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# Impact of land use on carbon sequestration potential of soils in Agroecological Zone-9 of Bangladesh

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ABSTRACT

This study aimed to ascertain the effect of land uses (cropland, orchard, grassland, and fallow) on soil organic carbon (OC) pools in two depths (0–10 and 40–50 cm). Particulate organic matter (POM) (>53 µm) and mineral associated OM (MOM) (<53 µm) pools were physically separated from bulk soils and analyzed for OC and nitrogen (N) analysis. For both soil depths, the soil from grassland showed considerably higher OC (0.96-1.47%) and N (0.084-0.095%) values than the other land uses. In surface depth, the lowest OC was found in cropland soil (0.83%) and in sub-surface, it was in fallow land soil (0.75%), whereas the orchard soil had moderate OC in both depths. Depth showed significant differences in OC distribution. Surface soils had higher OC than the sub-surface soils which can be explained by the continuous addition of organic residues (crop/leaf/dried grasses) on the top soil. The distribution of POM and MOM fractions among the soils of different land uses were different. Interestingly, cropland and orchard soils had higher MOM-OC (MOC) than POM-OC (POC) in comparison to the relatively less disturbed grassland and fallow land soils. The amount of OC and N in OM pools was significantly different among the land uses in both depths. In surface depth, cropland soil showed the lowest POC content whereas the orchard and fallow land soils showed relatively higher. The MOC content was highest in fallow land (2.73%), lowest in orchard (1.30%) and cropland had moderate amount. In sub-surface depth, amount of OC was higher than surface soils and the trend of OC distribution between POM and MOM was different. Grassland soil had the highest OC (2.89-3.10%) for both fractions, followed by cropland > orchard > fallow. These findings showed that in cropland disturbance in soil could aid in depleting OC only from the most labile POM pool keeping the OC almost intact in stable MOM pool. Less disturbance in native soil condition such as grassland does not always benefit in enhancing/maintaining OC, rather it depends on the quality and quantity of OM added in the soils from the vegetation cover.

**Keywords:** Land use, soil management, soil organic matter, stable organic matter, tillage

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# 1 Introduction

Global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide ($CO_2$). Soil carbon (C) sequestration, or the process of absorbing and storing atmospheric $CO_2$ in soil for an extended period of time, is one possibility for reducing the increase in $CO_2$ concentrations in the atmosphere (Kiem and Kogel-Knabner, 2002). About 53% of the C on Earth is stored in soil, making it the greatest C reservoir. However, land use and management have a significant impact on whether the soils will operate as a sink or a source of $CO_2$. Soil disturbance and C dynamics are greatly influenced by land use and vegetation type. Conversion of grassland/forest to crop land, typically lead to decline of soil organic C (OC) (Guo and Gifford, 2002). With increasing population, crop intensification is increased everywhere to fulfill their food demand. As for example, many of the single rice cropped land is using for double or triple cropping with rice year-round or combination of other crops in Bangladesh. This intensive cropping pattern could be exhaustive for the soil or on the other hand, C buildup is possible if the land managed wisely, e.g., growing leguminous or other restorative crops or keeping land fallow for a season, crop residue incorporation etc. Typically, the main source of soil OC is plant biomass. Biomass gets integrated into OC as it breaks down. While some soil OC degrades rapidly and is known as labile OC, which primarily contributes to the cycling of soil and plant nutrition, stable OC decomposes slowly over hundreds to thousands of years (Eusterhues et al., 2003). The primary stabilization mechanisms that prevent the stable OC from breaking down also help to sequester C. Compared to stable OC, labile OC is probably more responsive to land use and management (Leifeld and Kogel-Knabner, 2005).

In Bangladesh, preserving and enhancing soil OC storage has become a crucial issue for feeding an increased population and also reducing greenhouse gas emissions. Soil OC storage, i.e., C sequestration is essential to improve soil quality, increase agronomic productivity and use efficiency of inputs like fertilizers and water, thus helps to maintain the capacity of soil to perform its production and environmental functions on a sustainable basis. However, our national level studies have dealt with mostly the effect of external application of OC, i.e., organic matter (OM) amendment to soil (Iqbal et al., 2014). However, to practice an effective need based OM management, it is essential to know the current status of C in our soils under present land use systems. Furthermore, most of the Bangladeshi research currently in existence on the effects of land use has either ignored soil variability or concentrated on changes in total soil OC (Alam et al., 2016; Hossain, 2014; Islam et al., 2016). It seems that treating soil OC as a single, homogeneous pool ignores the variation in relative abundances and possibility for multiple (stabilized and labile) OC pools as a result of land use and management. Therefore, this study aimed to look at the effect of existing land use types on soil C sequestration potential of selected area of agroecological zone (AEZ)-9 of Bangladesh.

# 2 Materials and Methods

## 2.1 Site selection and soil sampling

Non-calcareous dark-grey floodplain soil was selected for this study which is one of the most abundant soil types for AEZ-9. Soil samples were collected from Bangladesh Agricultural University, Mymensingh. Four land use types, i.e., cropland, orchard, grass land, and fallow were selected to represent the existing land use of the area. Three sampling sites per land uses, thus total 12 sites (3 per land use × 4 land uses) were selected for soil sampling. Each site represents as a field replication, thus there were three replications per land use types. All the sites were in closer distance to ensure similar soil type, topography and climate condition. Rice had been cultivated in the croplands, and mango fruit (*Mangifera indica*) trees were grown in orchard for about 15 years. The grasslands were covered with naturally grown deep rooted native grasses for over 10 years, and fallow land was left uncultivated and covered with naturally regenerated grasses for over 5 years. Arable land was flood irrigated, conventional tillage, and typical fertilization, while orchards were managed only by pre-plowing, very rare irrigation, and annual fertilizer and manure applications. Grasslands and fallow lands were left untouched. Soil core samples was collected at a depth of 0-10 and 40-50 cm from three points of each site. Additionally, samples were taken from the same points with auger from each site and then bulked separately for each land use type. The composite soil samples were dried at room temperature, crushed, mixed thoroughly, sieved with a 2 mm sieve and preserved in plastic container.

## 2.2 Physical fractionation of soils

Bulk soils were fractionated into particulate (labile) OM (POM: >53 µm) and mineral associated (stable) OM (MOM: <53 µm) based on the methodology developed by Cambardella and Elliott (1992) with slight modification (Yeasmin et al., 2020).

## 2.3 Soil analyses

Bulk soil samples were analyzed for particle size, texture, pH, EC, carbonate, total organic carbon (TOC) and nitrogen (N). Soil fractions i.e., particulate and mineral associate were analyzed for OC and N. Organic carbon in the bulk soil and soil fractions was determined as total organic carbon (TOC), particulate organic carbon (POC) and mineral organic carbon (MOC) respectively, using the wet oxidation method of Walkley and Black (1934). The Kjeldahl method of Bremner (1960) was used to determine total N.

### 2.4 Statistical analysis

Analysis of variance was done to determine the impact of depth and land use on the total soil and fractionated OC pools using the software program IBM SPSS 21.0.

## 3 Results and Discussion

### 3.1 General soil characteristics

Non-calcareous dark grey flood plain soil was the type of soil used for all four land uses. Soils from all land uses at both depths were non-saline (EC 48-181 µS $cm^{-1}$) and with a pH between 7.26 and 7.94 (Table 1). Both depths of the examined soils from various land uses had comparable textures., i.e., siltloam; which is expected since the soil type was similar. Increase of the clay percent in the sub-surface soil was evident in all land use types (Table 1). The C:N ratio ranges between 10.7-17.0 and varies between land uses. These variations in C:N ratios among land uses may be related to differing plant covers and may reflect variations in the quality of plant residues entering the soil OM pool (Islam et al., 2016; Yimer et al., 2007). The fallow land sub-surface soils have the highest ratio while the cultivated surface soils have the narrowest ratio. This shows that cultivated (disturbed) soils have higher rates of mineralization and oxidation of organic materials. Since orchard soil receives less disturbance annually than cropland's soils, which are farmed three times for rice, the C:N ratio of orchard surface soils was substantially greater (11.2) than cropland. The ratio was relatively wider in the sub-surface soils in all land use types. This wider ratio could be could be due to higher microbial processing since denser microorganisms is expected in sub-surface soils in comparison to the disturbed surface soils (Schrumpf et al., 2013).

### 3.2 Effect of land use

#### 3.2.1 Bulk soil

Total OC in bulk soils ranges from 0.80 to 1.47% (Fig. 1a) and was significantly different in different land uses at both depths. In surface depth, grassland soil had the highest OC (1.47%) which was followed by orchard > fallow > cropland. When it comes to the addition of OC to the surface soil, this pattern is consistent with the contribution of the land use systems. This suggests that uncultivated grassland is better in sequestering surface OC than orchard/tree plantations, fallow ground, or farmland that has been intentionally cultivated. This is consistent with the findings of numerous earlier investigations (Jin et al., 2014). For instance, Lugo and Brown (1993) discovered that tropical grasslands could store more OC than the surrounding forests; Tate et al. (2000) reported that OC storage in the total profile was 13% higher in a grassland than in a forest and crop land; and a review by Conant et al. (2001) found that roughly 70% of the studies under evaluation showed an increase in OC following the conversion of native rain forests to grasslands; Guo and Gifford (2002) suggested that OC stocks may be larger under natural grassland than under natural forest.

In sub-surface depth, amount of OC was lower than the surface in all land use types (Fig. 1a). Again, the highest amount was in grassland soil (0.96%) which was followed by the cropland > orchard > fallow. Lower C in deep soil can be explained by the decrease of OM content with increasing depth (Wynn et al., 2005). Deep rooted native grass species could contribute to this highest amount of OC in this subsurface grassland soil. In case of cropland, three times paddy rice cultivation requires puddling and ploughing which involves incorporation of rice stump in the sub-surface zone that could results in higher OC in this depth than orchard and fallow land. On the other hand, mango tree's roots and shallow rooted poorly grown grasses are not adding too much to the sub-surface OC. The total N varied between 0.05 and 0.134% (Fig. 1b), and it was essentially identical to the OC across all land uses and at both depths.

#### 3.2.2 Soil physical fractions

Sand and POM (>53 µm) were separated by physical fractionation from silt and clay and their associated OM (<53 µm), or MOM (Cambardella and Elliott, 1992; Jagadamma and Lal, 2010). The MOM fractions were always more abundant than POM on a mass basis (Fig. 2) and did not vary too much with increasing the depth (not shown here). This could be explained by the siltloam texture of the soils of all land uses. This soil texture has more silt + clay percent compared to sand. The highest POM fractions were found in fallow land soil, which was followed by grassland, orchards, and crops. This trend is totally opposite for MOM fraction: cropland > orchard > grassland > fallow.

In surface depth, the POM fraction associated OC (POC) percent was highest (2.25%) in orchard and fallow land and was lowest in cropland soils (1.02%) (Table 2). On the other hand, a contrasting pattern was seen in the MOM fraction associated OC (MOC)

**Table 1.** General characteristics of soils (< 2 mm) from four land use types at two depths

| Land use | Depth (cm) | pH† | EC (μS $cm^{-1}$) | Sand (%) | Slit (%) | Clay (%) | C:N |
|---|---|---|---|---|---|---|---|
| Cropland | 0-10 | 7.35 | 48 | 37 | 54 | 9 | 10.7 |
| | 40-50 | 7.39 | 52 | 35 | 53 | 12 | 13.8 |
| Orchard | 0-10 | 7.94 | 181 | 39 | 52 | 9 | 11.2 |
| | 40-50 | 7.82 | 174 | 35 | 48 | 17 | 14.6 |
| Grassland | 0-10 | 7.27 | 111 | 35 | 56 | 9 | 10.9 |
| | 40-50 | 7.26 | 106 | 30 | 60 | 10 | 11.5 |
| Fallow | 0-10 | 7.33 | 142 | 39 | 52 | 9 | 11.3 |
| | 40-50 | 7.36 | 146 | 36 | 53 | 11 | 17.0 |

† 1:5 $H_2O$; EC = electrical conductivity; All parameters representing mean value of two replicates, except particle size analysis. Standard error (S.E.) for pH = 0-0.12, EC = 1-4.5 and C:N = 0-0.003

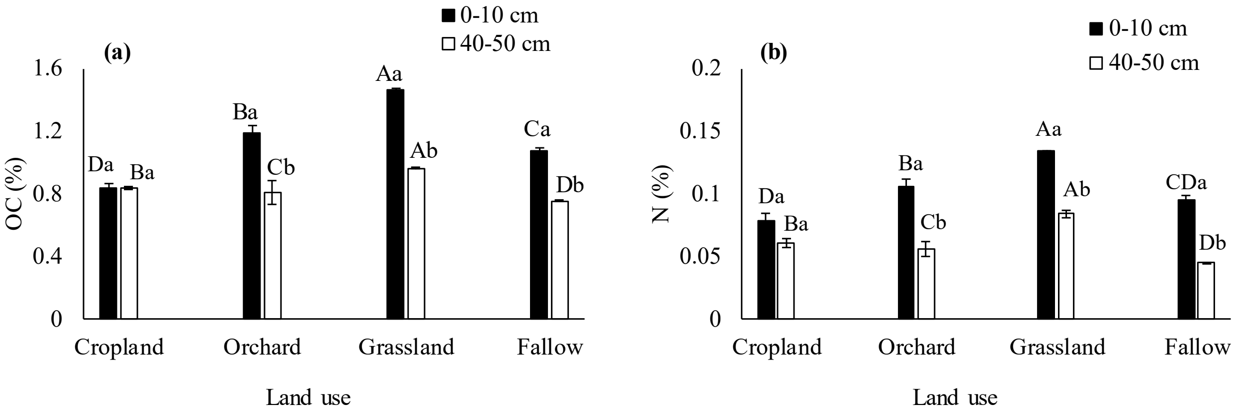


**Figure 1.** Amount of total organic carbon (OC) (a) and nitrogen (N) (b) of bulk soils under different land uses at two depths. Vertical bars represent standard error of two replicates. Uppercase letters indicate significant differences (p <0.05) among land uses at corresponding depth and lowercase letters indicate significant differences between depths of each land use

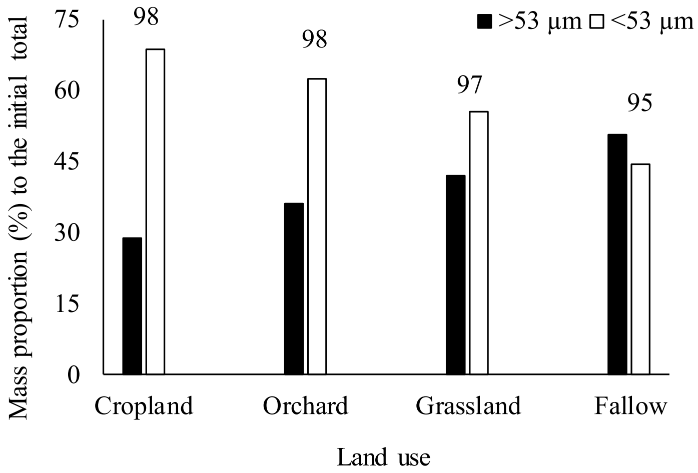


**Figure 2.** Mass proportion of the physical fractions to the initial total soil used in fractionation for different land uses without considering depth. The values on the top of the columns of each land use represent the total mass recovery of the fractionation process

**Table 2.** Mean values (n=3) of organic carbon (OC) and nitrogen (N) and C:N ratio in physical fractions of soils from four land use types at two depths

| Land use | Depth (cm) | OC (%) | | N (%) | | C:N | |
|---|---|---|---|---|---|---|---|
| | | >53 µm | <53 µm | >53 µm | <53 µm | >53 µm | <53 µm |
| Cropland | 0-10 | 1.02 C | 1.90 B | 0.05 C | 0.10 B | 20.4 | 19.2 |
| | 40-50 | 2.53 B | 2.72 B | 0.10 A | 0.12 B | 25.9 | 22.5 |
| Orchard | 0-10 | 2.25 A | 1.30 C | 0.11 A | 0.07 C | 20.1 | 18 |
| | 40-50 | 2.33 C | 2.52 C | 0.08 B | 0.08 C | 30.6 | 30 |
| Grassland | 0-10 | 1.84 B | 1.98 B | 0.09 B | 0.14 A | 20.7 | 13.8 |
| | 40-50 | 2.89 A | 3.10 A | 0.11 A | 0.15 A | 27.5 | 21.3 |
| Fallow | 0-10 | 2.24 A | 2.73 A | 0.11 A | 0.14 A | 20 | 19.5 |
| | 40-50 | 2.04 D | 2.22 D | 0.07 B | 0.08 C | 31.4 | 27.3 |

Standard error (S.E.) for OC =0.01-0.09 and N =0-0.03. Uppercase letters indicate significant differences ($p < 0.05$) among land uses at corresponding depth and fraction size

percent, which was largest in fallow land (2.73%) and lowest in orchards (1.30%). The lowest POC may be explained by the rapid breakdown of POM in cropland due to intensive farming practices, whilst greatest POC may be caused by the buildup of tree leaves and dead grass masses in orchard and fallow land, respectively. Even though the farmland soil's overall OC content was lower than that of other systems, the OC is primarily distributed to the MOM fractions. This may indicate that quick POM breakdown is the cause of the reduced OC in disturbed soil. The more labile parts of the POC pool undergo microbial breakdown, and the remaining parts transform into a more stable form of OM (Paul, 1984). The C:N ratio for the POM fractions ranges from 20 to 20.7, which is also true for these surface soils, whereas the ratio for the MOM fractions is smaller (13.8 to 19.5) (Table 2). Since this OC is anticipated to be heavily processed by microbes, it has been noted that the more stable OC has a narrow C:N ratio (Baisden et al., 2002).

In sub-surface depth, the OC percent was higher (2.04-3.10%) than the surface soils and the trend of OC distribution between labile and stable OC was quite opposite (Table 2). Here, for both POM and MOM fractions, grassland soil had the highest OC% (2.89-3.10) followed by cropland > orchard > fallow. The POC trend could be again described by contribution of the deep-rooted native grass species in adding more OM compared to the other systems. Interestingly, in deep soils, both the grassland and cropland soils also had higher MOC than others. If we consider native grassland as non-disturbed soil, then it suggests that although the depletion of total OC in cropland soil was observed, the MOC pool was increased (Álvaro-Fuentes et al., 2008; Cambardella and Elliott, 1992). The overall C:N ratios for both fractions were higher (21.3-30.6) compared to the surface soils and the POM fractions had wider than the MOM fractions as expected (Table 2).

### 3.3 Effect of depth

The results revealed (Table 1 and Table 2) that depth has significant impact on OC distribution in soil profile. Surface bulk soils had more total OC than the subsurface soils due to the continuous crop residue and other source of organic residues in cropland and orchard/grassland/fallow land, respectively. Although sub-surface soils contained lower total OC in all land use systems, the amount of OC amount in the both POM and MOM fractions were higher compared to the corresponding surface soils. Additionally, the higher amount of OC and narrower C:N ratio of MOM fractions than POM in sub-surface soils suggests the capacity of deep soil for sequestering OC via possible strong mineral-OC association mechanisms.

## 4 Conclusion

Based on this study it may concludes that instead of bulk soil's total OC, separated OC pools are the best indicator for OC status in terms of showing the soil's capability for C storage/sequestration. Although OC is depleted during cultivation, this does not always mean that stable OC is also depleted. Increasing OC storage does not necessarily benefit from less disturbed native soils. It mostly depends on the vegetation cover, and the amount and type of organic residues added to the soil. The ability to sequester OC is greater in sub-surface soils than in surface soils. Thus, there is a great possibility to enhance/maintain OC in on-calcareous dark-grey floodplain soil of Mymensingh, Bangladesh with careful management, such as consistent residue addition, minimal tillage, and balanced fertilization, even though it is heavily cultivated land.

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## Conflict of Interest

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

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