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Impact of Diverse Agricultural Land Uses on Soil Organic Matter Fractions: A Comprehensive Evaluation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Organic matter is a crucial component of soil that influences various soil properties and functions, including nutrient cycling, soil structure, water holding capacity and microbial activity. Different agricultural land uses significantly influence the quantity and quality of soil organic matter (SOM)

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fractions. The primary constituent of SOM is humic substances, also known as humus. These are stable compounds originating from the decomposition of organic matter derived from plants, animals, and microorganisms. The soil humic fraction is categorized into humic acid (HA), fulvic acid (FA) and humin (HN) based on the solubility in acid and alkaline medium. The structural arrangement, chemical constitution and stability of the humic substances in soil are affected by various factors, including climate, parent material, altitude, vegetation and the management practices employed in the area. In this context the present study was proposed to assess the impact of various agricultural land use systems on humic acid, fulvic acid and humin fraction in soils of different agro-ecological units (AEUs) of southern Kerala. The study focused on specific AEUs in southern Kerala, including the 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). Within each AEU, various agricultural land use categories such as, coconut, rice, rubber and uncultivated land were selected as specific focal points for this investigation. The HA, FA and HN content in soil exhibited varying ranges across different AEUs, ranging from 0.57 to 2.06, 0.73 to 2.33, and 0.62 to 1.59 per cent respectively. Among the various land uses, rubber exhibited significantly higher levels of HA (1.72%), FA (2.01%) and HN (1.44%) compared to coconut, rice and uncultivated land. Among the different organic matter fractions, FA (32.30-36.18 %) contributed more towards SOM than HA (29.40-32.51 %) and HN (26.43-29.25 %).

Keywords: Soil organic matter; humic acid; fulvic acid; humin; land uses; agro-ecological units.

1. INTRODUCTION

Soil organic matter (SOM) encompasses a wide array of organic compounds with diverse chemical structures, and these proportions tend to change over time. It serves as a critical component within soil, exerting influence on numerous soil properties and functions such as nutrient cycling, soil structure, water retention and the activity of soil microorganisms [1]. The major component of SOM is humic substances or humus, which comprises stable compounds derived from the decayed organic matter of plant, animal and microbial origins. Humic substances represent the most extensively decomposed and stable organic compounds, accounting for 40–60 percent of SOM [2]. These substances possess slow turnover rates and extended residence time within soils, primarily because they aren't an efficient energy source for microbial population and exhibit resistance to degradation due to their complex molecular structures [3]. Humic substances play vital role in promoting soil aggregation thereby stabilizing the soil structure, improving cation exchange capacity, buffering capacity and water retention of soil. Additionally, they have the capability to form complexes with heavy metals, thereby mitigating soil toxicity. The humic substances, characterized by complex structures with varying molecular orientations, are operationally classified based on their solubility in acidic and alkaline aqueous media. Humic acids dissolve in alkali solutions, while fulvic acids are soluble in both acidic and alkaline conditions and humin remains insoluble [4].

The humic substances present in any soil system is influenced by a multitude of factors, including its input from various sources and the subsequent loss due to decomposition. Despite their inherent resistance to biological degradation, changes in land use types and management practices have the potential to alter the chemical composition of humic substances [5]. The structural formation, chemical composition and stability of these humic substances are influenced by numerous variables such as climate, parent material, altitude, vegetation type and soil management practices [6]. Changes in agricultural management practices have the potential to modify the chemical properties of soil humic substances [7]. Studies have shown a gradual decline in concentrations of humic substances within soils that underwent conversion from forested areas to arable land for farming purposes. The observed decrease is often linked to the microbial oxidation of organic materials, previously safeguarded within soil aggregates, which are subsequently disrupted due to cultivation. Alterations in the C:N ratio following land use changes signify fluctuations in the extent of SOM decomposition [8]. In this context the present study was designed to assess the impact of various agricultural land uses including coconut, rice, rubber and uncultivated land on HA, FA and HN constituent of SOM across selected agro-ecological units of southern Kerala.

2. METHODOLOGY

Agro-ecological units (AEUs) serve as broad spatial divisions that take into account variations in climate, landforms, and soils. These delineations, introduced by the FAO, highlight similar agro-climatic conditions to pinpoint the regions that are agriculturally favourable, indicating their suitability for specific crops or combinations of crops. This helps in identifying and optimizing areas with the potential for particular agricultural activities. The study focused on selected AEUs in south Kerala, including the 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). Within each AEU, various agricultural land use categories such as coconut, rice, rubber and uncultivated land were also selected for the investigation.

A survey was conducted within these selected AEUs and land uses for identifying specific sites for soil sampling. Three sites were selected randomly from each land use representing each AEU and were considered as replications for the study. Surface soil samples (0-25 cm depth) were collected from the identified locations across the selected AEUs. 60 soil samples were collected in total, with 12 of them gathered from a single AEU. The soil samples were shade dried, powdered, sieved through a 2 mm sieve and stored in a moisture free environment for further analysis. The soil samples after processing were analyzed for electro-chemical properties such as soil pH, electrical conductivity (EC), and cation exchange capacity (CEC) following the methodology described by Jakson[9]. Fulvic acid and humic acids were isolated by sequential extraction in alkaline and acidic solutions while humin was determined in the soil residue (after fulvic acid and humic acid extraction) by mineral fraction digestion using a 0.1M HCl/0.3M HF mixture [10]. The generated data underwent statistical analysis utilizing the GRAPES software [11]. The statistical methodology employed was factorial one way ANOVA.

3. RESULTS AND DISCUSSION

3.1 Electro-chemical Properties of Soil

The results of the study showed that the soil pH within all AEUs ranged between 4.77 and 5.73, indicating an acidic nature (Table 1). The soil type of AEU 8, 9 and 12 are laterite and AEU 1 and 3 are sandy, which are acidic in reaction [12]. This may be attributed to the impact of parent material, topographic position, leaching of basic cations due heavy rainfall, high organic matter content and management practices carried out in the locality [13]. The land use systems showed a significant impact on soil pH with the highest mean value of 5.63 recorded in uncultivated land and significantly lowest pH of 4.91 observed in rice which was on par with rubber (4.94). In all the AEUs, the highest pH was observed in uncultivated land and the lowest pH was observed in rubber (AEU 1 and 3) and rice (AEUs 8, 9 and 12) land uses. This might be due to the variation in rhizosphere activity and accumulation of organic matter under different land use systems which release organic acids and there by reduces soil pH as reported by Sihi et al. [14]. This is confirmed from the negative correlation (r= -0.0.56) obtained between pH and SOM as shown in Fig. 6.

The electrical conductivity (EC) of soil ranged between 0.06 to 0.44 dS m^{-1} in different AEUs under various land use systems (Fig. 1). The EC was found to be less than 1 dS m^{-1} in all the AEUs. It is considered as normal range with no salinity hazards. This can be attributed to the leaching of soluble salts from soil due to high rainfall [15].

Cation exchange capacity (CEC) of soils of different AEUs under various agricultural land use systems is shown in Fig. 2. The CEC of soil varied between 2.60 to 6.69 c mol(+) kg^{-1}. Among the different AEUs, the highest CEC of 4.68 c mol(+) kg^{-1} was recorded in AEU 12 which was found to be significantly different from other AEUs and the lowest was observed in AEU 1 (3.79 c mol(+) kg^{-1}). Land uses also exerts significant impact on CEC of soil. Among the land uses rubber registered greater CEC of 6.09 c mol(+)kg^{-1} and uncultivated land showed lower CEC (2.89 c mol(+)kg^{-1}). This might be attributed to the difference in organic matter addition to the soil from different land uses [16]. This evident from the positive correlation of CEC (r=0.92*) with SOM (Fig. 6). This suggests that CEC of soil is predominantly associated with SOM with only minor contribution from clay minerals as stated by Gruba et al. [17].

3.2 Soil Organic Matter Fractions

The results shown in Fig. 5 revealed that the organic matter in soil varied between 2.67 and

5.47 per cent in different AEUs under various agricultural land use systems (Fig. 5). The highest value was obtained for rubber land use (5.47 %) and lowest for uncultivated land (2.60 %). Among the AEUs the highest value was recorded for AEU 12 (4.35 %) followed by AEU 9 (4.23 %), AEU 8 (4.22 %), AEU 3 (3.85 %) and AEU 1 (3.60 %). The differences observed in land uses and AEUs can be attributed to the difference in microclimate, vegetation canopy and litter input [2].

Humic acid content varied from 0.57 to 2.06 per cent (Table 2), fulvic acid ranged between 0.73 and 2.33 per cent (Fig. 3) and humin ranged from 0.62 to 1.59 per cent (Table 3) across different AEUs under various land uses. Among the different AEUs higher concentration of fulvic acid and humin was were observed in AEU 12 whereas humic acid in AEU 9. The higher concentration of fulvic acid compared to humic acid in all AEUs, regardless of land use, can be attributed to the regular incorporation of fresh organic residues. The higher concentration of humic acid obtained from AEU 9 might be due to the climate and moisture content prevailing in the area which have resulted in more favourable condition for humic acid formation. In all the AEUs, a higher concentration of organic matter fractions, including fulvic acid, humic acid, and humin, was observed in soils from rubber plantations that received larger quantities of fresh biomass. This is primarily attributed to the high plant density and dense vegetation canopy in rubber plantations, contributing to the elevated levels of these organic matter fractions. The SOM content tends to be higher in tree-based land use systems which in turn contributes to the increased concentration of SOM fractions [5]. This is confirmed from the positive correlation obtained between SOM and its fractions such as humic acid (r= 0.97***), fulvic acid (r = 0.97***) and humin (0.96***) as shown in Fig. 6.

Table 1. Effect of agricultural land uses on pH of soil

AEUs(A)	LAND USE (L)				Mean
	Coconut	Rice	Rubber	Uncultivated land	
AEU 1	5.30	4.96	4.95	5.47	5.17^{AB}
AEU 3	5.44	5.01	4.90	5.60	5.24^{A}
AEU 8	5.36	4.87	5.06	5.73	5.26^{A}
AEU 9	5.25	4.77	4.83	5.59	5.11^{B}
AEU 12	5.47	4.93	4.96	5.73	5.27^{A}
Mean	5.37^{B}	4.91^{C}	4.94^{C}	5.63^{A}	
	A	L	A x L		
S.E(m)	0.041	0.037	0.082		
CD (0.05)	0.117	0.105	NS		

** Mean values represented by same upper case superscript letters are not significantly different*
**NS- Non significant*

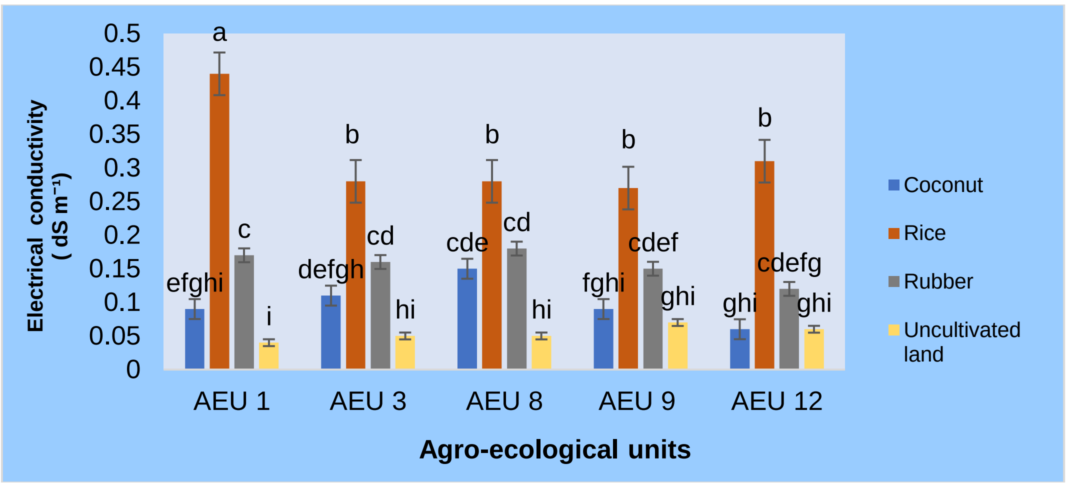

Fig. 1. Effect of agricultural land uses on electrical conductivity of soil
**Interaction values represented by same lower case superscript letters are not significantly different*

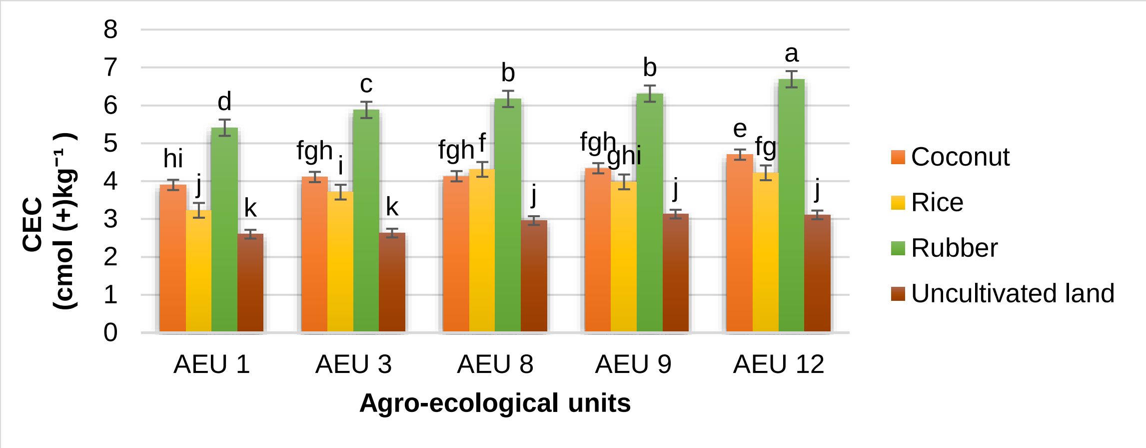

Fig. 2. Effect of agricultural land uses on cation exchange capacity of soil

**Interaction values represented by same lower case superscript letters are not significantly different*

Table 2. Effect of agricultural land uses on humic acid (%) in soil

AEUs (A)	LAND USE (L)				Mean
	Coconut	Rice	Rubber	Uncultivated land	
AEU 1	1.30^{g}	1.02^{i}	1.39^{ef}	0.57^{k}	1.07^{D}
AEU 3	1.40^{ef}	1.03^{i}	1.47^{de}	0.87^{j}	1.19^{C}
AEU 8	1.49^{d}	1.20^{h}	1.87^{b}	0.83^{j}	1.34^{B}
AEU 9	1.67^{c}	1.16^{h}	1.81^{b}	0.90^{j}	1.38^{A}
AEU 12	1.32^{fg}	1.15^{h}	2.06^{a}	0.83^{j}	1.34^{B}
Mean	1.44^{B}	1.11^{C}	1.72^{A}	0.80^{D}	
	A	L	A x L		
S.E(m)	0.014	0.013	0.029		
CD (0.05)	0.041	0.037	0.083		

**Interaction values represented by same lower case superscript letters are not significantly different*

** Mean values represented by same upper case superscript letters are not significantly different*

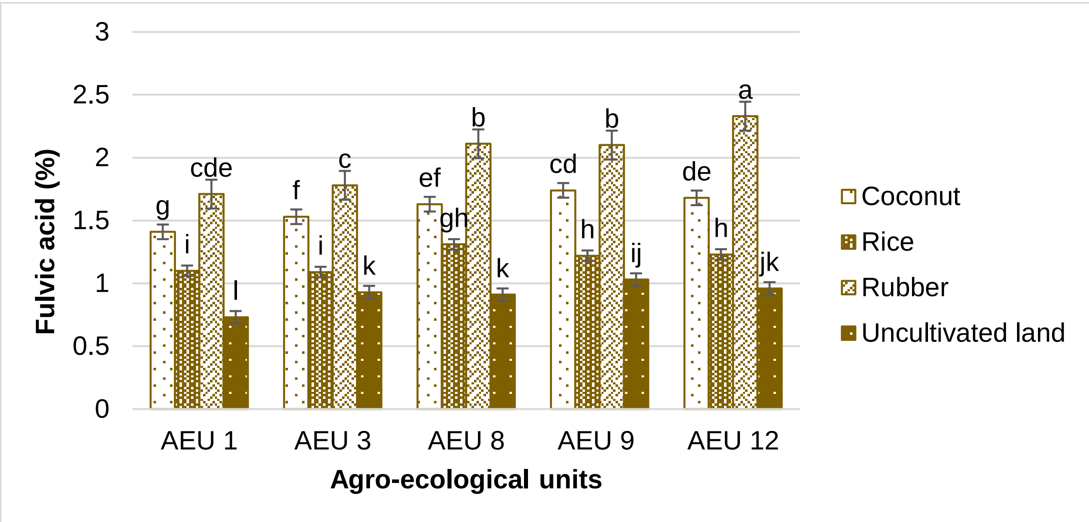

Fig. 3. Effect of agricultural land uses on fulvic acid in soil

**Interaction values represented by same lower case superscript letters are not significantly different*

Table 3. Effect of agricultural land uses on humin (%) in soil

AEUs (A)	LAND USE (L)				Mean
	Coconut	Rice	Rubber	Uncultivated land	
AEU 1	1.17cde	1.01fg	1.43b	0.62j	1.06bc
AEU 3	1.21cd	0.99g	1.25c	0.70hij	1.04c
AEU 8	1.20cd	1.10ef	1.44b	0.68ij	1.11ab
AEU 9	1.15de	1.09efg	1.48b	0.78h	1.12a
AEU 12	1.15de	1.07efg	1.59a	0.75hi	1.14a
Mean	1.18b	1.06c	1.44a	0.71d	
	A	L	A x L		
S.E(m)	0.017	0.016	0.035		
CD (0.05)	0.050	0.044	0.099		

**Interaction values represented by same lower case superscript letters are not significantly different*
** Mean values represented by same upper case superscript letters are not significantly different*

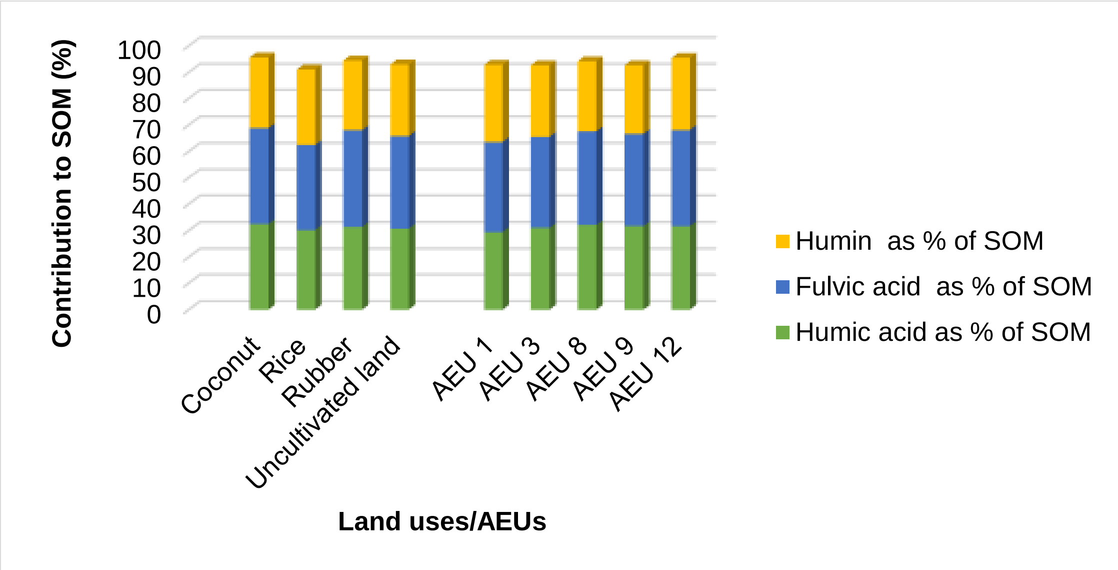

Fig. 4. Contribution of humic acid, fulvic acid and humin to SOM

Percentage contribution of humic acid, fulvic acid and humin to total SOM ranged from 29.40 to 32.51, 32.30 to 36.42 and 26 to 29.25 per cent respectively (Fig. 4). Among the OM fractions fulvic acid contributed more towards SOM content than humic acid and humin irrespective of AEUs and land uses. Fulvic acids are typically more soluble and have a lower molecular weight compared to humic acid and humin, making them more mobile and, as a result, making them more prevalent in soil solutions. In terms of proportion of different OM fractions to SOM in different land uses, higher proportion of humic acid to SOM was higher in coconut land use while fulvic acid to SOM was higher in rubber land use and humin to SOM was higher in rice land use. Higher proportion of fulvic acid to SOM in rubber land use might be attributed to the fresh biomass addition compared to other land uses. The higher percent contribution of humic acid to SOM in coconut land use could be due to the relatively slower decomposition compared to rice land use. The humin proportion in rice land use is higher than other land use indicating the occurrence of more decomposition process in rice soils. The vigorous ploughing and intercultural operations carried out in rice land use hastence the decomposition of organic matter in soil. The results are in conformity with the findings of Seddaiu et al. [18].

The ratio of humic acid to fulvic acid reflects the mobility of organic carbon in soil (Fig. 5). The humic acid to fulvic acid ratio (HA/FA) ranged between 0.85 to 0.93 across various AEUs under different land uses which indicates the presence of higher fulvic content compared to humic acid and it also indicates a lower decomposition rate of organic matter or frequent addition of organic manure to the soil [19]. Humic acid to fulvic acid ratio less than 1 indicate the good quality of SOM and greater than 1 indicate the loss of labile C fractions of SOM. The higher HA/FA recorded in rice cultivation areas suggests an increased level of humification, likely attributable to the intensive ploughing and tillage practices conducted during cultivation. The variation in the ratio of humic acid to fulvic acid in various soils serve as indicators of varying levels of humification influenced by vegetation and agro-ecology as reported by Dutta et al. [20].

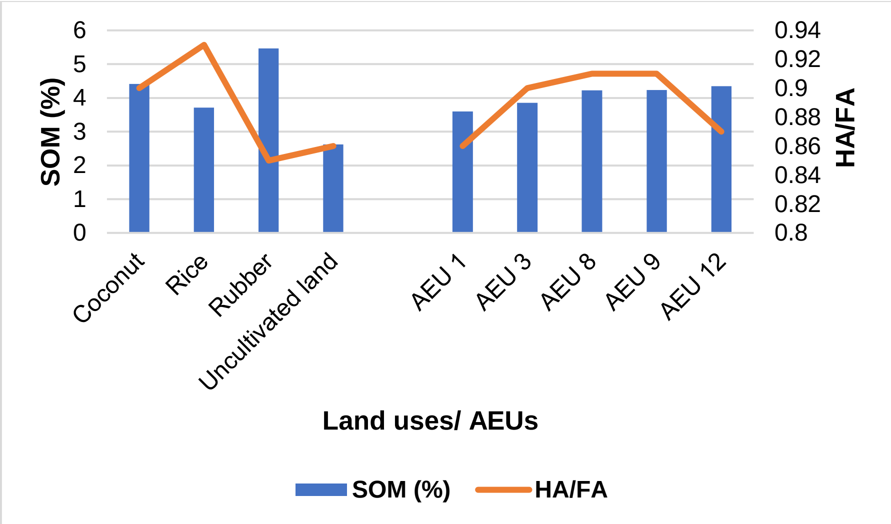

Fig. 5. SOM and HA/FA ratio as influenced by various agricultural land uses in different AEUs

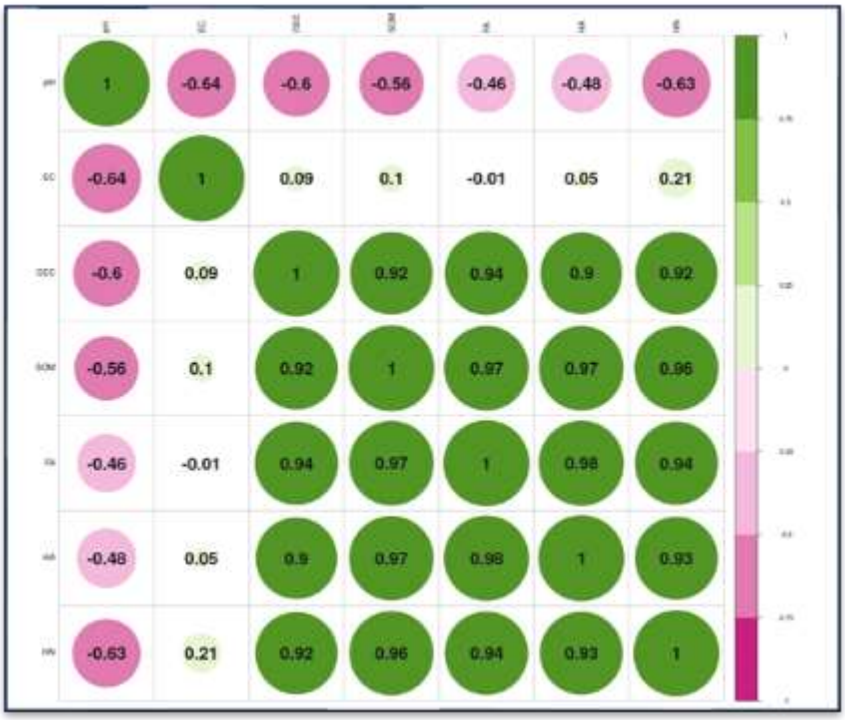

Fig. 6. Correlogram showing Pearson's correlation between various soil properties and SOM fractions

**Green and pink represent positive and negative correlations respectively. The size of the circle indicate the strength of correlation (r), (p=0.05)*

4. CONCLUSION

Different land uses significantly influenced both the quantity and quality of SOM. Among the land uses, rubber exhibited the highest accumulation of organic matter followed by coconut and rice , while the lowest was recorded in uncultivated land. Intensive cultivation practices found to have negative impact on organic matter accumulation in soil. Excess tillage disrupts soil aggregation and augments the rate of organic matter decomposition in soil. Among the land uses higher concentration of HA, FA and HN were observed in rubber than others which is attributed to the higher litter addition to the soil throughout the year due to the high plant density and dense vegetation canopy contributing to the elevated levels organic matter fractions in soil. Across all observed land use systems, the fulvic acid fraction showed greater prominence compared to both the humic acid and humin fractions in SOM composition. This led to an HA/FA ratio below 1 across most land uses. The prevalence of a higher proportion of fulvic acids in comparison to humic acids suggested either a slow decomposition rate of SOM or frequent influxes of fresh organic residues to the soil. With respect to different AEUs, AEU 12 exhibited a favourable condition for accumulation of organic matter in soil. The AEU 12 is demarcated to represent undulating terrains characterized by low hills situated between midland laterites and the high hills of the Western Ghats. The soils in this area are notably strongly acidic, gravelly, lateritic, and contain high levels of organic matter. The vegetation and agro-ecology also contribute to the organic matter build up in soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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