Effects of land use/land cover on aggregate fractions, aggregate stability, and aggregate-associated organic carbon in a montane ecosystem

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Abstract

This study investigated the effects of land use/land cover (LULC) on aggregate fractions, aggregate stability, and aggregate-associated organic carbon (AAOC) in a montane ecosystem of Bhutan. The soil aggregate samples were collected from the genetic 'A' horizon and were wet sieved into large macroaggregates (> 2.0 mm), small macroaggregates (0.25-2.0 mm), microaggregates (0.053-0.25 mm), and mineral fraction (< 0.053 mm). The AAOC of each aggregate fraction was determined to assess their role in soil aggregation. Under all LULC types, the large macroaggregates accounted for 86 to 93% of the total aggregates except under dry land (64%) and paddy land (35%). The aggregate stability under different LULC types decreased in the order of fir forest > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land. The AAOC of the large macroaggregates constituted for about 76-90% of the total AAOC under all LULC types except for dry land (65%) and paddy land (38%). Among the soil and other environmental variables, the AAOC of the small and large macroaggregates, LULC type, and AAOC of the microaggregates significantly influenced soil aggregate stability. The quadratic correlation of mean weight diameter (MWD) with the large macroaggregate AAOC depicted upper threshold of SOC to enhance soil aggregate stability.

Keywords: Aggregate stability; mean weight diameter; soil organic carbon; land cover; Himalaya

Extended Abstract

Introduction, scope and main objectives

Land use/land cover change is one of the main anthropogenic factors affecting the soil carbon dynamics and contributes to climate change. Unsustainable land use/management also contributes to rapid release of soil carbon into the atmosphere through destruction of soil structure. Soil organic carbon (SOC) is the key binding agent in soil aggregate formation. It reduces aggregate wettability and enhances mechanical strength of the soil aggregates. In turn, the stable aggregates physically protect SOC from microbial degradation and increase the SOC residence time in the soil (Six *et al.*, 2002; Daynes *et al.*, 2013; Stockmann *et al.*, 2013).

Soil aggregation may be variably influenced by diverse plant species under different land use/land cover (LULC) types due to difference in their organic matter (OM) inputs. As such, the variation of soil aggregate stability under different LULC types could be attributed to difference in aggregate-associated organic carbon (AAOC) of different aggregate fractions. However, the effects of LULC and other environmental variables on soil aggregate fractions, aggregate stability, and AAOC are not fully investigated and understood in the Himalayan region due to limited studies.

Therefore, this study was aimed to: (i) investigate the effects of LULC on aggregate-size distribution, aggregate stability, and AAOC; (ii) assess the relative importance of different soil and environmental variables on aggregate stability and AAOC; and (iii) examine the role of AAOC in aggregate stability in a montane ecosystem of Bhutan.

Methodology

The study was undertaken in western part of Bhutan (27°04.87' to 27°38.28' N and 89°14.03' to 89°35.82' E) with altitude ranging from 1769 m to 5520 m above mean sea level. The dominant LULC types at the site include mixed conifer (36%), blue pine (24%), broadleaf (8%), fir (5%), shrubland (14%), grassland (3%), dry land (rain-fed agriculture) (4%), paddy land (2%), and orchard (1%). Soil samples were collected from the genetic 'A' horizon of the predetermined sampling sites using conditioned Latin Hypercube sampling design (Minasny and McBratney, 2006). Bulk soil samples were analyzed to determine the C concentration, pH, and particle sizes, while air-dried soil aggregate samples (3-5 mm) were sieved through a nest of sieves with different sieve sizes (i.e. 2.0, 0.25, and 0.053 mm) to determine the aggregate size distribution and aggregate stability. Based on the proportion of different aggregate fractions, the mean weight diameter (MWD), an index for aggregate stability, was calculated according to Kemper and Rosenau (1986). The AAOC of each aggregate fraction was analyzed using the isotopic ratio mass spectrometry (IRMS). One way analysis of variance (ANOVA) followed by the *post-hoc* Tukey-Kramer HSD test ($\alpha = 0.05$) was performed to investigate the significance of differences of aggregate-size distribution, aggregate stability, and AAOC of different aggregate fractions under different LULC types. Further, the relative importance of various soil and environmental factors affecting aggregate stability and AAOC of different aggregate fractions was assessed by using the "importance" function in the random forest package in *R* following Akpa *et al.* (2014).

Results

The large macroaggregates (> 2.0 mm) constituted the highest proportion (> 86%) of the total aggregates followed by the mineral fraction (< 0.053 mm), small macroaggregates (0.25-2.0 mm), and microaggregates (0.053-0.25 mm) under all LULC types. The proportion of large macroaggregates was significantly higher ($p < 0.05$) than other aggregate fractions under all LULC types except under paddy land. Among different LULC types, the proportion of large macroaggregates under all forest types, shrubland, and grassland was significantly higher ($p < 0.05$) than under different agricultural lands. However, the proportion of small macroaggregates, microaggregates, and mineral fraction was significantly higher ($p < 0.05$) under paddy land and dry land than under other LULC types except for the small macroaggregates and microaggregates under dry land from fir, broadleaf, grassland, and orchard.

The aggregate stability, as indicated by the MWD, decreased in the order of fir > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land. The high value of MWD is indicative of stronger soil aggregation and more aggregate stability. Although MWD varied among LULC types, only the MWD under dry land and paddy land was significantly lower ($p < 0.05$) than under other LULC types. Similar to the variation of MWD, the AAOC in the large macroaggregates under different LULC types decreased in the order of fir > broadleaf > mixed conifer > grassland > shrubland > blue pine > orchard > dry land > paddy land. While the large macroaggregate AAOC under fir, broadleaf, and mixed conifer was significantly higher ($p < 0.05$) than under dry land and paddy land, the AAOC of the small macroaggregates and microaggregates was significantly higher ($p < 0.05$) under dry land and paddy land than under other LULC types except for dry land from orchard, grassland, broadleaf, and fir.

In terms of the relative importance, the small and large macroaggregates, LULC type, and AAOC of the microaggregates were found to be the most important variables affecting aggregate stability. And for the

AAOC of the different aggregate fractions, LULC type, bulk density, cation exchange capacity (CEC), and pH were the most important variables. When MWD was plotted with AAOC of the large macroaggreagate, a quadratic relationship was depicted indicating the upper threshold of SOC to enhance the aggregate stability.

Discussion

The relatively high proportion of large macroaggregates (>2.0 mm) under different forest types, shrubland, grassland, and orchard could be attributed to their high OM input, slow decomposition, organo-mineral complexation, and less soil disturbance compared to dry land and paddy land. Further, the hydrophobicity in forest soils might have also protected and enhanced soil aggregation to form larger macroaggregates by increasing cohesiveness and decreasing dispersion of soil aggregates (Bronick and Lal, 2005). On the contrary, the significantly high ($p < 0.05$) proportion of other aggregate fractions under dry land and paddy land could be due to disaggregation of large macroaggregates from cultivation (Kumari *et al.*, 2011) and low SOC content to bind and form large macroaggregates. The combination of large and small macroaggregates as macroaggregates (> 0.25 mm) in this study, accounted for 50 to 93% of the total aggregates which is similar to the results (54 to 80%) reported by Kumari *et al.* (2011).

The high aggregate stability under different forest types, shrubland, grassland, and orchard could be due to their high OM input from the aboveground biomass (Blanco-Canqui and Lal, 2004) which provides mulching effect and better habitat for soil meso- and micro-fauna and flora to improve soil aggregation. The hydrophobic property of the forest soils must have also enhanced the aggregate stability. Our result agrees with Shrestha *et al.* (2007), which reported higher aggregate stability under forest than under rain-fed upland and paddy land. Under different agricultural lands, orchard had significantly high ($p < 0.05$) aggregate stability than under dry land and paddy land and this could be attributed to good groundcover, extensive root system, high OM input, and limited soil disturbance under orchards. The significantly high ($p < 0.05$) aggregate stability under dry land compared to paddy land could be due to the former's close proximity to the farmhouse which receives relatively more organic manure than paddy land. Further, paddy land is subjected to deliberate flooding, plowing, and puddling resulting to destruction of soil structure and low aggregate stability.

The significantly higher ($p < 0.05$) AAOC in the large macroaggregates than in all other aggregate fractions across all LULC types could be because the large macroaggregates constituted for more than 90% of the total aggregate fraction except under dry land and paddy land. This is in line with the results reported by Kumari *et al.* (2011) and Huang *et al.* (2014) under different tillage and land use systems. The significantly high ($p < 0.05$) AAOC of the large macroaggregates under forest, shrubland, and grassland could be due to their high OM input, slow decomposition, and formation of organo-mineral complexes compared to other LULC types. The significant influence of AAOC of large and small macroaggregates and AAOC of microaggregates on aggregate stability further confirmed the important role of SOC in soil aggregation. However, the quadratic correlation of MWD with AAOC of the large macroaggregates indicates the upper threshold for SOC to enhance aggregate stability. This agrees with the result reported by Saha *et al.* (2011).

Conclusions

This study investigated the effects of LULC on aggregate stability and AAOC, and the latter's role in aggregate stability under a montane ecosystem of Bhutan. The aggregate-size distribution was dominated by the large macroaggregates under all LULC types except under dry land and paddy land. Similar to the proportion of large macroaggregates under different LULC types, the aggregate stability also decreased in the order of fir > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land indicating a strong influence of LULC types. The large macroaggregate AAOC constituted the bulk of the total SOC (>76%) under all LULC types except under dry land (65%) and paddy land (38%). The results showed that LULC and AAOC of different aggregate fractions have significant influence on soil aggregate stability. Likewise, the AAOC of different aggregate fractions greatly vary under different

LULC types indicating its strong influence. The quadratic correlation of aggregate stability (MWD) with AAOC of the large macroaggregates suggests an upper threshold for SOC to enhance aggregate stability. Overall, the results indicated a complex interrelation of aggregate stability and AAOC with LULC and other soil and environmental factors, and needs further investigation to better understand their intrinsic relationships particularly in a fragile and very dynamic landscape like in the Himalayas.

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