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# Soil Carbon Sequestration and Nutrient Status of Rice-Based Cropping Systems: A Case Study from Mymensingh District in Bangladesh

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**ABSTRACT**

Carbon (C) sequestration in soil plays a crucial role in increasing soil quality through recommended management practices including applying organic amendments, following cropping patterns, fallow periods etc. This study aimed to assess the influence of rice-based cropping patterns on soil C and nutrient status in surface (0-15 cm) and sub-surface soil (15-30 cm). Soils of five rice-based cropping patterns [*Boro (winter rice)*-Fallow-Fallow, *Boro*-Fallow-*Aman (monsoon rice)*, *Boro*-Fallow-*Aman*-Mustard, *Boro-Aus (summer rice)-Aman*, Vegetables-short Fallow-*Aman*] from farmers' fields of Mymensingh district in Bangladesh were collected. Bulk soils were physically fractionated into particulate organic matter (POM: >53 µm) and mineral associated OM (MOM: < 53 µm) to assess the organic C (OC) distribution. Bulk soils were analyzed for soil pH, electrical conductivity, soil texture, nutrients (OC, nitrogen (N), phosphorus (P), potassium (K) and sulphur (S)) contents. The results showed that all studied parameters varied significantly among the cropping patterns and soil depths. Surface soils contain higher amount of OC, N, P, K and S than sub-surface soils under all rice-based cropping patterns. Overall, relatively higher macronutrients (P, K, S) concentration was found in the cropping patterns with a greater number of crops compared to the patterns including fallow period. In contrast, OC and N were the highest in *Boro*-Fallow-Fallow field followed by Vegetables-short Fallow-*Aman* and the rest three patterns, which might correspond to less disturbance of soil. All the rice-based cropping patterns had noticeable proportion of MOM (presumably stable OC) than labile POM which indicates the capacity of paddy soils in sequestering OC in soils. However, this capacity can be influenced by the pattern and probably also by the management systems, *e.g.*, tillage and nutrient managements. These findings revealed the necessity of paying more attention to the selection of cropping pattern and proper land/or crop management for higher C sequestration in arable soil.



## 1. Introduction

Around 1500 gigaton (Gt) of organic carbon (OC) are thought to be present in the first meter of the soil profile worldwide, making up a sizable carbon (C) pool in the soil (Guo et al., 2002; Stockmann et al., 2013). Compared to the biotic pool's 560 Gt of C (Lal, 2008) and atmospheric $CO_2$ [4], this is significantly higher. Because the soil has such a large store of carbon, it is limiting the atmospheric buildup of $CO_2$, which would exacerbate the issue of climate change. The process of sequestering carbon involves moving atmospheric $CO_2$ into long-lived pools and keeping it safe so that it is not released right away (Lal, 2004a). Given that 50% of agricultural soils and 24% of all soils are already degraded worldwide, there is a significant chance to store atmospheric carbon in soil for an extended amount of time (Batjes, 2013). Agricultural soils are thought to have the capacity to sequester up to 1.2 billion tons of $CO_2$ annually, although this is unlikely given that the majority of them are already degraded (IPCC, 2014a).

In addition to maintaining the stability of the global climate, soil C sequestration is essential for improving soil quality and agricultural output. Global agriculture is now aware of the potential for C sequestration through improving soil C stocks through sustainable land management (Smith et al., 2008). Prudent land use and suggested management

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techniques, such as crop rotation, soil tillage, residue retention, fallow periods, nutrient and water management, and so on, can improve soil C sequestration (Baker et al., 2007; Lal 2004a).

Rice (*Oryza sativa* L.) represents a large portion of global agriculture and is grown largely in South and East Asian countries as their staple food. Rice fields are reported to have higher soil OC storage (Pan et al., 2004) and sequestration compared to dry croplands (Wissing et al., 2011). According to Kögel-Knabner et al. (2010), there are several mechanisms that may contribute to the build-up of soil organic matter (OM) in paddy (rice) soils. These include occlusion in aggregates, the creation of organo-mineral relationships, the addition of pyrogenic OM, and phyto-opal related stabilization of OC. Long-term submergence leads to the dissolution of stable aggregates and deterioration of soil OM, even though it is well known that submergence increases the amount of OM in the soil (Mohanty and Painuli, 2004). Selection of different crops in cropping patterns are known to favour the build-up of soil OC and improve soil nutrients contents in comparison with monocultures (Moore et al., 2000). Agriculture in Bangladesh is primarily characterized by a rice monoculture practice and is grown in single-double-triple crop pattern as single or with other non-rice crops. It is well known that continuous monoculture is not effective at sequestering C or maintaining soil fertility (Campbell et al., 2007). The use of chemical fertilizers in an unbalanced and selective manner has contributed to a decline in soil health, whilst intensive agriculture, which involves the production of high yielding varieties of rice and other crops, has caused a significant loss of nutrients from the soil (John et al., 2001). It is necessary to analyze suitable rice-based farming in order to gauge the stability of both the global climate and agricultural production. The present study was therefore conducted to quantify OC pools (total, labile and stable) and major nutrient status in soils from different rice-based cropping patterns of the selected area, to assess the influence of rice-based cropping patterns on soil OC and nutrient levels, and to examine soil depth effect on the C sequestration potential and nutrient status of soils.

## 2. Materials and Methods

### 2.1. Experimental location

Soil samples of five cropping patterns were collected from farmers' fields at (24°52'05.4"N 90°24'15.2"E) Kakni union of Tarakanda upazila of Mymensingh district, Bangladesh. Farmers are practicing different rice based cropping patterns in the fields close to each other for a long time (> 15 years). This area belongs to the Old Brahmaputra Floodplain Agro-ecological Zone-9 (AEZ-9) having non-calcareous dark grey soil. The location of the farms has similar climatic condition, topography and soil types, and only different in land uses (*i.e*., cropping patterns). Fields were selected after a preliminary survey of this area and interview with the farmers. The most abundant five selected rice based cropping patterns were- *Boro* (winter rice)-Fallow- Fallow, *Boro*- Fallow- *Aman* (monsoon rice), *Boro*- Fallow- *Aman* - Mustard, *Boro*- *Aus* (summer rice)- *Aman* and Vegetables- short Fallow- *Aman.* During cultivation, the farmers use a shallow ploughing at the beginning of land preparation followed by two deep ploughings by power tiller before planting each crop in all patterns, except the *Boro*-Fallow-Fallow, where a shallow and a deep ploughing are practiced. The farmers generally grow rice using the chemical fertilizers based on local farmer's practice. Farmer used only fertilizers for rice and only organic amendments like cowdung and compost (available in their household), and there was no report in using any kind of amendments (chemical/ organic) for the mustard crop of the patterns. For these selected patterns, the farmers used variety-BRRI dahn48, BRRI dhan49 and BRRI dhan29 for *Aman* and *Boro*, respectively.

### 2.2. Sample collection and preparation

Top (0-15 cm) and sub-soils (15-30 cm) from five fields representing five rice-based cropping patterns were sampled. Soil samples were collected randomly from 10 points in the field and were bulked together to a composite sample for each site separately. The samples were air dried, ground, passed through 2 mm sieve and then stored in airtight containers.

### 2.3. Physical fractionation of soil

With minor modifications, bulk soils were physically separated in accordance with Cambardella and Elliott (1992). Twenty grams (20 g) of air dried (2 mm) sub-samples was placed in 250 mL plastic bottles and then 70 mL of sodium hexametaphosphate was added @ 5.0 g $L^{-1}$. After that, the mixer was agitated for fifteen hours at 130 rpm in a horizontal shaker. Subsequently, the complete mixer was run through a 53 μm sieve and cleaned using deionized water. Particulate organic matter (POM: greater than 53 μm) was the material that was adhered to the sieve, and mineral associated organic matter (MOM: less than 53 μm) was the material that went through the sieve. After that, all recoverable fractions were dried in an oven at 40°C. The dehydrated components were manually crushed into a fine powder. Subsequently, the fine powder was weighed and kept for later examination in a plastic vial.

### 2.4. Sample analysis

#### *2.4.1. General characterization of bulk soil*

The pH, carbonate, electrical conductivity (EC), and texture of bulk soils were determined. A 1:5 soil-to-water ratio was used to measure the pH and EC of the soil using a glass electrode pH meter and a conductivity meter, respectively (Jackson, 1962; Page et al., 1982). The titration method was used to assess the carbonate and bicarbonate (Rowell, 1994). The hydrometer method was used to analyze particle size (Buoyohcos, 1962). Analytical measurements and laboratory extractions of each bulk soil sample were carried out twice.

#### *2.4.2. Chemical analyses of soil*

Soil organic carbon (OC) and total nitrogen (N) contents of both bulk soil and soil fractions were measured by following the wet oxidation method Walkley and Black (1934) and Kjedahl method (Bremner, 1965), respectively. Phosphorus (P), potassium (K) and sulphur (S) of bulk soils were determined via spectrophotometry (Olsen, 1954), flame photometer (Warnkce and Brown, 1998) and spectrophotometry (Combs et al., 1998) techniques, respectively.

### 2.5. Statistical analysis

The effects of cropping pattern and depth on soil C sequestration potential and nutrient status were determined using analysis of variance (ANOVA). The R software package (version 3.5.3) was used for all statistical studies.

## 3. Results

### 3.1. General characteristics of soil

All the collected soils from five rice-based cropping patterns at both depths were moderately acidic (pH ≤ 5.3-5.8) and non-saline in nature (EC: 141-162 µS $cm^{-1}$) (Table 1). The texture of the studied soils of the field of different patterns was similar for both depths, *i.e*., sandy loam. Soil particles- sand, silt and clay ranged from 50-56, 31-34 and 13-20 %, respectively (Table 1). There was no notable carbonate and bicarbonate present in the collected soils.

### 3.2. Major nutrient elements in bulk soils from different rice-based cropping patterns

The OC, N, P, K and S contents in the soils were significantly varied among the cropping patterns and soil depth (Figure 1, Table 2). The OC and N contents ranged from 0.90-2.6% and 0.073-0.228%, respectively considering all the cropping patterns and soil depth (Figure 1A, B). At both depths, the OC and N contents were highest in soils from *Boro*-Fallow-Fallow cropping pattern which was followed by Vegetables- short Fallow-*Aman* > other three patterns. Considering the depth, top soil had higher OC and N in all cropping patterns.

The C:N ratio ranged from 8.5-12.3 and significantly varied among the cropping patterns and soil depths (Figure 1C). Relatively wider C:N ratios were observed in the top soils compared to the sub-soil. The highest C:N ratio was 12.25 in *Boro*-Fallow-*Aman* and the lowest was in *Boro*-Fallow-Fallow (8.48-11.6) for the both depths.

All the other studied (P, K, S, Na) nutrients showed significant differences among the cropping patterns and soil depths (Table 2). Concentration of P ranged from 7.2-29.8 ppm and was highest in *Boro*-Fallow-*Aman* cropping pattern followed by Vegetables- short Fallow -*Aman* > *Boro*-*Aus*-*Aman* > *Boro*-Fallow > Fallow for the top soils. The trend was almost similar in the sub-soil depth. The K concentration was in the range between 0.071-0497 meq $100^{-1}$. At the top soil, the highest K concentration was observed in *Boro*-*Aus*-*Aman* followed by Fallow-Fallow-*Boro* >*Boro*-*Aman*-Mustard > Vegetables- short Fallow -*Aman*. Sulphur concentration varied between 4-18 ppm, with the highest value in *Boro*-*Aman*-Mustard followed by Vegetables- short Fallow -*Aman* > *Boro*-Fallow-*Aman* > *Boro*-Fallow-Fallow in the surface soil.

### 3.3. Organic carbon and nitrogen in physical fraction of soils from different rice-based cropping patterns

#### *3.3.1. Mass, organic carbon and total nitrogen distribution*

Bulk soils were physically fractionated into two fractions- <53 µm and >53 µm. On a mass basis, >53 µm fractions was more abundant (31-73%) than <53 µm fraction (24-46%) in all cropping patterns and depths (Table 3). Among the cropping patterns, Vegetables- short Fallow -*Aman* and *Boro*-Fallow-Fallow cropping patterns had relatively higher mass proportion for >53 µm fraction (65-73 and 52-60%, respectively) compared to the *Boro*-Fallow-*Aman*, *Boro*-Fallow-*Aman*-Mustard and *Boro*-*Aus*-*Aman*. Consequently, for the <53 µm fraction, relatively higher mass proportion was observed in the later three cropping patterns compared to the prior mentioned two patterns. Considering the depth, top soils had relatively more mass in > 53 µm fraction than the <53 µm compared to the sub-soils for all the cropping patterns.

#### *3.3.2. Contents of organic carbon and total nitrogen*

It was observed that OC, N contents and C:N ratios of soils significantly varied among the different cropping patterns and soil depths (Table 4, Figure 2). Organic C content varied in the range of 0.63-2.60% considering all the cropping patterns and soil depth (Table 4). Considering the fractions, the distribution of OC was higher in <53 µm fractions (0.93-2.6%) than the >53 µm fraction (0.63-2.41%) irrespective to all the cropping patterns. Among the cropping patterns, *Boro*-Fallow-Fallow contained the highest OC followed by *Boro*-Fallow-*Aman*-Mustard, Vegetables-short Fallow-*Aman*, *Boro*-Fallow-*Aman*, *Boro*-*Aus*-*Aman* regardless the depths. Overall, OC content was significantly higher in top soils (1.10-2.60%) in both fractions than the sub-soils (0.63-2.05%) of the corresponding cropping patterns. Total N content ranged from 0.04-0.313% in all the cropping patterns and soil depth (Table 4). In general, N content followed more or less similar trend among the cropping patterns and soil depths.

The C:N ratio ranged from 0.80-15.2 in all the cropping patterns at two depths (Figure 2). Considering the fractions, >53 µm had significantly wider C:N ratio (10.8-15.7) than the respective <53 µm fraction (8.0-12.8) in all cropping patterns and depth. Overall, the trend in cropping patterns followed as: Vegetables-short Fallow-*Aman* > *Boro*-Fallow-*Aman*-Mustard >*Boro*-*Aus*-*Aman* > *Boro*-Fallow-*Aman* > *Boro*-Fallow-Fallow. Overall, the ratios were higher in sub-soil depth than the top soil.

Table 1. General characteristics of soils (<2 mm) from different rice-based cropping patterns at depths (0-15 and 15-30 cm)

| Cropping pattern | Depth (cm) | pH (1:5 $H_2O$) | EC ($\mu Scm^{-1}$) (1:5 $H_2O$) | Sand (%) | Slit (%) | Clay (%) | Texture |
|---|---|---|---|---|---|---|---|
| *Boro*- Fallow- Fallow | 0-15 | 5.5 | 145 | 55 | 33 | 13 | Sandy Loam |
| | 15-30 | 5.5 | 146 | 50 | 34 | 17 | |
| *Boro*- Fallow-*Aman* | 0-15 | 5.3 | 142 | 52 | 34 | 15 | |
| | 15-30 | 5.4 | 141 | 53 | 33 | 15 | |
| *Boro*-Fallow-*Aman*-Mustard | 0-15 | 5.6 | 142 | 54 | 34 | 13 | |
| | 15-30 | 5.5 | 145 | 52 | 33 | 16 | |
| *Boro*-*Aus*-*Aman* | 0-15 | 5.8 | 162 | 50 | 33 | 18 | |
| | 15-30 | 5.7 | 161 | 50 | 31 | 20 | |
| Vegetables- short Fallow -*Aman* | 0-15 | 5.7 | 155 | 56 | 31 | 14 | |
| | 15-30 | 5.5 | 155 | 54 | 31 | 16 | |

All parameters representing mean value of two replicates, except particle size analysis. Standard error (S.E.) for pH =0-0.13 and EC =1-5

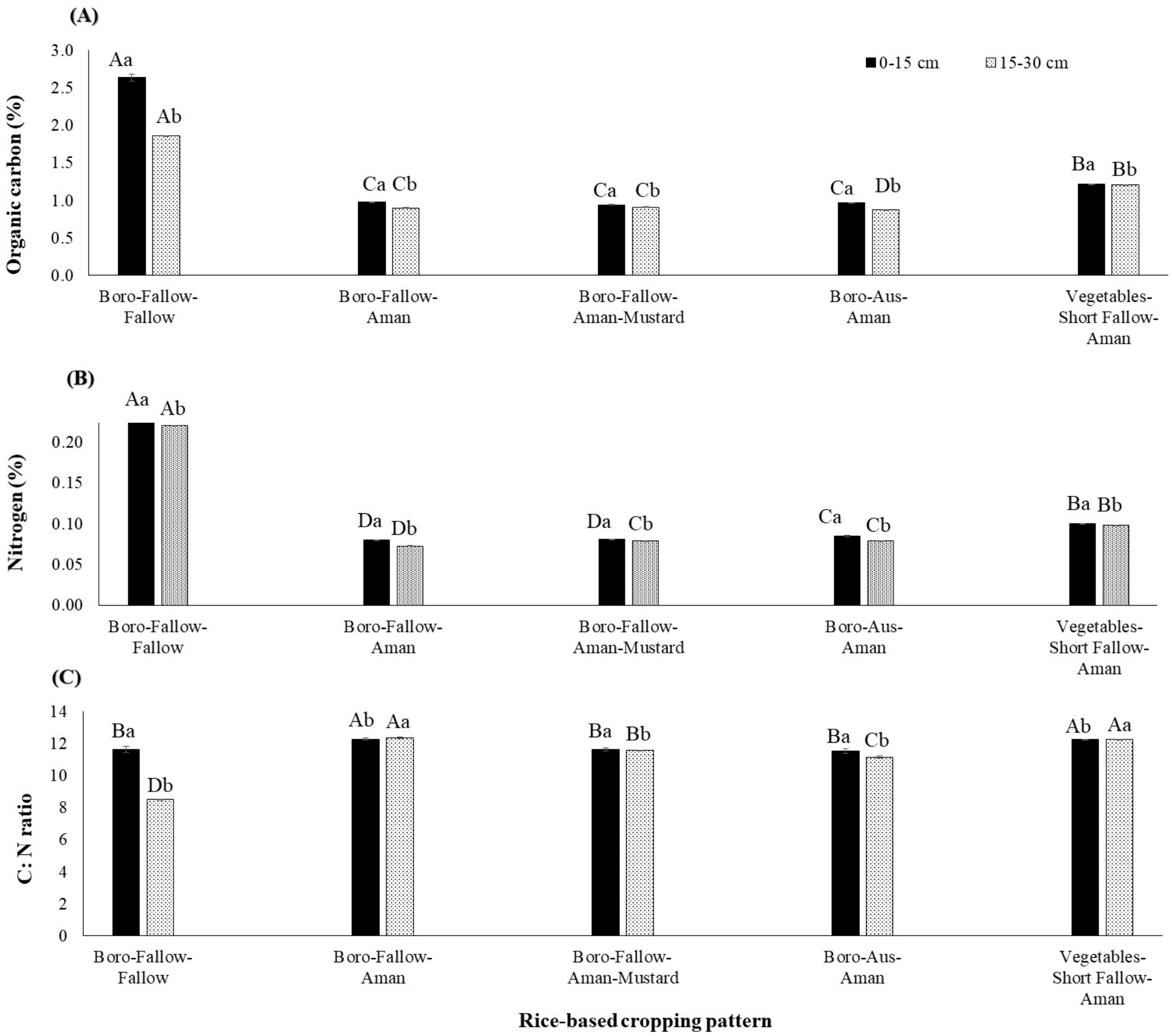


Figure 1. Amount of organic carbon (A), nitrogen (B) and C:N ratio of top (0-15 cm) and sub soils (15-30 cm) from different rice-based cropping patterns. Vertical bars represent standard error of three replicates. Substantial variations between cropping patterns at corresponding depth are indicated by uppercase letters, while substantial differences between depths at corresponding cropping patterns are shown by lowercase letters.

**Table 2.** Major nutrient elements in bulk soils (<2 mm) from different rice-based cropping patterns at two depths (0-15 and 15-30 cm)

| Cropping pattern | Depth (cm) | P (ppm) | K (meq 100 $g^{-1}$) | S (ppm) |
|---|---|---|---|---|
| *Boro*- Fallow- Fallow | 0-15 | $16.9^{Da}$ | $0.197^{Ba}$ | $8^{Db}$ |
| | 15-30 | $8.9^{Eb}$ | $0.124^{Bb}$ | $9^{Ca}$ |
| *Boro*- Fallow-*Aman* | 0-15 | $29.8^{Aa}$ | $0.081^{Da}$ | $12^{Ca}$ |
| | 15-30 | $12.5^{Bb}$ | $0.071^{Cb}$ | $4^{Eb}$ |
| *Boro*-Fallow-*Aman*-Mustard | 0-15 | $20.4^{Ca}$ | $0.123^{Ca}$ | $16^{Aa}$ |
| | 15-30 | $12.2^{Cb}$ | $0.093^{BCb}$ | $7^{Db}$ |
| *Boro-Aus-Aman* | 0-15 | $7.2^{Eb}$ | $0.386^{Aa}$ | $4^{Eb}$ |
| | 15-30 | $17.5^{Aa}$ | $0.124^{Bb}$ | $18^{Aa}$ |
| Vegetables- short Fallow -*Aman* | 0-15 | $21.4^{Ba}$ | $0.122^{Cb}$ | $13^{Ba}$ |
| | 15-30 | $12.0^{Db}$ | $0.497^{Aa}$ | $12^{Bb}$ |

All parameters representing mean value of two replicates. Standard error (S.E.) for phosphorus (P)= 0.01-0.26, potassium (K) =0.0-00.40 and Sulphur (S)=0.00-0.50. Substantial variations between cropping patterns at corresponding depth are indicated by uppercase letters, while substantial differences between depths at corresponding cropping patterns are shown by lowercase letters.

**Table 3.** Proportion (% of the initial) of mass in physical fractions (>53 and <53 μm) of soils from different rice-based cropping patterns at two depths (0-15 and 15-30 cm)

| Cropping Pattern | Depth (cm) | Mass (% of initial) | | Total recovery (%) |
|---|---|---|---|---|
| | | > 53 μm | < 53 μm | |
| *Boro*- Fallow- Fallow | 0-15 | 60 | 39 | 99 |
| | 15-30 | 52 | 31 | 83 |
| *Boro*- Fallow-*Aman* | 0-15 | 54 | 45 | 100 |
| | 15-30 | 54 | 46 | 99 |
| *Boro*-Fallow-*Aman*-Mustard | 0-15 | 58 | 42 | 100 |
| | 15-30 | 49 | 35 | 84 |
| *Boro-Aus-Aman* | 0-15 | 60 | 40 | 100 |
| | 15-30 | 31 | 43 | 73 |
| Vegetables- short Fallow -*Aman* | 0-15 | 73 | 24 | 97 |
| | 15-30 | 65 | 35 | 99 |

Data presented here are the mean value of three replications. Standard error of mass: >53 μm= 0.06-2.49 and <53 μm=0.04-1.60

**Table 4.** Mean values (n=3) of organic carbon (OC) and nitrogen (N) in physical fractions (<53 and >53 μm) of soils from different rice-based cropping patterns at two depths (0-15 and 15-30 cm)

| Cropping Pattern | Depth (cm) | OC (%) | | N (%) | |
|---|---|---|---|---|---|
| | | <53 μm | >53 μm | <53 μm | >53 μm |
| *Boro*- Fallow- Fallow | 0-15 | $2.60^{Aa}$ | $2.41^{Ab}$ | $0.313^{Aa}$ | $0.223^{Ab}$ |
| | 15-30 | $1.71^{Bb}$ | $1.85^{Aa}$ | $0.161^{Bb}$ | $0.168^{Aa}$ |
| *Boro*- Fallow-*Aman* | 0-15 | $2.41^{Ba}$ | $1.15^{Cb}$ | $0.233^{Ba}$ | $0.106^{Cb}$ |
| | 15-30 | $2.05^{Aa}$ | $0.78^{Bb}$ | $0.200^{Aa}$ | $0.063^{Bb}$ |
| *Boro*-Fallow-*Aman*-Mustard | 0-15 | $1.67^{Da}$ | $1.30^{Bb}$ | $0.148^{Ea}$ | $0.112^{BCb}$ |
| | 15-30 | $1.30^{Ca}$ | $0.74^{Cb}$ | $0.116^{Ca}$ | $0.049^{Db}$ |
| *Boro-Aus-Aman* | 0-15 | $1.44^{Ea}$ | $1.10^{Db}$ | $0.180^{Ca}$ | $0.095^{Db}$ |
| | 15-30 | $1.00^{Da}$ | $0.75^{Cb}$ | $0.089^{Da}$ | $0.055^{Cb}$ |
| Vegetables- short Fallow -*Aman* | 0-15 | $1.71^{Ca}$ | $1.30^{Bb}$ | $0.159^{Da}$ | $0.120^{Bb}$ |
| | 15-30 | $0.93^{Ea}$ | $0.63^{Db}$ | $0.073^{Ea}$ | $0.040^{Eb}$ |

Standard error (S.E.) for OC: >53 μm =0.001-0.027; <53 μm= 0.001-0.005 and N: <53 μm =0.001-0.311; >53 μm= 0.001-0.007. Substantial variations between cropping patterns at corresponding fraction sizes for every depth are indicated by uppercase letters, while substantial differences between fractions at corresponding cropping patterns and depth are shown by lowercase letters.

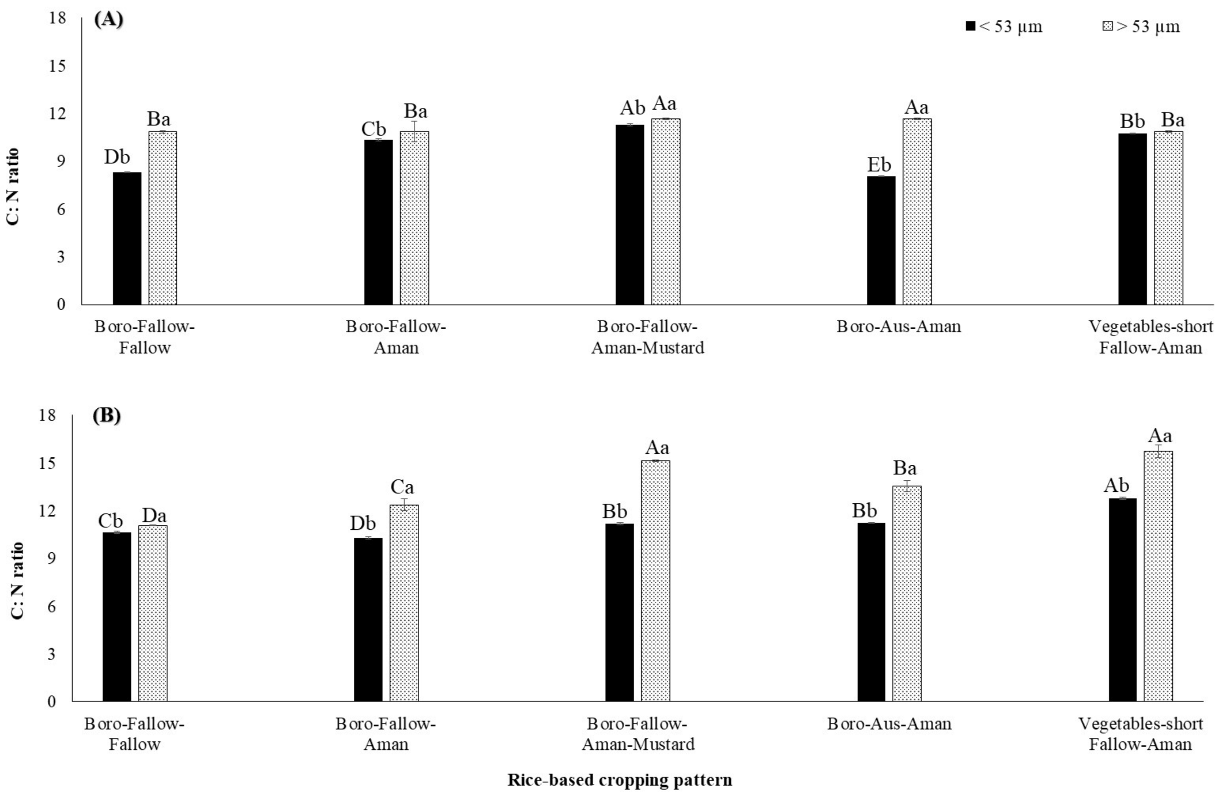


**Figure 2.** Mean values (n=3) of C:N ratio in physical fractions (< 53 and > 53 µm) of soils from different rice-based cropping patterns at two depths (0-15 and 15-30 cm). Vertical bars represent standard error of three replicates. Substantial variations between cropping patterns at corresponding fraction sizes for every depth are indicated by uppercase letters, while substantial differences between fractions at corresponding cropping patterns and depth are shown by lowercase letters.

## 4. Discussion

### 4.1. Effect of cropping pattern and depth on bulk soil carbon and nutrient contents

The highest OC and N contents in bulk soils were observed in *Boro*-Fallow-Fallow among the cropping patterns. This could be attributed to the above biomass and fine root density of natural grasses in fallow land grown after *Boro* cultivation every year (Fu et al., 2010, Xiangrong et al., 2010). This indicates that fallow land with naturally grown grasses is more beneficial to surface OC content than cultivated cropland (Jin et al., 2014). Moreover, less number of tillage was applied in this field which could also aid to less disturbance of the soil and slow OM decomposition, resulting higher OC accumulation (Lugo and Brown, 1993). Considering the depth, top soils contained more OC and N than the sub-soil irrespective to cropping patterns, which is in line with the accepted fact that top soil can receive continuous crop residue from decaying plants and their roots compared to the sub-soil (Merante et al., 2017; Poeplau et al., 2015). The C:N ratio significantly varied among the cropping patterns which could be explained by the difference in composition of crop residues which were added from patterns with different vegetation cover (Kamkar et al., 2014).

The major nutrient contents studied in this experiment also varied among the cropping patterns and depth. It is observed that different nutrient elements varied differently among the cropping patterns, with few inconsistencies in the trend. As for example, P content followed the trend of *Boro*-Fallow-*Aman* > Vegetables- short Fallow -*Aman* > *Boro*-Fallow-*Aman*-Mustard > *Boro*-*Aus*-*Aman* > *Boro*-Fallow-Fallow, K concentration followed as- *Boro*-*Aus*-*Aman* > *Boro*-Fallow-Fallow >*Boro*-Fallow-*Aman*-Mustard > Vegetables- short Fallow -*Aman*, S values followed as- *Boro*-Fallow-*Aman*-Mustard > Vegetables- short Fallow-*Aman* > *Boro*-Fallow-*Aman* > *Boro*-Fallow-Fallow in the surface soil. Since these soil samples were collected from the farmer owned natural field conditions, inconsistency in some results should be considered. However, in general, relatively higher nutrient concentration was found in the cropping patterns with a greater number of crops compared to the patterns including fallow period. This could be related to the amount of externally applied chemical fertilizers (and organic amendments) to the crops cultivated per year in the cropping patterns (Yousaf et al., 2017). Nayak et al. (2012) reported that application of recommended dose of N–P–K either through organic fertilization or through inorganic fertilizer had effect on OC, N and other nutrient contents in soils.

### 4.2. Effect of cropping pattern and depth on soil organic carbon sequestration

The physical fractionation separated into- i) sand and particulate organic matter (>53 µm): (POM, labile OM) and ii) silt + clay along with their associated (stable) OM (<53 µm); mineral associated organic matter (MOM) (Cambardella and Elliot, 1992).

In all cases, mass of POM fractions was more abundant than MOM fractions, which indicates the presence of more labile/active source of OM in the soil. POM fractions were characterized by the narrower C:N ratio compared to the MOM fractions in all the soils from the cropping patterns and depths. This suggests a more advanced stage of decomposition of OM in the MOM fractions (John et al., 2005). Generally, the C:N ratio in soils decreases with depth (Rumpel and Kögel-Knabner, 2011), but in this study the ratio did not follow this trend. This C:N ratio trend in the sub soil could be because of the deficit of microbial decomposition (Schrumpf et al., 2013).

Interestingly, the rice-based patterns with two- or three-times rice in a year, *i.e.*, *Boro*-Fallow-*Aman*, *Boro*-Fallow-*Aman*-Mustard and *Boro*-*Aus*-*Aman* had higher proportion of MOM fractions than the Vegetables-short Fallow-*Aman* and *Boro*-Fallow-Fallow cropping patterns. This indicates the possibility of potential distribution of more stable OM in the paddy soils from their total OM. This corresponds to the probable higher OC sequestration potential of paddy soils than the other upland crop field (Pan et al., 2010). This was also parallel to the higher MOM associated OC (stable) in all the soils irrespective to all the cropping patterns compared to the POM associated OC (labile). However, higher MOM associated OC in *Boro*-Fallow-Fallow pattern in top soil is contradictory to the overall findings. Nevertheless, the persistent higher stable OC in the other rice-based cropping patterns still suggesting C sequestration potential of paddy soils.

Wu (2011) found that OM decomposition is diminished in lowland rice fields, possibly as a result of severely reduced circumstances (Watanabe, 1984). This indicates that OC formation in paddy ecosystems is faster and more dramatic than in other arable ecosystems. Additionally, the rate of decomposition decreases in submerged settings due to the absence of oxygen for microbial activity (Jenkinson, 1988). An incomplete decomposition of organic materials and decreased humification of OM under submerged conditions, resulting in net accumulation of OM in paddy soils as also reported by Benbi and Brar (2009) and Sahrawat (2004). Moreover, a characteristic redox gradient is created in soil profiles by water management tailored to paddy specifics. The highest potentials were continuously observed near the roots' surface, most likely as a result of atmospheric oxygen diffusing via shallow water or oxygenated water seeping into the upper soil layer (Doran et al., 2006; Schmidt et al., 2011). Planting upland crops after paddy farming results in longer-lasting oxygen conditions. The dynamics of the organic and mineral soil constituents may be impacted by management-induced changes to the oxic and anoxic states of paddy soil (Cheng et al., 2009). The inconsistent or indefinite differences of OC storage potential among the different rice-based cropping pattern, including longer/shorter Fallow, single/double/triple rice, dry land crop etc. could be explained with this management induced erratic redox gradient in the soils throughout the year.

Considering the depth, top soils had more POM fraction than the MOM compared to the sub-soils for all the cropping patterns and the OC was higher in the top soil fractions than the sub-soil. This suggests that although the sub-soil contains low OC content than top, still it possesses the capacity of sequestering OC via possible strong mineral-OC association mechanisms (Datta et al., 2010).

Overall, all the rice-based cropping patterns studied here had noticeable proportion of stable OC than labile which again indicates the capacity of paddy soils in sequestering OC in soils (Yeasmin et al., 2022). However, this capacity can be influenced the crop included in the pattern and their management system. Since the major nutrient contents were related to the number of crops in the pattern and the external chemical fertilizer application, farmers should practice more balanced fertilization in the field.

## 5. Conclusion

The OC, N and other studied macronutrients (P, K, S) contents of soils significantly varied among the different cropping patterns and soil depths. Organic C content varied in the range of 0.63-2.60%; and among the cropping patterns, *Boro*-Fallow-Fallow contained the highest OC followed by, *Boro*-Fallow-*Aman*-Mustard, Vegetables-short Fallow-*Aman*, *Boro*-Fallow-*Aman*, *Boro*-*Aus*-*Aman* regardless the depth. Organic C content was significantly higher in top soils (1.10-2.60%) in both fractions than the sub-soils (0.63-2.05%) of the corresponding cropping patterns. Total N content ranged from 0.04-0.313% and N trend was more or less similar to OC among different cropping patterns. The highest OC and N in *Boro*-Fallow-Fallow attributes to the contribution of the above biomass and fine root density of natural grasses in fallow land grown after *Boro* cultivation, and also related to the relatively reduced tillage operation. Concentration of different nutrients ranged in between 7.2-29.8 ppm, 0.071-0497 meq 100 $g^{-1}$ and 4-18 ppm for P, K and S, respectively. Overall, relatively higher nutrient concentration was found in the cropping patterns with a greater number of crops compared to the patterns including fallow period. Considering the soil fractions, POM fraction (> 53 µm) was more abundant (up to 73 %) than the MOM fraction (<53 µm) (up to 46 %) in all cropping patterns and relatively more prominent in top soil than sub-soil. The OC content was higher in MOM fractions (0.93-2.6 %) than the POM fractions (0.63-2.41 %) in all cropping patterns with significantly higher in top soil than the sub soil. In general, higher OC content was observed in the cropping patterns consisting fallow period(s) than the intensive cropping patterns with a greater number of crops. However, all the rice based cropping patterns showed possibility of potential C sequestration in different degrees by showing higher OC content in stable OM (MOM), presumably protected through mineral OM association. This potential could be more effective through proper land and crop managements, including wise crop selection in cropping pattern, maintaining seasonal fallow, reduced tillage, balanced nutrient management etc.

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## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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