Biomass turnover interactions with soil C sequestration among the land uses in the Western Ghats

Soil carbon (C) forms a major pool in global C cycle and is estimated to store 1500–2000 Pg of carbon in the upper 1 m soil layer[1]. Absolute amounts of C stored in the soil may vary considerably from one vegetation/land use type to another[2]. Atmospheric CO_2 assimilated by plants is added to soil via roots and litter, undergoes decomposition with time, and only a fraction of the total carbon added to the soil is actually sequestered. In general, the soil C is higher in the surface layers and decreases with depth[3,4]. The rate of C-sequestration depends on the net balance between C-inputs and C-losses per unit time[5]. The Western Ghats, a mountain range along the western coast of India, represent a range of flora and vegetation with natural forests co-existing with rather recently sprung up man-made plantations, and several other agricultural and horticultural ecosystems. The Western Ghats are considered as hotspots of biodiversity and are in the list of UNESCO world heritage sites. Over the last two decades, there are increasing number of reports on substantial shift in land uses in this region[6–8]. Land use change brings with it a number of biological changes in the above and below ground ecosystems. Soil C, a precursor of biological activity in the soil, also changes with land use type due to changes in biomass turnover, quantitatively and qualitatively. Increasing soil C sequestration is not only important as a strategy for halting climate change and global warming but also as a precursor of biological activity in soil which regulates many ecosystem services[9–11]. It is therefore important to quantify not only the change in land use but also the effect of this change on important associated processes. The carbon storage capacity of a soil under a land use system depends on the amount of biomass recycled, the management practices[12], soil type and climate. The Western Ghats in India provide a unique opportunity to take the cross sectional view of different man-made and natural land use systems in terms of their C storage capacities. The anthropogenic activities in and around the pristine forests might also lead to enhanced soil C oxidation and release of CO_2 to the atmosphere[13]. On one hand, CO_2 release events are likely to happen with the expansion of man-made plantations into the native forest lands. On the other hand, the establishment of perennial cropping systems on the degraded lands with marginal productivity might help in moving atmospheric CO_2 into soil sink. These changes have a critical role to play in climate change mitigation and adaptation assessments, and in devising strategies for the future with low C footprints.

A study was carried out on the relationship between biomass turnover and soil organic C stocks under various land use types at two sites – Sirsi and Koppa in the Western Ghats of Karnataka (Figure 1). Major land uses selected were: evergreen (EG) forest, semi-evergreen (SEG) forest, dry-deciduous (DD) forest, moist-deciduous (MD) forest, teak plantation, acacia plantation, areca plantation, coffee and tea plantation, rubber plantation and paddy crop land. Degraded (DEG) forests and barren lands were also included for comparison. The quantity of annual *in situ* biomass recycled in forests and other perennial land use systems was determined by quantifying the litter generated. In case of man-made systems, both *ex situ* (FYM, litter, green manure, etc.) and *in situ* biomass additions were accounted through farmer questionnaires as well as direct field observations/data collection. Soil samples were collected from freshly dug soil profiles near the litter sampling spots. Air-dried and sieved soil samples were analysed for soil organic C using modified Walkley-Black's wet oxidation method by keeping the soil-chromic acid mixture at 160°C for 30 min so as to achieve complete recovery. Simultaneously, observations were made for field bulk density and fine soil fractions (excluding gravel), and soil organic C stocks were estimated for 1 ha-m soil volume.

The quantity of biomass recycled in the form of litter, residues and amendments among different land use systems varied significantly depending on *in situ* turnover and *ex situ* additions (Figure 2). The semi-evergreen forest systems and areca plantations recorded high annual biomass turnover of >8.0 tonne ha^{-1} while, the evergreen, moist and dry deciduous forests recorded a turnover of 5.0 to 7.0 tonne ha^{-1}. Teak and acacia plantations also showed similar levels of biomass turnover. Among other commercial plantations – coffee, tea and rubber, 3.0–5.0 tonne ha^{-1} of biomass addition was recorded in the form of litter and organic manure. Paddy, a dominant agricultural crop in the region, showed a biomass turnover of 4.3 tonne ha^{-1} through litter, FYM and straw/stubble additions. Degradation of forests with anthropogenic activity was noticed in patches across all the forest types.

The soil organic C content was highest in natural forests amongst all land use systems ranging from 0.5% to 2.7%. Amongst forest systems, it was highest in semi-evergreen forests and decreased in the order: moist deciduous > evergreen > dry deciduous. The soil organic C was highest in the surface soil and decreased gradually with depth. Among the man-made land uses, agricultural and forestry plantations, the soil organic C content in the surface soil layer (0–0.2 m) was higher in coffee and tea plantations (around 2%), and was least in acacia plantations (1.3%). Rubber and teak plantations recorded around 1.2% of soil organic C in surface soils. The soils of coffee and tea plantations, at 40–60 cm depth, had >1.0% of soil organic C as compared to other plantations which stored less than 1%. In contrast, the barren lands with sparse vegetation could also record 0.6–0.8% soil organic C in the surface layers and it decreased further with depth. In paddy fields, the first two surface layers recorded more than 1% soil carbon (1.4% in 0–0.2 m and 1.2% in 0.2–0.4 m) and it decreased to 0.5–0.8% in deeper layers (pooled data is represented in Figure 3).

The soil organic C stocks, based on field bulk density (inclusive of gravel), ranged from 67 to 218 tonne ha^{-1}. The soils of least/undisturbed natural forests could store 195–220 tonne ha^{-1}, while man-made plantations such as teak, acacia and degraded forests could store in the range 120–132 tonne ha^{-1}. Meanwhile,

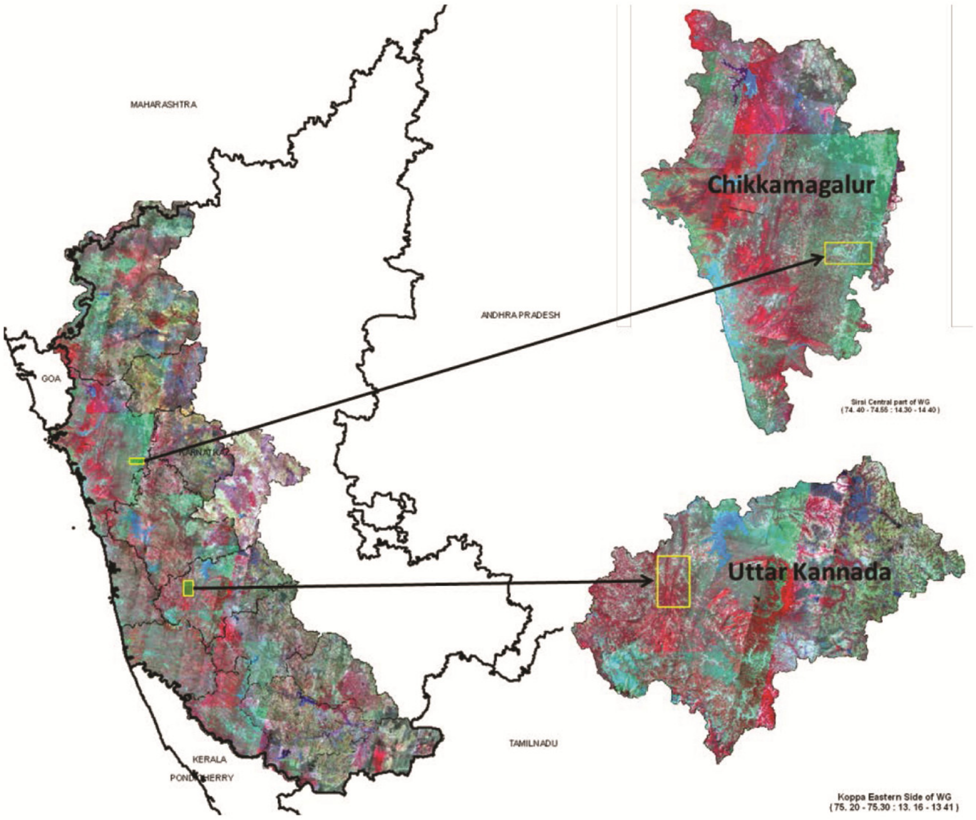

Figure 1. Location of the study sites in the Western Ghats of India.

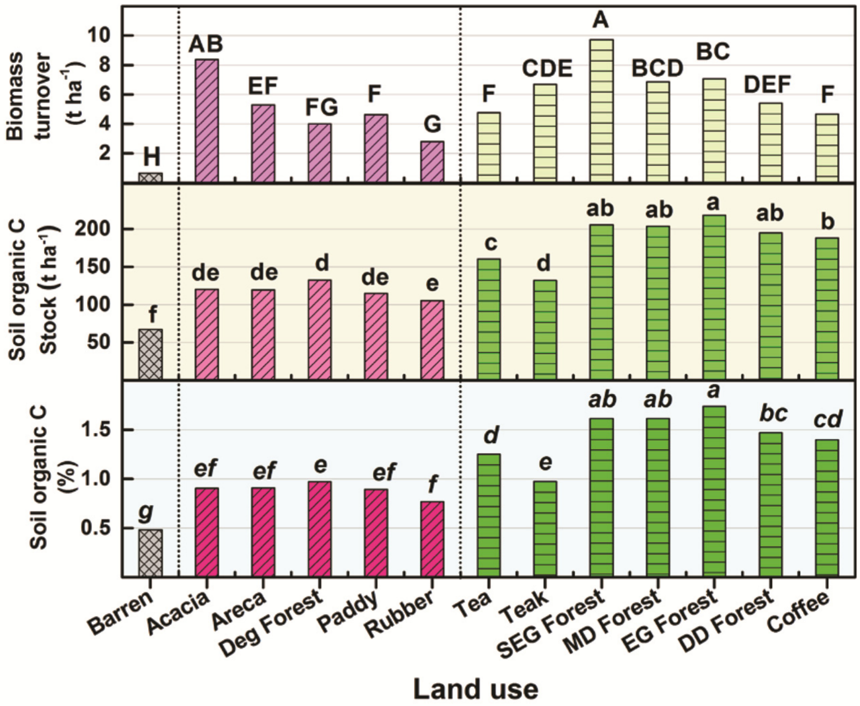

Figure 2. Effect of land use on soil organic carbon (C), soil organic C stock and biomass turnover under different land uses in the Western Ghats of India. Columns labelled with same letters are not significantly different at $P < 0.05$.

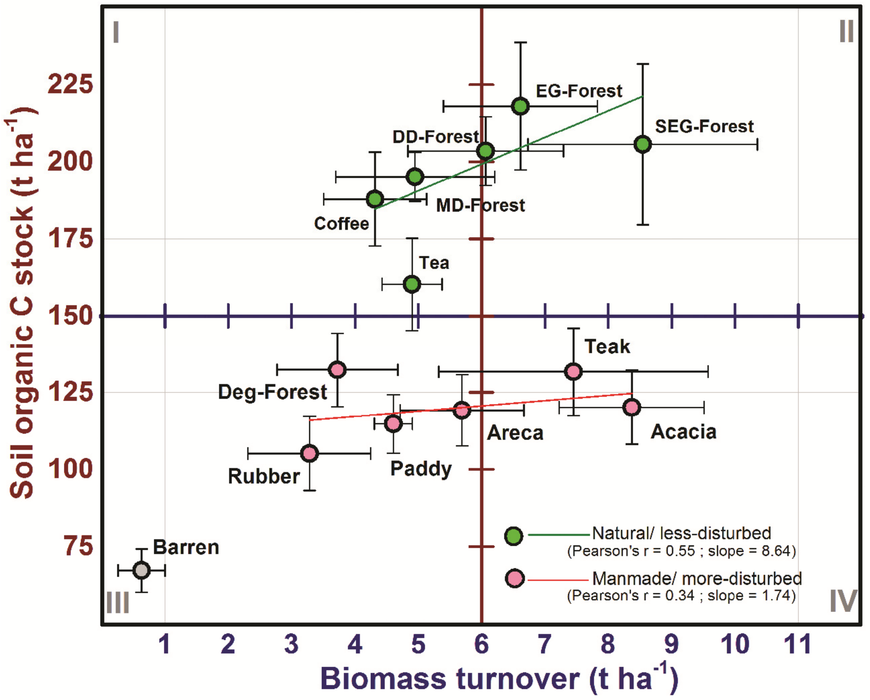

Figure 3. Relation between biomass turnover and soil organic C stock in major land uses in the Western Ghats.

coffee and tea plantations could still maintain 160–188 tonne of soil carbon as compared to paddy soils which stored about 110 tonne ha^{-1}. The soil organic C stocks for the fine soil volume (excluding gravel) ranged from 54 to 173 tonne ha^{-1}. Undisturbed natural forests could store higher amounts of organic C in soils compared to man-made systems (plantations/horticultural/agricultural). However, the degraded forests showed a significant drop in soil carbon and recorded only 110 tonne ha^{-1}, probably due to low biomass turnover. Teak plantations could maintain about 132 tonne ha^{-1} soil organic C. However, the acacia plantations, mostly present on degraded lands, recorded 120 tonne ha^{-1} soil organic C. An interesting observation was that the coffee plantations with shade from large trees recorded only slightly lesser soil organic C stocks (158 tonne ha^{-1}) than the natural forests. It was significantly higher compared to all other land use systems. The tea plantations existing along higher altitudes had about 131 tonne ha^{-1} of soil organic C. However, the existing paddy soils in the valley region recorded 101–106 tonne ha^{-1} soil organic C. Least soil C content was noticed in the barren lands having least vegetative cover amongst all land uses.

The soil C under a particular land use has its origin either from CO_2 assimilated by plants via photosynthesis or *ex situ* addition from external sources like manure/compost. The soil organic C is thus a direct function of biomass turnover[14], though the rate of biomass turnover might not relate directly to the rate of soil C sequestration, as evident in this study. Management intensity and quantity of organic matter has been noted to play an important role in decomposition and C sequestration in soil[15–17]. Different land uses studied, could be divided into two broad groups based on the relationship between biomass turnover and soil C sequestration (Figure 3). Group I included the land uses wherein biomass turnover resulted in soil organic C accumulation of 100–135 Mg ha^{-1}. This group was constituted by man-made/more disturbed land use systems (LUS). In these LUS, soil tillage, vegetation harvesting, logging and other management activities are involved. Another group formed (Group II) included natural or less disturbed land uses like dry deciduous (DD) forest, moist deciduous (MD) forest, evergreen (EG) forest, semi-evergreen (SEG) forest along with tea and coffee plantations. Both these groups had a linear relationship between biomass turnover and soil organic C. The peculiar characteristics of these relationships were that in Group II these were stronger (Pearson's $r = 0.55$) with higher slope (= 8.64) than in group I (Pearson's $r = 0.34$, slope = 1.74), indicating adverse effects of the intensive management on the organic carbon sequestration. Perhaps it is also possible that the quality of biomass might also be contributing to these relationships but it is outside the scope of this study. The changes in land use in Western Ghats from group I to group II land uses would result in substantial release of CO_2 and loss of soil stored organic C, which should be a serious concern for climate change researchers, in particular, and land use planners, in general. This relationship between biomass turnover and soil C sequestration could play an important role in determining sink-source potential of a land use for atmospheric CO_2. Exploiting this relationship could be very helpful in planning climate change mitigation projects as well as in managing landscapes for enhanced ecosystem services driven by increased soil C.

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