Long-Term Effects of Rice and Non-rice Ecology on Pools of Carbon in Surface and Deep Soil in Farmer's Field

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The greatest terrestrial sink of carbon (C) is soil. In addition to improving soil quality, carbon absorption in soil helps reduce atmospheric CO_2 loading. Not only the surface soil, but also the deep sub-soil act as a storehouse of C. Besides, the study of C dynamics in tropical rice soil is important in countries like India where rice is the predominant crop and soil C sequestration is at risk due to high temperatures. In this context, this study tried to understand the C dynamics in surface as well as deep soil under rice and non-rice ecology. Representative soil samples were collected from five sites of rice-rice (rice ecology) and vegetable-vegetable (non-rice ecology) cropping systems from three depths viz., 0-20 cm, 100-120 and 120-140 cm from long-term farmer's field of Nadia district of West Bengal belonging to Alfisols to compare C dynamics of surface and deep soils as well as rice and non-rice ecology. Results indicated that surface soils exhibited higher amount of total C, total organic C and inorganic C in comparison to deep soil irrespective of crop ecologies. The rice ecology showed higher total C and total organic C in comparison to non-rice soil. As per water solubility, water-soluble (room temperature) C and hot water-soluble C which were highest in surface soil compared to deep soil as the former usually

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receives maximum amount of fresh C input compared to deep soil. Irrespective of crop ecology, water-soluble C (WSC), hot water-soluble C (HWC), recalcitrant C (RC) were highest in surface soil compared to deep soils. Again, irrespective of soil depth, WSC and RC were highest in rice ecology and lowest in non-rice ecology. But, HWC content was highest in non-rice ecology and lowest in rice ecology. Irrespective of crop ecology, per cent contribution of labile pool of C (WSC+ HWC) and that of RC pool towards TOC was the highest and the lowest respectively. However, irrespective of soil depth, per cent contribution of labile pool of C and that of recalcitrant pool of C towards TOC was highest and lowest in soils under non-rice ecology and rice ecology respectively. Thus, this study conclusively indicated the potential of subsoil layer to act as a C sink in comparison to surface soil. The rice soil also has been identified as a niche for soil C sequestration.

1. INTRODUCTION

Soil organic matter (SOM) is an essential form of biological activity in soil and is recognized as the Earth's greatest terrestrial carbon pool [1-4]. The SOM plays a significant role in improving the soil's biological, chemical, and physical properties and is also an indicator of the quality and productivity of soils [5]. The maintenance of SOM is very crucial for crop production and productivity; it improves soil fertility through various actions, viz., production of organic acids, phytohormones, solubilization of nutrients, and enhancing water holding capacity [6,7]. Generally, crop residue and animal residue are the chief sources of soil organic matter content. However, soil microorganisms act as secondary sources of organic matter, and they are helpful for decomposition. The SOM is present in various forms and stages; it might be changed due to the decomposition rate by microorganisms [8].

Both the primary component of soil organic matter and a major player in the global carbon cycle and climate change is soil organic carbon (SOC) [9] and it controls a number of soil characteristics, including bulk density, aggregate stability, porosity, aeration, and water retention capacity [10]. Organic carbon decomposition stimulates certain types of substances, and these substances act as regulators in the soil through ion exchange and retention, especially the NPK minerals [11]. A higher content of soil organic carbon indicates good quality and productivity soil, and it improves soil health, fertility, and sustainable crop production in long-term cropping systems. Tropical countries like India and Asian countries have the lowest average of organic matter content than in comparison with other countries [12]. In India, an average of 0.5% SOC content is present [13], however, it is very less amount than the world average organic carbon content [14] and the total carbon stock of Indian soil is 14 Pg (upper 30 cm) and 64 Pg (150 cm) [15].

In India, the area under rice cultivation is nearly 43.7 m ha majorly, and submerged conditions of rice cultivation help methane emission, rice cultivated soils are known to retain higher amounts of resilient C among all terrestrial ecosystems than drylands [16].

Based on its chemical characteristics and techniques of extraction, the entire soil C has been separated into many pools [2,17]. The pools include the inorganic pool, organic pool, water-soluble C (WSC), hot water-soluble C (HWC), and recalcitrant pool of C (RC). Understanding the dynamics of C cycling in soil ecosystems, including C storage, turnover rates, and possible reactions to environmental changes, is possible through the partitioning of soil carbon into different pools [2]. The various types of soil C and their functions in soil fertility, storage of carbon, and ecosystem functioning are characterized by a variety of extraction techniques and chemical characteristics. Given this context, the current investigation was carried out in order to evaluate the pools of C in surface and deep soils under both lowland rice and upland non-rice ecology.

2. MATERIALS AND METHODS

2.1 Soil Sampling

Representative soil samples were collected during 2019-2020 from long-term farmer's field of Nadia district of West Bengal belonging to Alfisols soil order from representative rice-rice (Rice ecology) and vegetable-vegetable (Non-rice ecology) cropping systems which were supposed to exist in that site for at least the last 15 (fifteen) years to have a look on the trend of

soil carbon as affected by cropping system and management practices [18]. Representative soil samples were collected from five sites of each cropping system from three depths viz., 0-20 cm, 100-120 and 120-140 cm to compare C dynamics of surface and deep soils as well as rice and non-rice ecology. Thus, a total of 30 (2 cropping systems x 5 sites x 3 depth) soil samples were gathered from the study sites. The composite soil sampling was done for each depth of each site of representative rice and non-rice ecologies and was then air-dried, mixed well, and passed through a 2 mm sieve and used subsequently for the analysis of different pools of C.

2.2 Soil Analysis

Soil samples were air-dried, sieved with 2 mm sieves and stored for determination of different pools of soil C.

2.2.1 Total C

To estimate the total C content, the soil samples were prepared following the method of Nelson and Sommers [19].

2.2.2 Inorganic C

Soil inorganic C i.e. total carbonates content in soil were determined by rapid titration method using dilute HCl and bromothymol blue as indicator [20].

2.2.3 Total organic C

The total organic C was obtained by subtracting the inorganic C from total C.

2.2.4 Water-Soluble C (WSC)

It was estimated by mixing soil and distilled water in a 50 ml centrifuge tube at a ratio of 1:10 (in this study, 3 g of soil in 30 ml distilled water) followed by 30 minutes extraction at 20° C and centrifugation at 3000 rpm for 20 minutes [21]. After centrifugation, the supernatant was filtered to get the WSC. The C remaining in this solution was named as labile pool 1 (L_1). The estimation of water-soluble C was done following the method of Nelson and Sommers [19].

2.2.5 Hot Water Extractable C (HWC)

After removing the WSC, second labile pool of C (L_2) was extracted from the remaining soil samples using hot water treatment [17]. The estimation of hot water-soluble C was done following the method of Nelson and Sommers [19].

2.2.6 Recalcitrant C (RC)

The recalcitrant C was determined by subtracting the sum of two water soluble pools from the TOC. Recalcitrant C pool (RC) = $TOC-(L_1+L_2)$

2.3 Percent Contribution of Sum of WSC and HWC towards TOC

Percent contribution of sum of WSC and HWC towards TOC was calculated by the following formula:

Percent contribution of sum of WSC and HWC towards TOC=(WSC+HWC)/TOC*100

2.4 Percent Contribution of Recalcitrant C towards TOC

Percent contribution of Recalcitrant C towards TOC was calculated by the following formula:

Percent contribution of Recalcitrant C towards TOC=(Recalcitrant C)/TOC*100

2.5 Statistical Analysis

Statistical analysis has been conducted using SPSS 20.0 version.

3. RESULTS AND DISCUSSION

3.1 Total C, Organic C and Inorganic C Pools

The status of soil total C, organic C and inorganic C of soils of Nadia, West Bengal, India is shown in Table 1 and Fig. 1. The impact of soil depth and crop ecology on the soil C pools has been presented in Table 1 and Fig. 1. It was noted from the table that surface soils exhibited higher amounts of total C, total organic C, and inorganic C in comparison to deep soil irrespective of the selected sites. This is quite natural as the surface soil receives the maximum C input in terms of discarded plant biomass. Topsoils exhibit high amount of C with limited residence periods due to favourable environment for decomposition, significant C input etc. [22,23]. However, outcomes revealed a significant presence of TC and TOC in subsoil layers. Again, it was observed that the amount of TC and TOC was higher in soils under rice ecology in comparison to upland soils of non-rice ecology. This was possibly due to the capacity of rice soil to store high amount of C. The absence of O_2 as a

terminal electron acceptor in submerged rice soil resulted in slow oxidation of C and higher turnover time [24]. All the soils stored a small amount of inorganic C. However, as evident from the results, this C pool was also slightly higher in surface soils in comparison to subsoil layers.

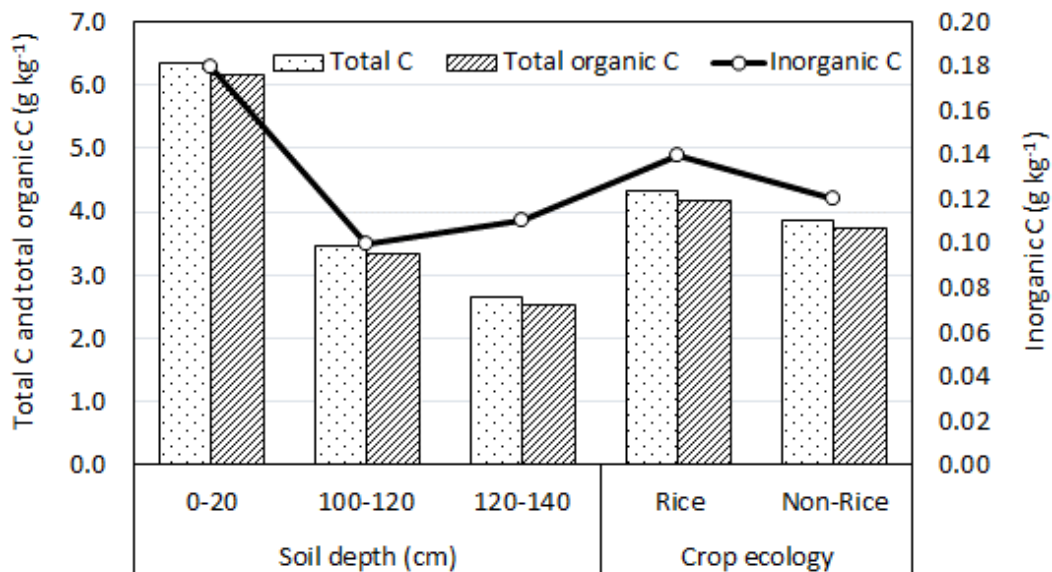## 3.2 Water Soluble C (WSC), Hot Water-Soluble C (HWC), Recalcitrant C Pools

Analysis of water-soluble C pools showed that there was a higher content in surface soil than in deep soil. This was true for both the water-soluble C pool (L_1) as well as hot water-soluble pool (L_2). This is quite expected as these pools represent very labile fraction of soil C [25] and surface soil, being the recipient of regular C input through leaf and litter fall has a large pool of labile C [26]. Apart from water and hot water-soluble C, recalcitrant pool which was derived by subtracting these two pools from TOC also showed decreasing trend along depth. While comparing the crop ecology irrespective of soil depth water-soluble and recalcitrant C was highest in rice ecology and lowest in non-rice ecology. But, hot water-soluble C content was highest in non-rice ecology and lowest in rice ecology. Irrespective of soil depth and crop ecology, the hot water-soluble Carbon pool was quantitatively much higher than the water-soluble pool at room temperature.

Table 1. Status of total C, total organic C and inorganic C at different depths and crop ecology

Soil Depth (cm)	Soil C status (g kg^{-1})		
	Total C	Total organic C	Inorganic C
0-20	6.34[a]	6.16[a]	0.18[a]
100-120	3.45[b]	3.35[b]	0.10[b]
120-140	2.65[c]	2.54[c]	0.11[b]
Significant level	**	**	*
Cropping system			
Rice	4.32	4.18	0.14
Non-Rice	3.86	3.74	0.12
Significant level	**	**	ns
Depth x cropping system	**	**	*

*** ≤ 0.01, * ≤ 0.05, ns: not significant according to F-value of ANOVA. Different lower- case letters indicate significantly different values along soil depth at P ≤ 0.05 according to Duncan's test for separation of means*

Fig. 1. Distribution of total C, total organic C and inorganic carbon at different depths and different crop ecology
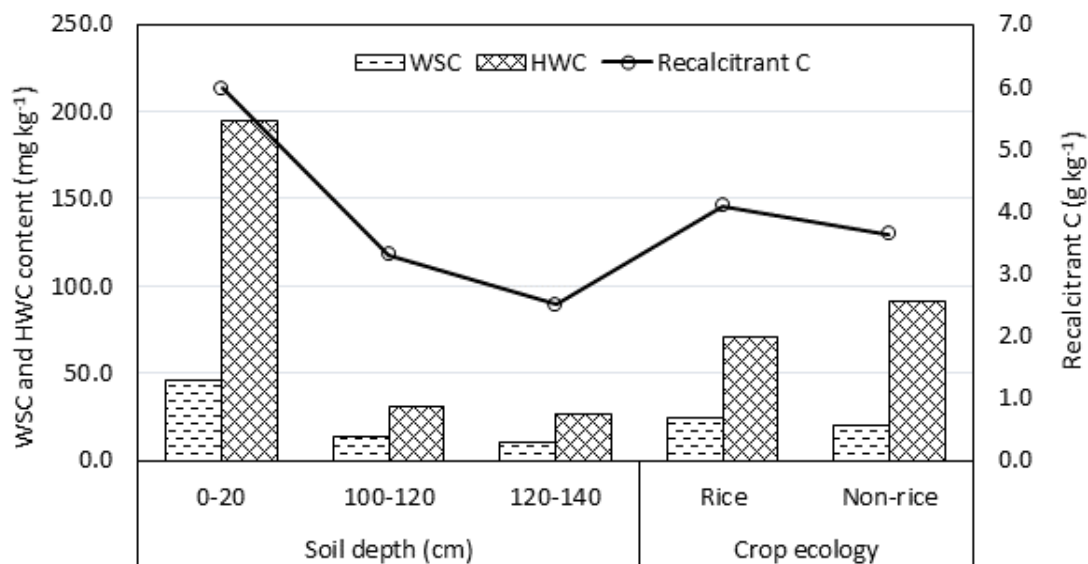
However, the variation of water-soluble, hot water-soluble C as well as the recalcitrant pool cannot be a representative of the true soil C dynamics, as the soil total organic C varied a lot with depth and ecology. To resolve this issue, the per cent contribution of the sum of water-soluble pools and hot water-soluble pool (i.e., $L_1 + L_2$) as well as recalcitrant pools towards TOC was calculated. The Table 2 depicted higher per cent contribution of sum of WSC and HWC pools towards TOC in surface soil compared to deep sub soil irrespective of crop ecology. On the contrary, recalcitrant C as a % of TOC increased in the subsoil layers than the surface soil irrespective of crop ecology. It indicated a higher residence time

of C in the subsoil, as found in earlier studies also [21].

The comparison of rice and non-rice ecology (irrespective of soil depth) resulted in a higher per cent contribution of sum of WSC+HWC towards TOC in soils under non-rice ecology (Table 2) than rice ecology. The percentage contribution of recalcitrant C pool towards TOC was more in soils under rice ecology. It means, a higher C stability in rice soils which possibly was due to the water logging and subsequent anaerobic conditions of rice soils. The absence of O_2 possibly resulted in slower microbial decomposition and low C mineralization [27,28].

Table 2. Status of Water-Soluble C (WSC), Hot Water-Soluble C (HWC), and Recalcitrant C (RC) in different depth and crop ecology and their contribution towards total organic C

Pools of C	WSC (mg kg^{-1})	HWC (mg kg^{-1})	RC (g kg^{-1})	Percent contribution of sum of WSC and HWC towards TOC	Percent contribution of RC towards TOC
Soil depth (cm)					
0-20	46.24[a]	194.64[a]	5.97[a]	3.88[a]	96.12[a]
100-120	14.20[b]	30.96[b]	3.30[b]	1.35[b]	98.65[a]
120-140	10.36[c]	26.44[b]	2.50[c]	1.45[b]	98.55[a]
Significant level	**	**	*	*	*ns*
Crop ecology					
Rice	24.96	70.52	4.08	2.28	97.72
Non-rice	19.72	90.88	3.63	2.96	97.04
Significant level	**	**	*	**	*ns*
Depth × cropping system					
Significant level	*	**	*	*	*ns*

Fig. 2. Status of water-soluble C (WSC), hot water-soluble C (HWC), recalcitrant C (RC) at different soil depth and crop ecology

4. CONCLUSION

The results revealed higher total C and total organic C in surface soil in comparison to deep soil. The rice ecology showed higher total C and total organic C in comparison to non-rice soil. As per water solubility, water-soluble (room temperature) C (WSC) and hot water-soluble C (HWC) which was highest in surface soil compared to deep soil as surface soil usually receive maximum amount of fresh C input compared to deep soil. Irrespective of crop ecology, WSC, HWC, recalcitrant C (RC) was highest in surface soil compared to deep soils. Again, irrespective of soil depth, WSC and RC was highest in rice ecology and lowest in non-rice ecology. But, HWC content was highest in non-rice ecology and lowest in rice ecology. Irrespective of crop ecology, per cent contribution of labile pool of C (WSC+ HWC) and that of recalcitrant pool of C towards TOC was highest and lowest respectively. However, irrespective of soil depth, per cent contribution of labile pool of C (WSC+HWC) and that of recalcitrant pool of C towards TOC was highest and lowest in soils under non-rice ecology and rice ecology respectively.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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