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Can vegetation types work as an indicator of soil organic carbon? An insight from native vegetations in Nepal

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ABSTRACT

Soil is the largest pool of carbon after the ocean. The assessment of soil organic carbon (SOC) stocks under different types of vegetations is critical for evidence-based implementation of soil carbon trading under different market mechanisms. Using data from 490 permanent soil sample plots with elevations ranging from 271 m to 3238 m above sea level, from three different watersheds in Nepal, this study aims to compare SOC under five different forest types and determine whether forest types could be indicator of SOC: *Shorea robusta*; mixed broadleaf; *Schima-Castanopsis*; pine; and *Rhododendron-Quercus* forests. In each vegetation type forests with dense canopies (≥70% canopy cover) have higher amounts of SOC than that of open canopy forests (<70% canopy cover). On average, with up to 30 cm soil depth, dense canopy *Rhododendron-Quercus* forest has the highest amount of SOC (14,136 g C/m^2), followed by dense canopy mixed broadleaf forest (12,576 g C/m^2). One-way analysis of variance (ANOVA) indicates significant differences in soil organic carbon (SOC) amounts across the five forest types (df = 485, F = 17.299, p = 0.000) and therefore forest types could be indicator of SOC. Moreover, within the similar altitudinal zone and topographic, edaphic and climatic environments: soils under the mixed species forests have higher amounts of SOC than that of single species dominated forests; and soils under forests with nitrogen fixing trees have a higher amount of SOC than those from other forests. Therefore, in addition to forest types these two conditions within the given vegetation types could work as sub-indicators of SOC. In comparison with global studies, all Nepalese forest types had much higher levels of SOC. Only two of the seven factors/indicators investigated (altitude and average age of dominant trees) were found to have significant impacts (r = 0.33 to 0.64) on SOC and only in the dense and sparse canopy pine forests. The reasons of not having any impacts of all other factors on SOC in different vegetation types have been discussed.

1. Introduction

Soil is the largest pool of carbon after the ocean, storing about 1580 Gt of organic carbon and 600 Gt of inorganic carbon in the top meter of soils (Post et al., 1982; Batjes, 1996; Luo et al., 2010; Stockmann et al., 2013). The pool of soil organic carbon (SOC), the generic term for the carbon held within soils that is primarily associated with the products of living organisms, is twice the size of the atmospheric carbon pool and three times the size of the vegetation biomass carbon pool (Luo et al., 2010).

At a global level, the conversion of forested lands to agriculture, including cultivation and pasture, has been linked to a soil carbon loss of about 136 Gt C since 1970 (Lal, 2004a). Murty et al. (2002) reviewed 109 global studies and found that the conversion of forest to agricultural land led to an average loss of approximately 22% of soil carbon while the transition from forest to pasture resulted in no overall change globally (despite reported changes ranging from −50% to +160%). Likewise, Guo and Gifford (2002), in a meta-analysis of 74 studies, suggested that land use changes from permanent forest to cropland resulted in the greatest loss of SOC.

Reversing this loss is possible, as globally SOC sequestration has the potential to mitigate 5–14% of total annual greenhouse gas emissions over the next 50–100 years (Chan et al., 2009). SOC sequestration has several other co-benefits, as it improves the productivity, profitability and sustainability of the soil system as a

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result of increasing plant nutrient content and water retention capacity. Hence, soil carbon sequestration is a highly desirable mitigation option that is synergistic with climate change adaptation, contributing to water and food security (Lal, 2004a; Lal et al., 2007).

In addition to reversing land use changes from croplands to forestland, reducing deforestation and degradation and the conservation and sustainable management of natural forests can enhance SOC. In order to achieve this goal, several forests management strategies have been practiced, including the establishment of protected areas, the involvement of armed forces and the establishment of new funds (White and Martin, 2002). Community forestry is also very popular in developing countries (Jodha, 1990; Malla et al., 2003; Dev et al., 2003) and there is a growing practise of handing over forests to local communities in these countries. At least 22% of the total forest area is community forestry in developing countries, compared with only three percent in developed countries (White and Martin, 2002). Sooner or later the forest management regimes in developing countries could be dominated by community forestry (Smith and Scherr, 2002). However, within community forests there are several types of forests and very little information about SOC dynamics, among them vegetation types. As vegetation type is an indicator for both the adoption of appropriate conservation strategies (Culmsee et al., 2014) and the quantity of SOC it could be used to design appropriate carbon projects and plans for community forests.

Nepal is a pioneering country in community forestry, with over 1.66 million ha (>28% of total forest land) of national forest managed by 17,808 Community Forest User Groups (CFUGs), and about one third of the total national population members of the CFUGs (DoF, 2012). Using data from 490 permanent soil sample plots from three watersheds and 105 community forests, which are REDD (Reducing Emissions from Deforestation and Forest Degradations) pilot areas, with elevations ranging from 271 m to 3238 m above sea level (asl), this study aims to: (1) compare SOC under five different forest types of Nepal which represent some of the dominant global forest types and determine whether forest types could be indicator of SOC; and (2) identify factors that determine the variation in SOC between and within the vegetation types. These benchmarked SOC databases will contribute to better (evidence-based) implementation of soil carbon trading under different market mechanisms and can be used to underpin community forestry guidelines and standards. Moreover, the identified indicators could provide useful insights for global researchers.

2. Forest carbon related pilot projects in Nepal

Among the different voluntary and mandatory marketing mechanisms, REDD is becoming very popular in reducing deforestation and forest degradation (Angelsen and MCneill, 2012) through the delivery of performance-based payments to forest managers in developing countries for the conservation and/or increase of forest carbon stocks. The Government of Nepal is implementing a range of REDD initiatives such as: the World Bank/Forest Carbon Partnership Facility supported REDD readiness activities; a new institutional body, the REDD Forestry and Climate Change Cell, has been created under the Ministry of Forest and Soil Conservation to coordinate and implement REDD activities; and the REDD Cell has prepared a REDD readiness proposal (Helvetas Swiss Inter-cooperation, 2011).

Pilot activities covering different aspects are underway, providing good lessons for Nepal's REDD readiness. About 105 community forest user groups (CFUGs) from three watersheds have been involved in REDD pilot projects over the past three years, funded by the Norwegian government's aid agency NORAD and jointly implemented by three renowned NGOs (International Centre for Integrated Mountain Development; Asia Network for Sustainable Agriculture and Bioresources; and the Federation of community Forestry Users, Nepal (Operational Guidelines of Forest Carbon Trust Fund, 2011). They have established 490 permanent soil sample plots in 105 community forests. This study presents soil sampling and analysis results from these plots.

3. Methodology

3.1. A brief overview of the study area

This study was carried out in 105 community forests, covering three watersheds with elevations ranging from 271 m to 3238 m asl. These sites are located in the central part of Nepal: (1) Kayerkhola watershed located at Chitwan district (271–1618 m asl); (2) Ludikhola watershed located at Gorkha district (418–1401 m asl); and Charnawati watershed located at Dolakha district (652–3238 m asl) (Fig. 1). They include five dominant vegetation types: *Shorea robusta* and *mixed broad leaf forests* at lower altitude; and *Schima-Castanopsis*, Pine and *Rhododendron-Quercus* forests in higher altitude sites. According to the IPCC (2006) the first two types fall under tropical moist forest, the third and fourth types under warm temperate moist forest and the last one under cool temperate moist forests. A brief discussion of these forest types is given in next section. These forests cover an area of 10,266 ha and provide benefits to 93,791 people from 15,380 households. These areas have diverse castes including *dalit* (untouchable group), ethnic groups and *Brahmin* and *Kshetri* (considered as upper caste) (Gellner, 2007). Similarly, livelihood options of the people living in these areas differ with altitude. The majority of these people are engaged in agriculture which is interdependent with forest resources.

3.2. A brief overview of the dominant forest types

3.2.1. Shorea robusta forest

S. robusta is a large tree up to 45 m in height and grows up to 1500 m asl, although its growth rate is very slow at higher altitudes. It is a deciduous, light demanding and slow growing tree, but it can grow faster at early stages under favourable conditions. Seedlings of this species are susceptible to dieback for 3–10 years under frost, drought and/or fire conditions. It is popular timber tree and in high demand for building houses (GoN, 2002; Jackson, 1994).

3.2.2. Mixed broadleaved trees other than Shorea robusta

Lagerstroemia parviflora, *Anogeissus latifolius*, *Dalbergia sissoo*, *Acacia catechu*, *Bauhinia purpurea* and members of the *Terminalia* species are the major species in this category. *L. parviflora* is a large, deciduous, light-demanding tree valuable for its timber, found up to 1200 m asl. *Terminalia* spp. (*T. chebula*, *T. alata* and *T. bellirica*) are light demanding tree species growing up to 1100 m asl. *A. latifolius* is a strong light demanding tree species, available up to 1700 m asl. *D. sissoo*, *A. catechu* and *B. purpurea* are nitrogen fixing deciduous tree species present up to 1500 m asl (Jackson, 1994).

3.2.3. Schima-Castanopsis forest

Schima wallichi is a large tree with moderately shade-tolerant character which is generally found between 900 and 2000 m asl. Three *Castanopsis* species are found in the study area, namely *Castanopsis indica* (found between 1200 and 2900 m asl), *Castanopsis hystrix* (found between 1000 and 2500 m asl) and *Castanopsis tribuloides* (found between 450 and 2300 m asl). These species are palatable and used as fodder (Jackson, 1994).

3.2.4. Pine forest

Pinus roxburghii (available from 900 to 1950 m asl), *Pinus walichiana* (available from 1800 to 3600 m asl), *Pinus patula* (available from 1500 to 2500 m asl) and *Tsuga Dumosa* (available from