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Chethankumar P
PG Scholar, Kerala Agricultural University, Kerala, India

Meera AV
Integrated Farming System Research Station, Kerala Agricultural University, Kerala, India

John J
Integrated Farming System Research Station, Kerala Agricultural University, Kerala, India

Leno N
College of Agriculture, Vellayani, Kerala Agricultural University, Kerala, India

Corresponding Author:
Chethankumar P
PG Scholar, Kerala Agricultural University, Kerala, India

Influence of diverse cropping systems on soil health and carbon pool at varied depths in a wetland riverine alluvial soil

Chethankumar P, Meera AV, John J and Leno N

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Abstract
The drastic increase in atmospheric CO_2concentration since industrial revolution has resulted in global warming and resultant change in climate. By enhancing the soil carbon sequestration potential, it is possible to reduce the deleterious effects. Soil is the major sink of carbon, especially in the greater depths where carbon stocks are comparatively less. In this experiment, carbon pools and major soil properties were analysed at varied depths upto 105cm in a wetland soil where, rice- rice- green manure cropping system was being practised for the last seven years. The changes in soil properties obtained were compared with that of an adjacent field maintained with the traditional cropping system of rice- rice-fallow sequence. Much variation was noticed in the soil bulk density and major nutrients with depth and also with cropping systems. In general, the different soil carbon pools like particulate organic carbon, microbial biomass carbon, labile carbon and total organic carbon were found to be higher in rice- rice-daincha system due to the incorporation of more easily decomposable biomass compared to that of the fallow system. A similar trend was noticed in enzyme activities, indicating the development of conditions favouring the build-up of soil microflora with the inclusion of a green manure crop in the field other than keeping it fallow. This soil carbon enrichment would further play a vital role in improving soil health and climate change mitigation adaption measures.

Keywords: Cropping systems, soil carbon fractions, enzyme activities, soil health

Introduction

Increase in temperature due to drastic increase in atmospheric concentration of carbon dioxide has triggered multiple negative effects on ourplanet (Lal, 2004; Young, 2003) [22, 53] and ultimately resulted in climate change. The global surface temperature had increased by 0.88^{0} C since the late nineteenth century, and 11 out of the 12 warmest years have occurred after 1995 (IPCC, 2007) [14]. Climatic factors like precipitation and temperature decide the soil organic carbon (SOC) pool (Lal, 2002) [21]. Further, the quantity and quality of SOC pools are strong determinants of soil quality (Lal, 2003; Paul, 1984) [49]. Soil can act as a major sink of atmosphericCO_2 and hence its judicious management has significant potential incarbon sequestration and mitigation of greenhouse gas (GHG) emissions (Lal, 2007) [23]. Soil organic matter is the prime factor that determines the nutrient availability to plants. The extent of mineralisation of nutrients in soil and the ease with which plants can take up these nutrients, all are dependent on soil organic fractions. The role of cropping systems in increasing carbon sink capacity of soils and stabilizing CO_2 levels has become attention of scientific research. As the allocation of vegetation above and below ground and its decomposition determine the relative distribution of C input to the soil with depth (Jackson *et al*., 1996; Alemayehu *et al.*, 2010) [16, 1], the nature of crops included in the sequence *i.e.*, inclusion of crops with more biomass productionis an important controlling factor in deciding soil organic matter (SOM) addition (Post *et al*., 1982) [32].

Total SOC is composed of labile and recalcitrant pools (Tirol-Padre and Ladha, 2004) [46]. Labile organic carbon (LOC) fraction comprises of the physical fraction (particulate organic matter), chemical fraction ($KMnO_4$ C) and biological fraction (microbial biomass carbon) while recalcitrant pool (humus) is resistant to decomposition (Chan *et al*., 2001; Mandal *et al*., 2013) [5, 27].

The relative proportion of carbon fractions determines soil quality and is, therefore, a crucial factor in soil C dynamics. Non labile soil carbon fractions, having longer turnover times, havethe potential for long-term sequestration of SOC (Paul *et al.,* 2001) [31]. Information on vertical distribution of soil organic carbon (SOC) within a soil profile, is too scanty. The subsoil has the capacity for long-term storage of SOC, as the time for decomposition of organic matter (OM) increases with soil depth (Lorenz and Lal,2016) [25].
The cropping systems that could provide more C input than the critical level are likely to sustain the SOC level and maintain good soil health (Mandal *et al*., 2007) [26]. Analysis of long-term experiments indicated that increasing the intensity of cropping systems by reducing the fallow period increased carbon sequestration in the soil due to higher biomass production and residue incorporation (Duo *et al.,* 2007) [8]. This stimulates soil microbial activity and is reflected in variations in enzyme activities. Increased root biomass production through balanced nutrient application under intensive cropping system, in turn,resulted in increased storage of organic carbon fractions (Purakayastha *et al.,* 2002; Nayak *et al.,* 2012) [30]. Under humid tropical climate, the practice of increasing the intensity of crop rotation,for *eg*.,from monocroppingto double cropping had increased SOC sequestration (Rajput *et al*., 2015) [36].
In India, only a very few works have been done to study the carbon fractionsin different depths of soil.And hence, the present study was undertaken to characterize the soil carbon pools at varied depths in a rice based cropping system of a lowland riverine alluvial soil, with a view to manage the soils for improving soil health and attaining environmental sustainability.

Materials and Methods

Site Description

The study was carried out at Integrated Farming System Research Station (IFSRS), Karamana, Kerala Agricultural University, located at 8^0 28’ 25” N latitude and 76^0 57’ 32” E longitude, at an altitude of 5 m above mean sea level. The main objectives were to assess the major physical, chemical and biological properties and characterize the carbon pools at varied depths of a soil where green manure crop like daincha (*Sesbania bispinosa*) had been incorporating into the field during the summer period [CS_1] since 2011-12. The resultant changes in soil properties were compared with that from the field following the sequence, rice- rice- fallow [CS_2].

Collection of soil samples

Soilsamples were collected at varied depths *viz*., 0-30, 30-60, 60-90 and 90-105cm at 30 cm intervals from both CS_1 and CS_2 plotsat the end of third cropseason or summer season during May 2019, the samples were collected from five different locations of the field. CS_1 and CS_2sequences are being practiced in an area of 0.15 ha each. During the first two crop seasons *viz*., *Virippu* (May- September, 2018) and *Mundakan*(October- February, 2018-19), medium duration rice variety, *Uma* was cultivated.
During the third crop (summer – March- May, 2019) season, instead of keeping the field fallow, green manure crop, daincha (*Sesbania bispinosa*) seeds were sown and incorporated into the field at maximum flowering stage. The samples collected after one month period were processed to analyse physical, chemical and biological properties to ascertain the soil health and also to find the influence of biomass incorporation on fractionation of carbon in soil.

Physical properties

Bulk density was determined by using core sampler which wasdriven into the soil at desired depths. The core sampler with soil sample waslater dried in a hot air oven for 48 h (Veihmeyer and Hendrickson, 1948) [48] at 105 ^{0}C.Core samples were collected from different depths and variation in bulk density with depth was assessed.

Chemical properties

Soil pH and EC were measured in 1:2.5 soil: water suspension (Jackson, 1967). Available nitrogen (N) was determined by alkaline permanganate method (Subbiah and Asija, 1956) [40]. Extractable phosphorus (P) was determined by colorimetric method as outlined by Watanabe and Olsen (1965) [52] and exchangeable potassium (K) using neutral normal ammonium acetate method in flame photometer as described by Jackson (1973) [15]. Exchangeable Ca and Mg were estimated using EDTA titration method (Gill and Abrol 1991) [11] and micro nutrients*viz*., Fe, Mn, Zn and Cu using Atomic Absorption Spectrophotometer (Osiname *et al*. 1973).

Soil carbon fractions

Soil organic carbon(SOC)content was assessed by wet oxidation with potassium dichromate ($K_2Cr_2O_7$)in concentrated H_2SO_4mediumas described by Walkley and Black (1934) [50]. Labile carbon(LC) was determined by potassium permanganate ($KMnO_4$) oxidation method developed by Blair *et al* (1995) in which soil samples were treated with $KMnO_4$ and shaken and centrifuged at 2000 rpm for 5 minutes. Absorbance of filtrate obtained from samples and blank aliquot were measured using spectrophotometer. Microbial biomass carbon (MBC)was determined using chloroform ($CHCl_3$) fumigation–extraction method (Voroney and Paul, 1984) [49]. Particulate organic carbon (POC) was determined by Camberdella and Elliott (1992) [4] method. Soil samples were dispersed in 0.5 per cent sodium hexa-metaphosphate solution by shaking for 15 h on a reciprocal shaker and then the soil suspension was passed through a 53μm sieve. Contents obtained after sieving were oven-dried at 60^0C for 24 h and POC was determined by Walkley and Black method [50].

Biological properties

Soil enzyme activities *viz*., urease (Tabatabai and Bremner, 1972) [43], dehydrogenase (Thalmann, 1966) [45] and acid phosphatase (Tabatabai and Bremner, 1969) [42] were determined from the collected samples under both the cropping sequences. Microbial count *viz.* bacteria, fungi and actinomycetes were estimated (Goldman and Green, 2008) using fresh soil samples.

Results and Discussion

The physical, chemical, biological properties and carbon fractions of soil at varied depths (upto 105 cm at 30 cm intervals) as influenced by differentrice based cropping systems were determined and compared. The major results and their interpretations are detailed below.

Soil physical and chemical properties

Soil bulk density (BD), pH, EC and major nutrients like N, P, K, Ca and Mg under both CS_1 and CS_2 sequences are presented in Table1.In general, wetlands contain higher BD than that of garden lands (*Gilbert et al*., 2005) [10]. BD was found to increase with soil depth(2.03 Mg m^{-3} at 90-105cm depth). Surface soils hadacidic pH (5.14) andlowEC (0.36

dSm^{-1}) and decreased with depth. According to Jobbagy and Jackson (2001) [19], global vertical distribution of nutrients from shallow to deeper layers were in the order: P > K > Ca > Mg > Na = Cl = SO_4 and concentration of all nutrients were higher in the topsoil, except Na. Available major and secondary nutrients like N, P, K, Ca and Mg were higher in the surface layer and continuously decreased with depth (Blume *et al*.,2002) [3]. In CS_1, surface soil had medium N (326 kg ha^{-1}), high P (40 kg ha^{-1}), medium K (149kg ha^{-1}) and low exchangeable Ca (110 kg ha^{-1}) and Mg (15 kg ha^{-1}) contents. All the available nutrients were found to decrease with soil depth.

In CS_2, available N, P, K, Ca, Mg and EC were higher in surface layer (0-30 cm) and decreased with depth similar to CS_1 (Table 1). BD increased with depth (1.40 at 0-30cm and 2.03 at 90-105cm depth). According to Blume *et al.* (2002) [3], soil pH increased with the depth of the soil profile, here the surface layer (0-30cm) was highly acidic (pH 4.79) and value varied with the depth. Available N, P, K, Ca and Mg contents were low compared to $CS_1$and the highest values were obtained in the surface layer., 276, 37 and 142 kgha^{-1} available N (medium), P (high) and K (medium) were found respectively, in the top 0-30 cm layer. Exchangeable Ca and Mg were below sufficiency level in both the cropping sequences *ie.*, 88 and 14kgha^{-1}, respectively (Table 1). More quantity of primary and secondary nutrients were observed in CS_1compared to CS_2, due to inclusion of green manure in the cropping sequence and biomass incorporation into the soil. Similar results were observed by Bama and Somasundaram (2017) [2] in sunhemp-chillies-sunflower cropping system. Green manure incorporation helps to stabilize soil structure by improving infiltration rate and water holding capacity (Raimbault and Vyn, 1991) [35]. This results in better utilization of nutrients and causes marked increase in soil organic matter and other quality attributes compared to continuous monoculture cereal cropping systems (Wani *et al*., 1994) [51]. The release of bicarbonates and organic compounds during crop residue decomposition can solubilize more mineral P and thereby, increases P availability (Sharpley and Smith, 1989) [39].

Table 1: Soil physical and chemical properties under two different cropping systems

Rice- rice- daincha(CS_1)								
Depth (cm)	**BD (Mg m^{-3})**	**pH**	**EC (dSm^{-1})**	**N (kg ha^{-1})**	**P (kg ha^{-1})**	**K (kg ha^{-1})**	**Ca (kg ha^{-1})**	**Mg (kg ha^{-1})**
0-30	1.39±0.03	5.10±0.08	0.31±0.01	326±2.76	39±2.18	149±3.37	110±3.37	15±0.96
30-60	1.78±0.04	5.17±0.07	0.14±0.01	280 ±6.28	23±0.73	131±3.95	94±1.38	11±0.54
60-90	1.95±0.02	5.00±0.11	0.06±0.003	215±5.45	13±0.86	109±3.62	79±1.16	7.1±0.59
90-105	2.01±0.03	5.09±0.09	0.04±0.004	192±5.24	9.1±0.89	97±2.10	69±2.28	3.2±0.18
Rice –rice-fallow (CS_2)								
0-30	1.40±0.04	4.79±0.09	0.39±0.01	276±4.62	37±2.38	142±3.42	88±2.61	14±0.82
30-60	1.75±0.06	5.96±0.19	0.11±0.01	232±2.41	26±1.46	119±3.82	70±1.43	7.9±0.21
60-90	1.86±0.07	5.87±0.10	0.07±0.07	206±2.62	20±0.51	123±5.47	57±1.29	5.0±0.33
90-105	2.03±0.06	5.93±0.09	0.08±0.08	150±4.16	11±0.50	105±3.96	52±2.30	1.9±0.12

Soil carbon fractions

Soil carbon fractions *viz*., soil organic carbon (SOC), microbial biomass carbon (MBC), labile carbon (LC) and particulate organic carbon (POC) were estimated and results are presented in Table 2. Surface soils had higher SOC content and different carbon fractions compared to the lower depths (Dodds*et al*., 1996) [7] in both the cropping systems. Ecosystems having prominent vegetation had enhanced SOC stock in the soil through organic matter addition compared to fallow system (Raich and Potter 1995; Bama and Somasundaram, 2017) [34, 2]. Higher quantity of SOC (14.57 g kg^{1}), MBC(211µg g^{-1}), POC (762 mg kg^{-1}in >53µm and 2318 mg kg^{-1} in <53µm size) and LC (1874 mg kg^{-1}) were found in surface soil (0-30cm) of CS_1 compared to CS_2 (Table 2). Labile C in soil was increased due to multiple cropping systems which enhanced root biomass yield and also roots were reported to exudate C compounds that are labile in nature (Purakayastha *et al.*, 2008) [33]. CS_1 had higher LC content than CS_2 at varied depths (Table 2) due to root biomass addition to the field.

Table 2: Soil carbon fractions under different cropping systems

Rice –Rice-Daincha (CS_1)					
Depths	**SOC (g kg^{-1})**	**Labile carbon (mg kg^{-1})**	**POC(mg kg^{-1})**		**MBC (µg g^{-1})**
			>53µm	**<53 µm**	
0-30	14.57±0.70	1874±25.25	762±6.51	2318±34.86	211±7.21
30-60	11.47±0.31	759±21.97	478±8.20	1968±47.98	138±5.30
60-90	4.52±0.19	428±8.73	150±1.67	1032±23.41	104±4.05
90-105	1.60±0.05	280±4.75	65±1.88	541±7.44	-
Rice –Rice-Fallow (CS_2)					
0-30	13.90±0.46	1505±24.10	1503±7.24	2152±29.72	133±3.41
30-60	4.25±0.17	576±4.54	434±3.82	751±17.43	66±1.57
60-90	2.20±0.08	286±6.16	217±3.45	598±12.68	31±1.69
90-105	0.40±0.02	238±4.60	181±4.24	34±3.50	-

POC was mainly composed of plant residues that would increase with increasing root biomass (Puget and Drinkwater, 2001). In this experiment, field in which $CS_1$was practiced showed higher POC content than CS_2 due to more root addition to the soil. In general, POC of the soil particles of size <53µm was greater than that of >53µm size fraction, at all depths in both the cropping systems (Table 2). There was a drastic decrease in carbon fractions below the subsurface layer in a rice –rice-fallow system field (Dodds *et al*., 1996) [7]. Biomass incorporation into the soil increases microbial activity, which in turn enhances decomposition of soil organic matter compared to a fallow system (Manna *et al.,* 2006;

Smyrna 2016) [28, 41]. Taylor *et al.* (2002) observed that MBC was least below 60cm depth due to less microbial activity and biomass content. Here, a comparatively higher MBC was noticed in CS_1 (ranged from 211to 104 μg g^{-1}) compared to that in CS_2 (ranged from 133 to 31μg g^{-1}). A drastic reduction in MBC was noticed with depth and was almost negligible beyond 90cm, in both the cropping systems. Organic manure incorporation increases microbial biomass carbon as it serves as substrate for microorganisms. Easily decomposable carbon fractions in the substrate enhance fast multiplication of microbes (Tu *et al.*, 2006) [47]. Similar increase in MBC and LC fractions with organic amendments was reported by Mi *et al*. (2016) [29].

Soil micronutrients

Much variation in soil micronutrients *viz.*, Fe, Mn, Zn and Cu was observed with depth (Table 3) under both the cropping systems. Ilori and Shittu (2015) [13] reported that the distribution of micronutrients in the soil does not follow any particular pattern, but varies down the soil profile. In general, higher proportion of micronutrients was observed in CS_1 compared to CS_2 due to deposition of organics from previous cultivation. Surface soils had higher micronutrient content which decreased with soil depth, in both the cropping systems (Table 3). Similar results were found by Dhaliwal *et al.*, (2011).

Table 3: Micronutrients in soil under different cropping systems

Depth (cm)	Fe	Zn	Mn	Cu
	(mg kg^{-1})			
Rice –Rice- Daincha (CS_1)				
0-30	489.79±11.18	20.4±1.39	36.01±1.49	10.25±0.38
30-60	363.16±8.33	17.29±1.09	36.96±1.12	9.50±0.37
60-90	138.16±4.05	10.49±0.76	32.26±1.66	3.98±0.29
90-105	96.42±2.78	4.66±0.28	29.73±1.39	2.47±0.19
Rice –Rice-Fallow (CS_2)				
0-30	512.87±4.02	40.65±1.10	20.50±0.93	7.65±0.29
30-60	301.37±3.95	39.60±1.16	18.50±0.85	5.35±0.18
60-90	126.75±2.78	26.35±2.49	16.40±0.55	5.05±0.06
90-105	83.50±1.41	15.10±0.56	13.20±0.61	2.90±0.26

Reduction in Fe and Zn contents were noticed in CS_1 compared to CS_2 and the reverse for Mn and Cu. In daincha based cropping system, the content ranged from 489.79 to 96.42, 20.4 to 4.66, 36.01 to 29.73 and 10.25 to 2.47 mg kg $^{-1}$, respectively, for Fe, Zn, Mn and Cu from 0 to 105 cm depth. Addition of easily decomposable organic matter increases the solubility of micronutrients and makes it more readily available for plants due to association with functional groups like phenolic and carboxylic acids (Fuente *et al*., 2011) [9]. Organic manure addition lowers the soil redox potential which inturn increases the micronutrient availability. In presence of soil organic matter, reactions that favour the formation of stable organic matter complexes are favoured (Roussos *et al*., 2017; Dhaliwal *et al*., 2019) [37, 6].

Soil biological properties

Soil enzymes like dehydrogenase, urease and acid phosphatase and microbial counts *viz*., bacteria, fungi and actinomycetes were estimated using fresh soil samples. Landi *et al*, (2000) [24] reported that enzyme activities would be more in top soil containing higher organic matter and that the ratio of soil enzyme activity to biomass C decreased with depth. The enzyme activities onthe surface layer ranged from 21.3 to 3.97, 82.94 to 37.87 and24.03 to 10.09 μg g^{-1}, respectively, for dehydrogenase, urease and acid phosphatise at varied depths (Table 4).

In both CS_1 and CS_2, enzyme activities drastically reduced below 90cm soil depth. Biomass addition and change in cropping pattern had stimulated microbial activity and hence, higher enzyme activities were reported in CS_1compared to CS_2.This is in line with the findings of Kataoka *et al.* (2017) [20] who reported that, green manure decomposition released organic matter, a source of carbon and energy for the growth and multiplication of microorganisms, thus enhancing soil enzyme activities.

Table 4: Soil enzyme activitiesunder different cropping systems

Depth (cm)	Urease mg g^{-1} soil	Dehydrogenase μg g^{-1} soil	Acid phosphatase μg g^{-1} soil
Rice –Rice-Daincha (CS_1)			
0-30	82.94±2.88	21.3±1.23	24.03±0.85
30-60	67.39±2.63	12.76±0.56	18.31±0.85
60-90	37.87±2.23	3.97±0.20	10.09±0.65
90-105	-	-	-
Rice –Rice-Fallow (CS_2)			
0-30	81.79±2.80	20.34±0.94	22.77±0.65
30-60	76.54±2.48	15.93±0.39	9.67±0.21
60-90	30.50±1.52	4.79±0.10	7.99±0.32
90-105	-	-	-

Influence of cropping system on soil microbial count is depicted inTable 5.The microbial activities were higher at the surface and decreased with depth due to reduction in organic matter content and aeration. About 90 per cent reduction in activity between the surface and below 60cm observed (Taylor *et al.*, 2002). Here also,microbial activity was highest at surface soilin both the systems and continuously reduced with depth. It was almost nil beyond 90cm. These results are in conformity with the findings of Ocio *et al.* (1991).

Table 5: Soil microbial count under different copping systems

Depth (cm)	Bacteria	Fungi	Actinomycetes
	log cfug^{-1} soil		
Rice –Rice-Daincha (CS_1)			
0-30	8.52±0.17	5.54±0.13	5.92±0.02
30-60	7.71±0.10	4.99±0.04	5.60±0.07
60-90	3.56±0.09	2.13±0.03	2.57±0.04
90-105	-	-	-
Rice –Rice-Fallow (CS_2)			
0-30	8.59±0.07	5.64±0.11	5.98±0.11
30-60	7.45±0.11	4.99±0.04	5.77±0.07
60-90	3.05±0.08	2.10±0.07	2.47±0.05
90-105	-	-	-

Conclusions

Soil carbon sequestration is the best management strategy for mitigating global warming. Intensive cropping systems which produce large biomass will sequester more CO_2 from the atmosphere. Subsurface soils which contain lesser carbon content than surface layer has the potential for sequestering non-labile fraction of C for a longer period. In this experiment, higher soil C fractions were found in the rice-rice- dainchacropping system due to residual and organic matter addition from the previous crop compared to fallow system.

All other soil properties *viz*., physical, chemical and biological followed the same trend as that of carbon fractions. Intensive cropping system with deep rooted crops producing more biomass and reduction of fallow enhances the C stocks in the soil and helps in ecological balance.

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