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

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Abstract

The drastic increase in atmospheric CO₂ concentration 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 up to 105 cm 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-daichan 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 adaptation 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 our planet (Lal, 2004; Young, 2003) [22, 53] and ultimately resulted in climate change. The global surface temperature had increased by 0.88°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 atmospheric CO₂ and hence its judicious management has significant potential in carbon 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 CO₂ 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 production is an important controlling factor in deciding soil organic matter (SOM) addition (Post et al., 1982) [22].

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 (KMnO₄ C) and biological fraction (microbial biomass carbon) while recalcitrant pool (humus) is resistant to decomposition (Chan et al., 2001; Mandal et al., 2013) [8, 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, have 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) [29]. 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) [28]. 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 monocropping to 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 fractions in 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 (IFRSRS), Karamana, Kerala Agricultural University, located at 8° 28’ 25” N latitude and 76° 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 [CS1] since 2011-12. The resultant changes in soil properties were compared with that from the field following the sequence, rice- rice- fallow [CS2].

Collection of soil samples

Soil samples were collected at varied depths viz., 0-30, 30-60, 60-90 and 90-105 cm at 30 cm intervals from both CS1 and CS2 plots at the end of third crop season or summer season during May 2019. The samples were collected from five different locations of the field. CS1 and CS2 sequences are being practiced in an area of 0.15 ha each. During the first two crop seasons viz., Virippu (May-September, 2018) and Mundakani (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 was driven into the soil at desired depths. The core sampler with soil sample was later dried in a hot air oven for 48 h (Veihmeyer and Hendrickson, 1948) [48] at 105 °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 (K2Cr2O7: in concentrated H2SO4: grams as described by Walkley and Black (1934) [50]. Labile carbon(LC) was determined by potassium permanganate (KMnO4) oxidation method developed by Blair et al (1995) in which soil samples were treated with KMnO4 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 (CHCl3) 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°C 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 different 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 CS1 and CS2 sequences are presented in Table 1. 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–2 at 90-105cm depth). Surface soils had acidic pH (5.14) and low EC (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 = SO₄ 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) [18]. In CS₁, surface soil had medium N (326 kg ha⁻¹), high P (40 kg ha⁻¹), medium K (149 kg 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 in soil depth.

In CS₂, available N, P, K, Ca, Mg and EC were higher in surface layer (0-30 cm) and decreased with depth similar to CS₁ (Table 1). BD increased with depth (1.40 at 0-30 cm and 2.03 at 90-105 cm depth). According to Blume et al. (2002) [3], soil pH increased with the depth of the soil profile, here the surface layer (0-30 cm) was highly acidic (pH 4.79) and value varied with the depth. Available N, P, K, Ca and Mg contents were low compared to CS₁ and the highest values were obtained in the surface layer., 276, 37 and 142 kg ha⁻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 i.e., 88 and 14kg ha⁻¹, respectively (Table 1). More quantity of primary and secondary nutrients were observed in CS₁ compared to CS₂ 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 (Rainbault and Vyn, 1991) [33]. 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) [99].

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

| Soil carbon fractions | Rice–rice–daincha (CS₁) | Rice–rice–fallow (CS₂) |
|-----------------------|------------------------|------------------------|
| 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±4.37    | 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±1.95    | 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±2.62    | 79±1.16      | 7±0.59        |
| 90-105                | 2.01±0.03              | 5.09±0.09              | 0.04±0.004 | 192±5.24   | 9±1.89      | 97±2.10     | 69±2.28      | 3±0.18        |

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) [18, 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 (0-30 cm) of CS₁ compared to CS₂ (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) [31]. CS₁ had higher LC content than CS₂ at varied depths (Table 2) due to root biomass addition to the field.

**Table 2**: Soil carbon fractions under different cropping systems

| Depths | SOC (g kg⁻¹) | Labile carbon (mg kg⁻¹) | POC(mg kg⁻¹) | MBC (µg g⁻¹) |
|--------|-------------|------------------------|--------------|--------------|
| 0-30   | 14.57±0.70  | 1874±25.25             | 762±6.51     | 211±7.21     |
| 30-60  | 11.47±0.31  | 759±21.97              | 478±8.20     | 196±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     | -            |
| 0-30   | 13.90±0.46  | 1505±24.10             | 1503±7.24    | 215±29.72    | 133±3.41     |
| 30-60  | 4.25±0.17   | 576±6.54               | 434±3.82     | 751±17.43    | 66±1.57      |
| 60-90  | 2.20±0.08   | 286±7.16               | 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 CS₁ was practiced showed higher POC content than CS₂ 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 lowest below 60 cm depth due to less microbial activity and biomass content. Here, a comparatively higher MBC was noticed in CS1 (ranged from 211 to 104 µg g⁻¹) compared to that in CS2 (ranged from 133 to 31 µg g⁻¹). A drastic reduction in MBC was noticed with depth and was almost negligible beyond 90 cm, 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. Iori 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 CS1 compared to CS2 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) | Rice – Rice-Daincha (CS1) | Rice – Rice-Fallow (CS2) |
|------------|--------------------------|--------------------------|
|            | Fe           | Zn          | Mn       | Cu       | Fe           | Zn          | Mn       | Cu       |
| 0-30       | 489.79±11.18 | 20.4±1.39  | 36.01±1.49 | 10.25±0.38 | 301.37±1.35  | 4.99±0.04   | 36.56±1.62 | 9.45±0.08 |
| 30-60      | 363.16±8.33  | 17.29±1.09  | 36.96±1.12 | 9.50±0.37  | 30.50±1.32   | 4.99±0.04   | 26.35±2.49 | 9.45±0.08 |
| 60-90      | 138.16±4.05  | 10.49±0.76  | 32.26±1.66 | 3.98±0.29  | 30.50±1.32   | 4.99±0.04   | 26.35±2.49 | 9.45±0.08 |
| 90-105     | 96.42±2.78   | 4.66±0.28   | 29.73±1.39 | 2.47±0.19  | 30.50±1.32   | 4.99±0.04   | 26.35±2.49 | 9.45±0.08 |

Reduction in Fe and Zn contents were noticed in CS1, compared to CS2 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 on the surface layer ranged from 21.3 to 3.97, 82.94 to 37.87 and 24.03 to 10.09 µg g⁻¹, respectively, for dehydrogenase, urease and acid phosphatase at varied depths (Table 4).

In both CS1 and CS2, enzyme activities drastically reduced below 90 cm soil depth. Biomass addition and change in cropping pattern had stimulated microbial activity and hence, higher enzyme activities were reported in CS1 compared to CS2. 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.

| Depth (cm) | Rice – Rice-Daincha (CS1) | Rice – Rice-Fallow (CS2) |
|------------|--------------------------|--------------------------|
|            | Urease mg g⁻¹ soil       | Dehydrogenase mg g⁻¹ soil | Acid phosphatase mg g⁻¹ soil |
| 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     | -                        | -                        | -                         |

Influence of cropping system on soil microbial count is depicted in Table 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 60 cm observed (Taylor et al., 2002). Here also, microbial activity was highest at surface soil in both the systems and continuously reduced with depth. It was almost nil beyond 90 cm. These results are in conformity with the findings of Ocío et al., (1991).

Table 4: Soil enzyme activies under different cropping systems

Table 5: Soil microbial count under different cropping systems

Soil carbon sequestration is the best management strategy for mitigating global warming. Intensive cropping systems which produce large biomass will sequester more CO₂ from the atmosphere. Subsurface soils which contain lesser carbon from the surface and below the systems and continuously reduced with depth. It was almost nil beyond 90 cm. These results are in conformity with the findings of Ocío et al., (1991).

Conclusions

Soil carbon sequestration is the best management strategy for mitigating global warming. Intensive cropping systems which produce large biomass will sequester more CO₂ 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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