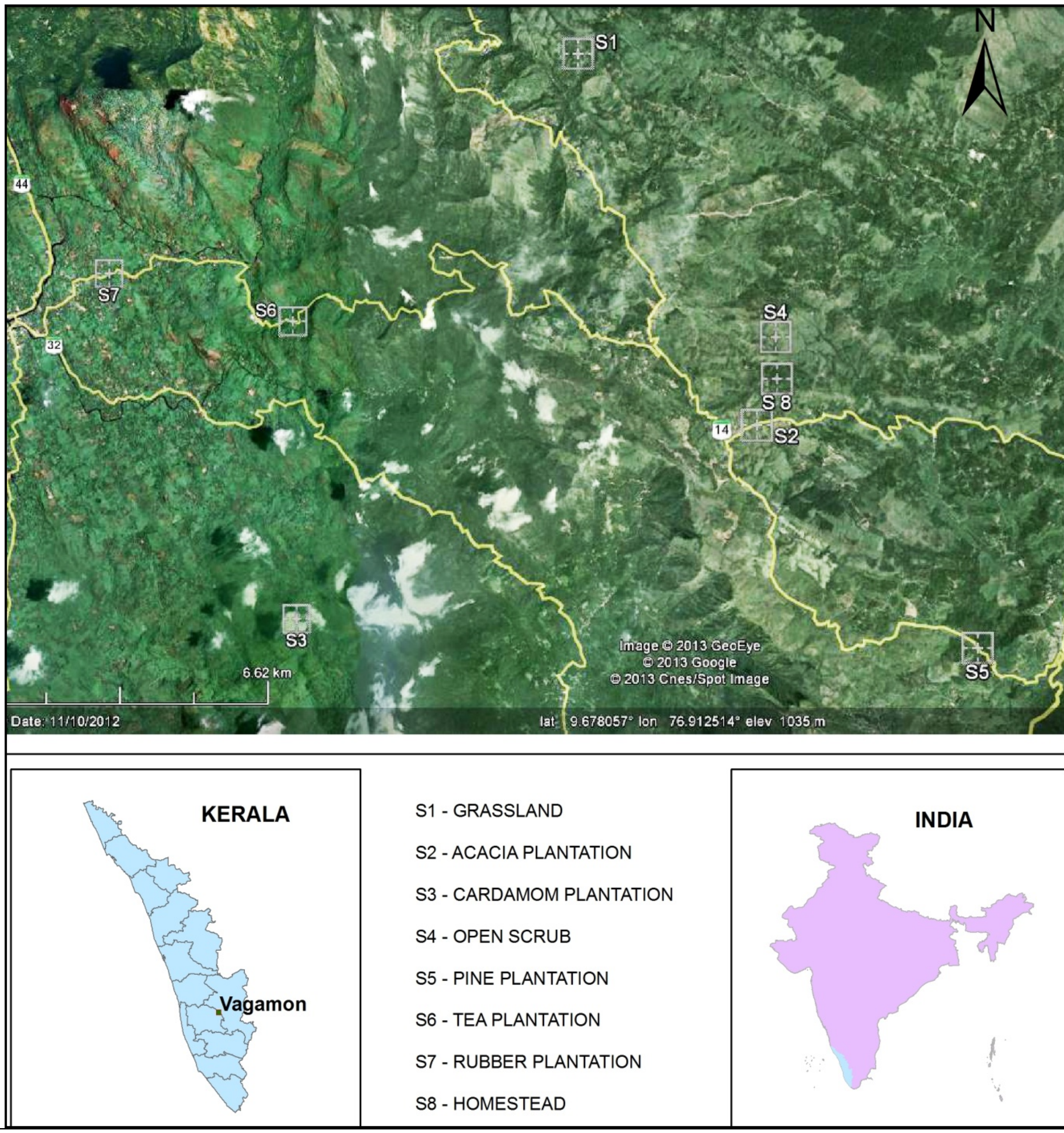

Figure 1 Location map and the sampling sites of Vagamon in the Western Ghats of Kerala, India.

2.1. Study Site

The study plot consist of eight sampling sites with grassland remaining as grassland (S1) and grassland converted land use types S2 to S8: plantations (acacia, tea, cardamom, pine, and rubber), open scrub and homestead. Characteristic variations were observed among the sampling sites in terms of vegetation and other land management aspects which are as follows:

Sample site 1 (S1) (9° 44' & 76° 53' 32.4'') is a natural grassland region devoid of conversion or disturbance activities. The major grass species of the area are *Cymbopogon citrates* and *Axonopus compressus.*

Sample site 2 (S2) (9° 40' 07.7" & 76° 55' 27.4") is an acacia plantation which is a recently-converted grassland site. The major vegetation type is Acacia auraculiformis and native grass species like Cymbopogon citratus and Axonopus compressus. Grazing and tourism activities are predominant in the area. Sparse understory vegetation and less litter fall is observed.

Sample site 3 (S3) (9° 37' 51.0''& 76° 50' 4.3") is a well-established cardamom (Eletaria cardamomum) plantation under conservative agricultural practices. Thick undergrowth and considerable litter fall were noted.

Sample site 4 (S4) (9° 39' 50" & 76° 55' 40'') is an open scrub area subjected to grazing. The area has a dense growth of mixed vegetation with native grass species, shrubs like Lantana camera, Osbeckia aspera and tree species like Psidium guajava, Phoenix sylvestris, Syzygium cumini and Macaranga peltata.

Sample site 5 (S5) (9° 39' 50" & 76° 55' 40'') is a managed pine (Pinus sp) plantation that is 60 years old and is a tourist destination. The site is devoid of undergrowths and other vegetations. A thick mat of non-degraded pine leaves restricts the undergrowth.

Sample site 6 (S6) (9° 37' 51.0"& 76° 57' 47.4'') is a tea (Camellia sinensis) plantation system. Due to the frequent ground clearing and landscaping activities undergrowth and litter is absent and erosion is found to be significant at this site.

Sample site 7 (S7) (9° 41' 14.8''& 76° 50' 4.3'') is a monoculture rubber (Havea braziliensis) plantation of yielding category with sparse undergrowth vegetation of Chromolaena odorata and Stachytarpheta jamaicensi.

Sample site 8 (S8) (9° 41' 47.8''& 76° 47' 51.5'') is a homestead area with shrubs (Chromalina odorattum, Coffea Arabica, Ocimum sanctum etc.) and trees (Manjifera indica, *Artocarpus heterophyllus*, *Psidium guajava etc.* Ground clearance and erosional activities were noted.

2.2. Soil Sampling

Soil samples were obtained in triplicate from different locations under the various land uses. Samples were collected from each depth of 0-10, 10-20 and 20 – 30 cm. Precautions were taken to minimize soil and site disturbances. Samples were air dried and ground to pass through a 2-mm sieve prior to laboratory analysis.

2.3. Soil Analysis

Soil organic carbon (SOC) contents were measured with a TOC analyser (Hiper TOC, Thermo). Characterisation of SOC functional groups was done using ^{13}C CPMAS (300 MHz solid state NMR spectrometer) at IISC, Bangalore, India. Particulate organic carbon (POC) was determined through dispersion in sodium hexametaphosphate [7] and aggregate stability was measured in terms of water stable aggregates (WSA) after sand correction with a wet sieving technique [7]. Soil bulk density measurements were made by the core method for every bulk sample [8-9]. Potential carbon mineralization (PCM) in terms of CO_2 emissions from the soil samples was determined through an incubation study followed by analysis by gas chromatography. Extraction of the soil protein glomalin was done for the easily-extractable glomalin (EEG) fraction utilizing gentle conditions of 30-min of autoclaving using 20 mM sodium citrate at pH 7.0 [9]. The data obtained were examined statistically by correlation analysis.

3. RESULTS

3.1. Soil Organic Carbon (SOC) Stock

Various land use categories had a significant effect on SOC values that ranged from 5.2 to 1.9% (Table 1). The maximum value was recorded under native grassland 5.2%, which is significantly higher (about 2.5 times) than the homestead (S8), 1.9%, which had the least SOC value. The maximum value significantly decreased at the other sites by about 11.5% in the plantation of acacia (S2), 23% in cardamom plantation (S3), 25% in open scrub (S4), 32.5% in tea plantation (S5), 42.5 % in pine plantation (S6), 53.8% at the rubber plantation (S7) and 63.5% in homestead (S8), respectively. Thus the conversion of natural grassland (S1) to other land categories (S2 to S8) resulted in the decline of the SOC pool (Table 1).

Maximum difference is observed between the SOC of natural grassland (S1) and homestead (S8) site

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63.5%. The C stock values also varied in accordance with the SOC concentration since no significant variation was observed in bulk density. However the bulk density values showed an increasing trend in the intensity of land conversion activities. Considering the SOC concentration of native grassland as the baseline, the loss of SOC for various converted land categories varied in the order: S2 (-0.6) > S3 (-1.2) > S4 (-1.3) > S5 (-1.7) > S6 (-2.2) > S7 (-2.8) > S8 (-3.3).

Table 1 Soil organic carbon concentration and stock

Site	SOC (%)	Bulk Density (g/cm^3)	SOC Stock (t/ha)
S1	5.2	1.2	187
S2	4.6	1.25	173
S3	4	1.28	154
S4	3.9	1.29	151
S5	3.51	1.3	137
S6	2.99	1.31	118
S7	2.4	1.33	95.8
S8	1.9	1.35	77.0

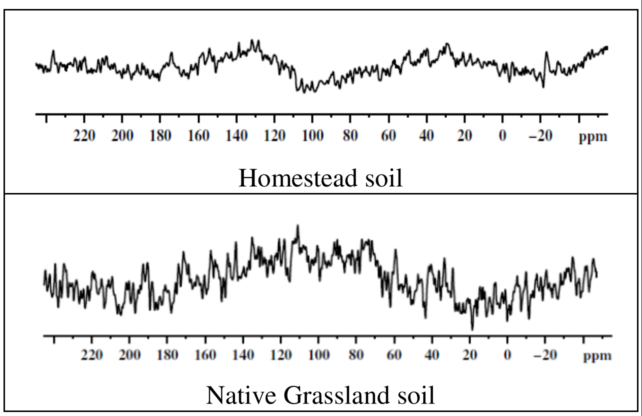

Figure 2 NMR spectra

Figure 2 shows the ^{13}C NMR spectra of soils under native grassland and at the homestead site. In the native grassland soils the aromatic region (160-110 ppm) is dominated by a peak with a maximum ca. 110 ppm for non-substituted and C substituted aromatic carbons. Apart from this, presence of lignin (155 ppm) and tannins (145 ppm) was also noted. A certain contribution of the quaternary aromatic carbon is also possible in the signals at ca. 105 ppm. In case of homestead and other converted soils, the carbonyl region (200-160 ppm) is more prominent and is dominated by a peak with a maximum at ca. 174 ppm traditionally attributed to carboxylic groups. A significant decrease in the signal intensity in the aromatic region (160-110 ppm) was noticed in the soils of the converted sites, especially homestead.

3.2. Particulate Organic Carbon (POC)

Across all land use categories, POC concentration ranged between 3.9 and 1.6% (Table 2). Except for the soils of the cardamom plantation (S3) site, POC values followed the same trend as SOC. Irrespective of cropland nature, soils of the cardamom plantation (S3) site had the POC value 3.9%, which is about 56% higher than the value recorded for natural grassland soil (S1). Since POC has been shown to be the labile fraction of SOC [6], it can be expressed as a percentage of SOC (POC/SOC). POC constituted 67 to 97.5% of total SOC and tended to be greater at the cardamom plantation (S3) site.

Table 2 Changes in POC concentration (as % of POC/SOC ratio)

Site	% POC	% SOC	POC/SOC
S1	3.5	5.2	67
S2	3.25	4.6	71
S3	3.9	4	98
S4	2.9	3.9	74
S5	2.64	3.51	75
S6	2.13	2.99	71
S7	1.9	2.4	79
S8	1.67	1.9	88

3.3. Water Stable Aggregates (WSA)

Samples were tested for their resistance to destruction by wet sieving conditions. The samples were categorised as micro (0.1mm) and macro (2mm) aggregates. The percentage aggregate stability is represented as % WSA after sand correction and the results are given Table 3 as percentages.

The effect of land use on the extent of different sized WSA was more pronounced in WSA in the 0.1 mm and 2 mm category (Table 3). WSA of 2 mm (macro-aggregate category) were highest (24.7%) in the soils at the cardamom plantation (S3) site and lowest

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(1.5%) in the soil of the homestead (S8) site. By contrast, WSA in the 0.1 mm (micro-aggregate) category were recorded highest (28.9%) in the soil of the homestead (S8) site and lowest (4.5%) at the cardamom plantation (S3) site. It was quite noticeable that the homestead site (S8) had about 6 times more micro-aggregates (28.9%) than in the soils of cardamom plantation (S3) (4.2%) but 5 times higher than that of the native grassland (S1) site. The proportion of micro-aggregates in the converted sites was comparatively high.

Table 3 Water stable aggregate proportion (WSA%)

Site	Land use	WSA Micro (0.1 mm)	WSA Macro (2 mm)
S1	Grassland	5.4	17.1
S2	Acacia	6.1	16.9
S3	Cardamom	4.2	24.7
S4	Open scrub	10.0	12.5
S5	Pine	25.1	6.9
S6	Tea	26.1	3.3
S7	Rubber	28.4	2.7
S8	Homestead	28.9	1.5

Table 4 Changes in glomalin concentrations

Sites	Land use Category	Glomalin (mg/g)
S1	Grassland	17.3
S2	Acacia	15.2
S3	Cardamom	19.6
S4	Open scrub	10.2
S5	Pine	9.9
S6	Tea	7.6
S7	Rubber	3.6
S8	Homestead	2.1

3.4. Soil Protein Glomalin

Significant differences in glomalin concentrations (mg/g^{-1}) were detected across all sites (Table 4). The highest concentrations of glomalin were found in soils from the cardamom plantation site S3, (19.6 mg/g) followed by native grassland, S1 (17.3 mg/g), whereas the lowest value was detected in the intensively disturbed site of homestead soil, S8 (2.1 mg/g). Site S3 showed about nine-fold increase in the glomalin concentration compared to the homestead site S8. A gradual decrease in the concentration of glomalin was observed among the sites, which is inconsistent with the land disturbance intensity.

3.5. Potential Carbon Mineralization (PCM) and Subsequent Global Warming Potential (GWP)

The amount of carbon released from bulk soil samples during the incubation ranged from 0.54 to 2.9 mg kg$^{-1.}$ The PCM concentrations were significantly influenced by land use changes, where the maximum concentration was recorded at the homestead site (S8) and the minimum at the cardamom site (S3). Nearly a 10 fold increase in the amount of C released was noted at the S8 site when compared with S3. The ratio PCM/SOC represents the carbon turnover [10] and the value ranged from 0.14 to 1.6%. The C turn over value ranged in the order S3<S1<S2<S4<S5<S6<S7<S8. The lowest turn-over value was represented at the cardamom plantation (S3) followed by native grassland site S1.

Table 5 Concentration in C mineralisation and C turn-over in mg kg^{-1}

Sites	PCM	% SOC-C	Carbon turn over
S1	0.76	5.2	0.146154
S2	1.21	4.6	0.263043
S3	0.54	4	0.135
S4	1.76	3.9	0.451282
S5	1.98	3.51	0.564103
S6	2.22	2.99	0.742475
S7	2.48	2.4	1.033333
S8	2.9	1.9	1.526316

3.6. CO_2 Production Potential

As products of carbon mineralisation, considerable amounts of CO_2 were produced during incubation. However, total CO_2 production, varied over a much wider range from 540 µg g^{-1} soil under S3 to 2900 µgg^{-1} soil under S8 (Table 6).

3.7. Global Warming Potential (GWP)

The global warming potential of soils under various land uses was assessed by considering the amount of

CO_2 released during the incubation experiment. According to IPCC, 1 mmol-CO_2 is assumed to be 1 for a 20- year period. GWP was calculated as described by Cai [11]. The calculated GWP of various land uses ranged in a decreasing order as: S8>S7>S6>S5>S4> S2>S1>S3, respectively (Table 6). A fivefold (nearly 81%) increase in the warming potential has been found for homestead soil (S8) compared to that of the cardamom site (S3). When compared to native grassland (S1), S8 showed a two fold increase in GWP. All the converted sites showed increased GWP.

Table 6 Carbon mineralisation and global warming potential

Samples	C Min. ($\mu g\ g^{-1}$ soil)	GWP
S1	760	17.3
S2	1210	27.5
S3	540	12.3
S4	1760	40
S5	1980	45
S6	2220	50.5
S7	2480	56.4
S8	2900	65.9

4. DISCUSSION

4.1. Soil Organic Carbon Stock

A sharp decline was observed in the SOC concentration as the category status shifted from natural to converted sites. Numerous investigations have shown that organic carbon stocks in soils are determined by the land use [12]. Natural grassland locked in a significant amount of SOC (196.8 t/ha). The presence of extensive root biomass of grass communities may be one of the reasons for high SOC content [13] since roots are considered to be a more stable form of carbon supply to the soil than litter [14]. Root material has a longer residence time in soil. It is chemically more recalcitrant, physico-chemically protected and gradually transformed to soil organic carbon [15].

Apart from native grass species, especially *Cymbopogon citrates and Axonopus compressus,* the presence of various plant-grass functional groups of *Lantana camera, Osbeckia aspera* increased the species richness and this might have accelerated the build-up of new carbon pools. Recent experimental evidence demonstrates that the type and diversity of plant species in grasslands plays an important role for carbon transfer into the soil and is able to modify carbon storage under a given land use scheme [12,16]. As higher plant biodiversity leads to larger plant biomass [17-19] and therefore a larger biomass input into the soil, it is generally assumed that differences in input amounts (not quality of the input material) are responsible for the observed variation in carbon storage in soils [20,21].

The chemical stabilization of organic carbon in the soil matrix of grassland also may contribute to high SOC content. In both these sites human interference and other disturbance factors were minimal and hence the SOC pool is found to be in an aggrading situation. Conversely, the SOC pool has been found to decline in the converted grassland sites (S2 to S8) as in plantations of acacia, cardamom, pine, tea, and rubber apart from homestead and open scrub. Soil organic matter losses due to conversion of native grasslands to cultivation are both extensive and well documented [22-24]. During conversion, activities like landscaping and ground clearance might have exposed the soil surface and breaking of aggregates thereby increasing the magnitude of erosion and subsequent loss of SOC. Thus, human-controlled factors during grassland conversion might have led to the depletion of soil carbon stocks [25,26].

Our results agree with those of Islam and Weil [27], who reported that the SOC in the soils of cultivated land was lower than those of native grassland. According to Jimenez et al. [28], understory vegetation may contribute to SOC increases but understory vegetation was completely absent at the pine and tea plantations, which may be the reason for the low SOC in these sites. In fact, levels of understory vegetation were significantly higher at the cardamom plantation site (S3).

In the cardamom plantation region (S3), a conservative type of management activities was recorded even though the SOC content showed a decline when compared to natural grassland. It may be noted that the cardamom plantation site promoted a healthy soil management practice with no-till, no fertiliser approach with bare minimum human interference. The site also allows the growth and flourishing of natural grassland vegetation along with the cardamom plants.

As a result of anthropogenic activities like ground clearance, a characteristic decline in vegetation was observed at the homestead site (S8) that results in less accumulation of litter and thus low input of organic carbon in soils. In addition to this, erosional activity was significant at this site and might have caused the displacement of SOC. Scrutiny of land disturbance intensity and soil carbon data suggested that if a given land use change is responsible for soil carbon losses, then the reverse change could potentially increase soil carbon stocks. But it is important to recognise that it can take decades if not centuries to recover to the original level of soil carbon stocks after disturbance due to land use change [3].

The effect of land use change on SOC quality was clearly shown by the NMR spectra. The spectrum of grassland SOC shows the presence and dominance of recalcitrant aromatic C groups clearly centred at 110-105 ppm (generally identified with a wide variety of aromatic structures, such as the C1 quaternary carbon of guaiacyl and syringyl lignin units, and the C6 of guaiacyl). By contrast, the soils of the homestead site are dominated by aliphatic compounds (carboxyl groups). Less intense signals in the aromatic C regions noted at the homestead site show the low availability of aromatic C structures in the soil, which might have been removed by intensive soil disturbances. The results suggest the accumulation and preservation of recalcitrant C materials, especially aromatic in nature [29] under native grassland conditions, will be removed by land use changes.

4.2. Particulate Organic Carbon

Significantly different levels of POC were found amongst the soils of different land use and management practices. The higher magnitude of POC and its contribution to SOC (i.e., POC/SOC) at the cardamom plantation site (S3) suggests that soils under this land accumulated an active C pool as reported by Saha et al. [30]. This difference may be attributed to the conservative agriculture practices at the S3 site. Studies by Chan [31] showed that POC concentration tends to be greater under more conservative management practices, which support, our findings. However, a decreasing trend in POC was observed in other converted grassland sites and the trend was in accordance with the findings of the same researcher [31].

As observed by Bongiovanni and Lobartini [32], the cultivated and disturbed soils appear to have harmfully affected the POC content. Intensive land-based activities including tillage, land clearance and tampering observed in all the sites except S1 and S3 might have led to the destruction of macro-aggregates which may result in the exposure of the inner core of POC, facilitating rapid decomposition by microorganism of this important organic carbon reserve in the soil [33,34].

Being more labile, POC is a more sensitive indicator of change than SOC due to land use and management and the low POC levels in the disturbed sites of the study area illustrate this fact. It has been shown that C presented in particulate organic matter (POM) can accumulate rapidly under land management systems that minimize soil disturbance and is an early indicator of changes in C dynamics and total soil C under different land uses and management systems [6]. Furthermore, being a fraction of SOC, POC variations under different land use practices can yield important information about the mechanisms of C sequestration [35].

4.3. Aggregate Stability

Land use exerts a significant effect on aggregate size distribution. The higher proportion of macro-aggregates in soils of grassland and cardamom plantation indicated minimal land disturbance whereas disturbed sites like pine, tea and rubber plantations showed a high proportion of micro-aggregates. This may be due to the disturbance-induced increase in macro-aggregate turnover as reported by Debasish [36]. Significantly higher macro-aggregate proportions in the cardamom soils may be due to conservative agriculture practices that include no-till activities. Vagamon being a tourist spot, the pedestrian movement was recorded high in the pine plantation and hence the chance of soil disturbance might be a possible reason for high micro-aggregates. In tea and rubber plantations, high micro-aggregate proportions may be due to tillage activities [37]. In addition, the use of agro fertilizers in these soils tends to reduce the soil faunal activity, adversely affecting soil aggregation [38]. In the homestead soil, land disturbance was recorded maximum and this may be the reason for increased macro-aggregate turnover. Apart from this, the erosional activity in the site is a natural stress factor contributing towards aggregate breakdown.

4.4. Glomalin

Variations of soil glomalin in different land use categories are explained by the extent of land disturbance [39,40]. Concentrations of glomalin in soils from various sites portrayed the intensity of land disturbance. The high glomalin concentration in native grassland soils (S1) represents its undisturbed condition, whereas the maximum glomalin value under cardamom plantation demonstrates the role and importance of conservative agricultural practices. Disturbance can reduce glomalin accumulation and hence the stability and degree of soil aggregation [39] as observed in S8 and other disturbed sites. It can be concluded that the land disturbances might have caused loss of soil organic

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matter leading to low soil biological activity (especially mychorrhizal fungal activity) and hence the glomalin production.

4.5. Potential Carbon Mineralisation, CO_2 production and the Global Warming Potential

Potential carbon mineralisation (PCM), a biologically active fraction of SOC [41,42], was in accordance with the textural and disturbance pattern of the soil. Greater PCM rates in S8 might be attributed to the human induced disturbances facilitating more C mineralisation whereas the highest C turnover value represented at this site shows its source capacity. This observation indicates the vulnerability of the S8 site as a potential C source due to disturbance. As a general trend, the PCM values declined with decease land disturbance intensity as observed in the native grassland and cardamom plantation and the least C turnover values represent the greater C sink capacity of these soils. CO_2 production and global warming potential of various soils followed the same trend of PCM values and this explains the role and capacity of grassland soils to store and release carbon.

4.6. Relation between SOC, POC, PCM, WSA and Glomalin

Our study showed that changes in the soil carbon storage in different sites were in accordance with the land disturbance intensity which is reflected in the proportion of aggregates, POC, PCM and glomalin (Figure 3). The presence of SOC positively influences POC (r = 0.89), macroaggregates (r = 0.81) and glomalin concentration (r = 0.89) whereas it is negatively correlated with C mineralisation (r = -0.89) and microaggregates (r = -0.88). When POC is correlated with other parameters, positive correlation was seen in case of macroaggregates (r = 0.98) and glomalin (r = 0.99). Conversely, POC is negatively correlated to microaggregates (r = -0.94) and C min (r = -0.98). The above parameters like SOC, POC, macroaggregates and glomalin can be considered as soil carbon storage biomarkers. However the results show that the carbon source capacity i.e., C mineralisation (PCM) values bear negative correlation with SOC and POC, macroaggregates (r = -0.96) and glomalin (r = -0.99) whereas a positive correlation can be seen in case of microaggregates (r = 0.93). Apart from the positive correlation of glomalin with SOC and POC, it is positively influenced by macroaggregates (r = 0.95) and shows negative correlation with microaggregates (r = -0.91) other than PCM.

Soil organic carbon (SOC) content in soil was found to be one of the main factors controlling the aggregate stability of soils [43,44], through binding the primary particles with the help of organic binding agents including particulate organic matter consisting of roots and fungal hyphae [45] and fungal exudates such as polysaccharides and glomalin [46,47]. These organic compounds may impart some degree of water repellency, thereby improving soil stability [48,49]. According to Van Veen and Kuikman, [50], aggregation should limit access to SOC and hence lower C mineralisation. Macroaggregates physically protect the SOC from C mineralization and thus help in soil carbon storage or sequestration [51]. Six et al. [52] underscored the importance of soil aggregation and more specifically the interactions of SOC and aggregate dynamics in controlling SOC sequestration in soils.

Compared to SOC, POC had a more positive effect on aggregate stability as aggregate formation was directly related to root-residue decomposition and POC dynamics under no-tillage practices and in undisturbed soils [53]: POC is a labile intermediate in the soil organic matter continuum from fresh organic materials to humified SOC. Disturbance-induced turnover of macroaggregates causes exposure of the inner core of POC, facilitating rapid decomposition by microorganisms of this important organic carbon reserve in soil [33,34]. Interestingly, POC concentration shows a lower association with C mineralisation and microaggregation than SOC. Considering the above findings; POC is more sensitive to changes in management than total SOC [54,55].

Glomalin appears to be highly correlated with aggregate stability [47] and with carbon sequestration in the soil by helping to physically protect organic matter within aggregates [56]. Glomalin is positively correlated with percent water-stable soil aggregates in both agricultural and native soils [9,39,56]. Glomalin may accumulate iron over time in soil, and this characteristic could account for the resistance to decomposition and formation of stable complexes within soil aggregates. Complexes formed by Fe and Al-hydroxides protect organic matter from decomposition in stable soil aggregates [45,57].

The increased levels of SOC and POC under grassland occur not only due to continuous addition of C from above- and belowground residues over several years [58-60], but also to their slower rates of mineralization because of decreased soil disturbance [6,33,44,61].

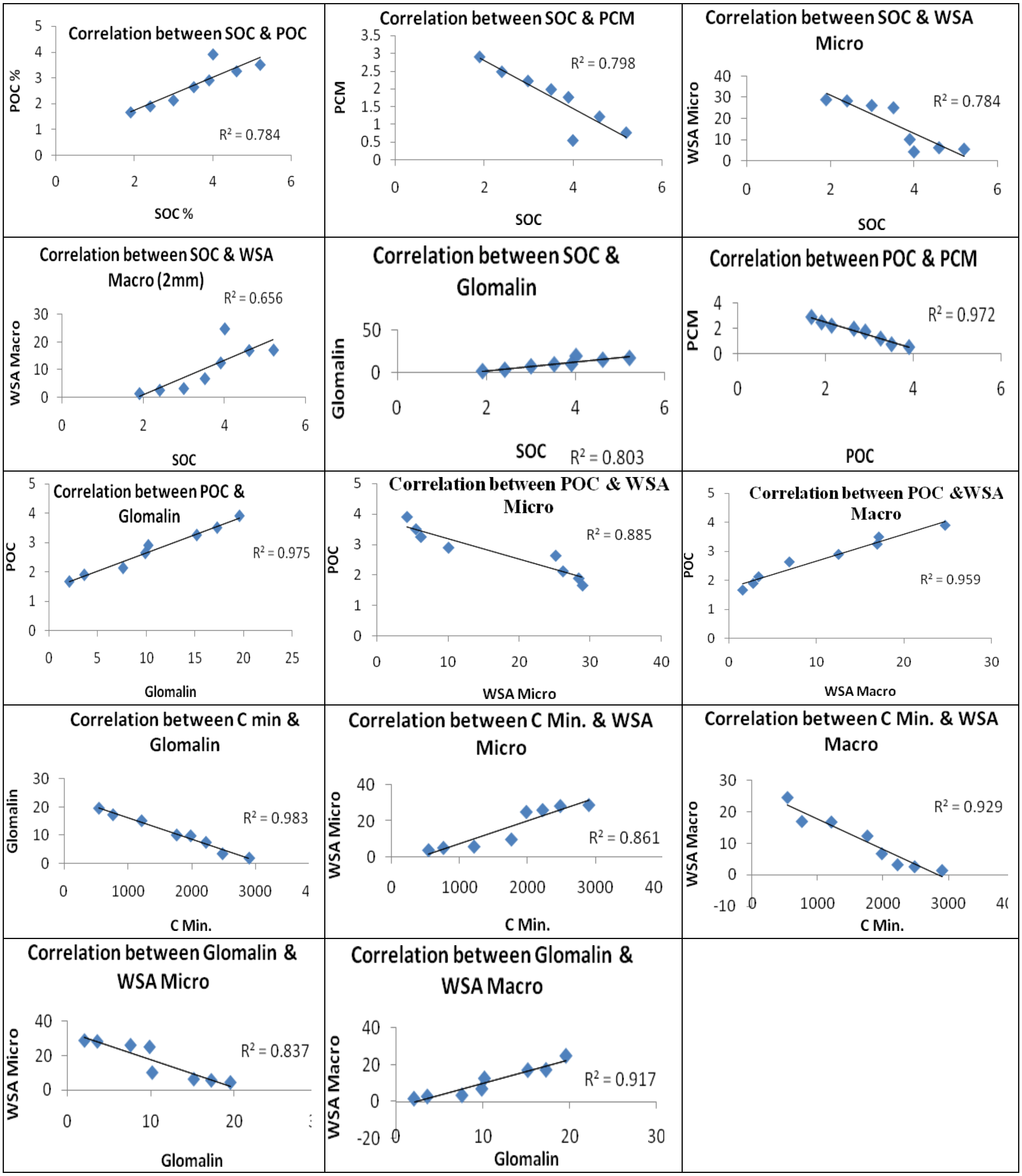

Figure 3 Correlation graph of SOC, POC, WSA and glomalin with land disturbance intensity

Therefore, grassland soil has been identified as one of the potential sites to sequester atmospheric CO_2 in the terrestrial ecosystem by helping to reduce some of the deleterious effects of greenhouse gases [62].

5. CONCLUSIONS

Soils play an essential role in carbon cycling and land use is a major determinant factor that affects soil carbon storage. This study acknowledges the role of SOC, POC, PCM, glomalin and WSA in addressing the carbon storage capacity of grassland that is under the influence of various land use patterns and changes. Our results illustrated that land use categories with respect to changes and intensity of activities have had negative influence on the carbon pool (both the organic and particulate). A significant relationship between these carbon stocks with the soil protein glomalin and aggregate stability has been noted. The significant negative correlation of SOC, POC, glomalin, and WSA (macro) with various land uses indicates the impact of land conversion on the soil carbon of grassland. However, activities in tune with natural grassland systems supporting conventional agricultural practices, as observed in cardamom plantation favour high POC stock, aggregation and glomalin concentration and this advocates the importance of conservative practices towards soil carbon storage from a sustainability perspective. It can be seen that POC is more sensitive and an earlier indicator than SOC of land disturbances and soil carbon changes for short-term studies in grassland ecosystems.

The study region Vagamon is vulnerable to degradation due to exacerbated intensive soil use and land disturbance as a result of human interference affecting its natural equilibrium. Apart from native grassland sites, the conventional cropping site of cardamom is also found to offer innate capacity to store soil carbon at a considerable rate. An understanding of the effect of land use conversion and disturbance intensity in soil carbon storage is therefore needed in the sustainable management of grasslands.

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