Soil and vegetation carbon pools in two community forests of Palpa district, Nepal

Y. Khanal[1], R. P. Sharma[2] and C. P. Upadhyaya[3]

Quantification of carbon in any vegetation and soil type is a basic step for evaluating the carbon sequestration potential of an ecosystem. For quantification, soil samples from varying depths (0–20, 20–40, 40–60, 60-80 and 80–100 cm) of each soil profile were collected for each sample plot laid out in Jarneldhara and Lipindevi Thulopakho Community Forests (CFs) of Palpa district. Individual trees in the sample plots of both CFs were measured. Biomass of standing trees, poles and saplings were estimated indirectly from diameter at breast height (dbh) and total height by using allometric relationships, while the biomass of grass, herb and litter were calculated directly from field measurements. Above-ground and below-ground (root) carbon pools in Jarneldhara CF were found to be 36.6 ± 3.4 t ha^{-1} and 10.5 ± 1.0 t ha^{-1} , respectively; while those on Lipindevi Thulopakho CF were 40.2 ± 4 and 11.4 ± 1.1 t ha^{-1} , respectively. Soil organic carbon pool in Jarneldhara and Lipindevi Thulopakho CF were 121.4 ± 7.4 and 94.6 ± 4.4 t ha^{-1} , respectively. This indicates that CFs have high potential to offset large portion of carbon emission through sequestration into both soil and vegetation, and act as a natural carbon sink.

Key words: Carbon pool, community forest, soil organic carbon, vegetation carbon, biomass

Forest plays a key role in the global and regional carbon (C) cycles, as they store large quantities of C in vegetation and soil, and exchange large quantities of C with atmosphere through photosynthesis and respiration. Forest acts as a source of atmospheric C when there is disturbance due to anthropogenic and natural causes and as a sink when re-growth occurs after disturbance, therefore, forest can be managed to alter the magnitude and direction of fluxes (Brown, *et al.,* 1996). The goal of reducing C source and increasing C sink can be achieved through effective protection and conservation of C pools in the existing forest.

The Kyoto protocol of the United Nations Framework Convention on Climate Change (UNFCCC) has recognized the role of forestry as a reliable carbon sequestration vehicle to reduce green house gas in the atmosphere. After the UNFCCC conference of parties in Bali, Indonesia during December, 2007, the debate and discussion on Reducing Emission from Deforestation and Forest Degradation (REDD) has emerged. This has created a good opportunity for studying C pools in forest ecosystem.

Vegetation and soil are viable sinks of atmospheric C and may significantly contribute to the mitigation of global climate change (Lal, 2004; Smith, 2004). Carbon sequestration in terrestrial ecosystems, especially into the soil, is a win-win strategy for developing countries, where land use change and agricultural intensification are most frequent (Lal, 2004). To quantify the sequestered C in forest ecosystem, temporal stocks of C under various forest types must be assessed. Estimating C pools in existing forests provides baseline data from which to project C sequestration over time (Shrestha and Singh, 2008).

Biological sequestration of CO_2 by forest has numerous benefits over other emission reduction strategies. First, it is considered the most cost-effective approach (e.g. Newell and Stavins, 2000; Stern, 2007; Banskota *et al.,* 2008). Second, managing

[1] Far-Western Regional Forest Directorate, Dhangadhi. Email: yajnamurti@hotmail.com
[2] Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Norway
[3] Institute of Forestry, Pokhara

forests in a sustainable way, especially in the tropical region, can substantially reduce C emission rate. For example, it was estimated that the global deforestation alone accounts for about 17.4% of the global greenhouse gas emission (IPCC, 2007). Third, terrestrial ecosystems have the potential to store large amount of carbon due to high global deforestation rate in the past (Upadhyay *et al.,* 2005). Thus, it seems that forest could be the most effective sink when forest is protected and managed in a sustainable way, and a huge amount of C is sequestered efficiently without requirement of large monetary investment.

Quantification of sequestered C in different forest types with different management regimes and soil profiles could be important for better planning of natural resources, and the making of good mitigation strategy for climate change effects. However, so far only a few studies on C sequestration have been carried out in Nepal (Shrestha and Singh, 2008). Most studies focused on carbon stocks in different land uses (e.g., Gautam, 2002; Shrestha and Singh, 2008). Similarly, few studies were focused only on organic carbon stocks in different forest soils of Nepal (e.g., Awasthi *et al.,* 2002; Shrestha *et al.,* 2004a; Sitaula *et al.,* 2004). Carbon sequestration potential of different forest types under different management regimes need to be explored. This study aims to quantify forest biomass, with both soil and vegetation C pools in two different CFs in a mid-hill region of Nepal.

Materials and methods

Study area

This study was carried out in Lipindevi Thulopakho and Jarneldhara community forests of Palpa district (Fig 1). Lipindevi Thulopakho CF is located in Tansen Municipality-13 whereas Jarneldhara CF is in Barangdi VDC Ward Number 3. The area of Lipindevi Thulopakho CF is 26.23 and that of Jarneldhara CF is 8.6 ha. They were handed over to the forest user communities in 1991 and 1994 A.D., respectively. Both CFs were situated on moderate to steep slopes with altitude ranging from 1100 – 1400 m above mean sea level. Jarneldhara CF mostly lies on northern aspect whereas Lipindevi Thulopakho CF lies on the north-eastern aspect. The soil type varies from sandy loam to clay loam and is mostly brown in colour. The average maximum and minimum temperature of the district was 23 ^{0}C and 14 ^{0}C with a mean annual rainfall of 1903 mm (DFO-Palpa, 2007). Lipindevi Thulopakho CF consists of scattered plantation of *Pinus roxburghii* along with natural *Schima-Castanopsis* forest whereas Jarneldhara CF mainly consists of natural *Schima-Castanopsis* forest.

According to forest users, the age of *Schima-Castanopsis* forest stands is about 10-15 years whereas *Pinus roxburghii* is 20-25 years. Average crown cover of the forest is about 40-60%. The major management activities undertaken in both CF were cleaning, bush land management, thinning, pruning and improvement felling. In addition to these, fire-lines were constructed in Lipindevi Thulopakho CF. Similarly, on some blocks of Lipindevi Thulopakho CF, up to three thinning operations have been carried out after the handing over of CF.

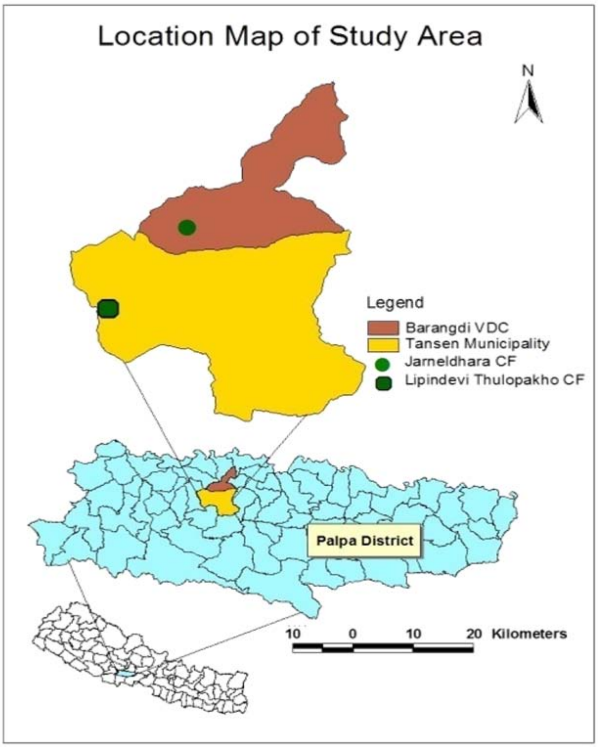

Fig 1: Study area in Palpa, Nepal

Data collection and analysis

Forest sampling and measurement

The studied CFs mainly consists of *Schima-Castanopsis* forest with varying tree size, density and species composition. In Lipindevi Thulopakho CF, there were also scattered plantations of *Pinus roxburghii*. So, in order to represent all variations, approximately 2-3% sample of forest area was selected subjectively from each community forest. Temporary plots were laid out in each selected forest type. Within the main plot with size 25 m x 20 m for trees {diameter at breast height (dbh) > 30 cm}, nested plots of size

10 m x 10 m for poles (dbh <10-30 cm), 5 m x 5 m for saplings (dbh 5-10 cm) were laid out (CFD, 2004). Similarly, five 1 m x 1 m plots within the main plots (four in four corners and one at centre) were also laid out for regeneration (dbh < 5 cm), grasses, herbs and litters.

The dbh and total height of all trees, poles and saplings above 5 cm dbh were measured. All herbaceous and woody vegetations (less than 5 cm dbh) inside the 1 m x 1 m plot were clipped and collected and the fresh weight of the samples were recorded and representative sub-samples of all woody, herbaceous plants and litters were taken to the laboratory for oven drying.

Biomass and carbon estimation

Based on the data of tree height and dbh measured for individual stands within the sample plot, total stem volume was calculated using the following relationship models (Sharma and Pukkala, 1990).

$$\ln(V) = a + b * \ln(dbh) + c * \ln(ht) \quad (1)$$

Where, V is the total stem volume with bark (m^3), *dbh* is the diameter at the breast height (*cm*), *ht* is total tree height (*m*), and *a, b*, and *c* are species specific model parameters. The species-specific parameter values of model (1) are presented in Table 1.

Table 1: Species-specific parameter estimates for model (1) (Sharma and Pukkala, 1990)

Tree species	a	b	c
Alder *(Alnus nepalensis)*	-2.7761	1.9006	0.9428
Chirpine *(Pinus roxburghii)*	-2.9770	1.9235	1.0019
Chilaune *(Schima wallichii)*	-2.7385	1.8155	1.0072
Miscellaneous in Hills	-2.3204	1.8507	0.8223

The total stem volume obtained from (1) was multiplied with species-specific dry wood density to get the oven dry weight of stem biomass. The biomass of branches, roots and leaves were assumed to be 45%, 46% and 11% of the stem biomass following Sharma (2003), which was later adopted by Shrestha and Singh (2008) for forest types identical to those in this study. Samples of undergrowth vegetation (tree species with dbh <5 cm, herbs, grasses and litter) were oven dried at a constant temperature of 70°C until the weights of the samples became constant (MacDicken, 1997) and the final constant weight was used as dry matter content. Dry biomass was converted to C content using an assumption that C content is approximately 43% of dry biomass (Negi *et al.,* 2003).

Sampling soil and estimating soil carbon content

A pit was made in the centre of each main plot with a maximum depth of 1 m or up to bedrock if it occurs at less than 1 m depth. If bedrock was present above 40 cm depth, the pit was dug in one corner of main plot. Soil samples were collected from different depths such as 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm for carbon content analysis. Similarly, metal core ring sampler (height 6 cm and inner diameter 4.8 cm) was used to collect samples for bulk density.

Soil Organic Carbon (SOC) content in the soil samples were estimated using Walkley and Black's wet oxidation method as described by Page *et al.* (1982). Soil pH was determined with pH electrode at soil/water ratio of 1:1 (w/w) (McLean, 1982). Soil bulk density was determined using soil core samples and stone correction was made as per Pearson *et al.* (2005). The corrected bulk density (g cm^{-3}) was used for the estimation of SOC density (t ha^{-1}) and SOC stock (Pearson *et al.,* 2005).

Bulk density (g cm^{-3}) denotes soil particles less than 2 mm diameter whereas coarse fragments include particles greater than 2 mm diameter. The oven dry mass and mass of coarse fragments were measured in gram (g) and the volume of the cores in cubic centimetre (cm^3). The density of rock fragments was assumed to be 2.65 g cm^{-3} (Pearson *et al.,* 2005).

Results and discussion

Vegetation carbon pool

Carbon pool in above-ground vegetation

Biomass of trees varies in different plots of same forest and within different forests due to variation in age and size of the trees, forest composition as well as tree density. The mean above-ground tree biomass in Lipindevi Thulopakho CF was found to be 89.7 ± 8.9 t ha^{-1} (Mean ± SE) which was higher than in Jarneldhara CF (82.6 ± 7.8 t ha^{-1}) (Table 2). Similarly, under-growth (live and dead) biomass of Lipindevi Thulopakho CF was found to be higher than that of Jarneldhara CF (Table 2), however, biomass difference was not significant (P>0.05). The share of under-growth biomass was only about 3%

of the total above-ground biomass. The under-growth biomass consisted mainly of litter biomass (by 65%) followed by biomass of regeneration (<5 cm dbh) trees and grass.

Table 2: Vegetation biomass (Mean ± SE, t ha^{-1})

CF	Above ground Tree	Under-growth (live &dead)	Below ground (root)
Jarneldhara	82.6 ± 7.8	2.5 ± 0.2	24.4 ± 2.3
Lipindevi Thulopakho	89.7 ± 8.9	3.9 ± 0.3	26.5 ± 2.6

Above-ground carbon pool (both tree and undergrowth) in Lipindevi Thulopakho CF (40.2 ± 4 t ha^{-1}) was found to be slightly higher than Jarneldhara CF (Table 3) due to larger sized trees which consequently have higher biomass values. Carbon pool in above-ground tree biomass was 33 times larger than the carbon pool in the under-growth biomass in Jarneldhara CF whereas it was 24 times larger in Lipindevi Thulopakho CF.

Various factors affect ecosystem carbon pool, including net primary productivity of plants and biomass decomposition. Net primary productivity differs according to vegetation types, age of the stand and the surrounding environment (Shrestha and Singh, 2008). This study suggests that larger vegetation carbon pool in Lipindevi Thulopakho CF than Jarneldhara CF is probably a function of the age and density of the stands and size of the trees. Shrestha and Singh (2008), Oli and Shrestha (2009), Shrestha (2009) and Baral *et al.* (2009) found more or less similar above-ground carbon pools in the mid-hill forests.

Table 3: Vegetation carbon (Mean ± SE, t ha^{-1})

CF	Above ground Tree	Under-growth (live &dead)	Below ground (root)
Jarneldhara	35.5 ± 3.4	1.1 ± 0.1	10.5 ± 1.0
Lipindevi Thulopakho	38.6± 3.9	1.6 ± 0.1	11.4 ± 1.1

Root carbon pool

Root biomass of two CFs is shown in Table 2. Root biomass of Lipindevi Thulopakho CF was found to be 26.45 ± 2.6 t ha^{-1} which was higher than that of Jarneldhara CF. Since the stem biomass of Lipindevi Thulopakho CF was higher than that of Jarneldhara CF, root biomass was also higher in Lipindevi Thulopakho CF.

Carbon pool in root biomass is shown in Table 3. Below-ground vegetation (root) carbon of Lipindevi Thulopakho CF was found to be 11.4 ± 1.1 t ha^{-1} which was slightly higher than Jarneldhara CF. Shrestha (2009) found similar root carbon pools in the community managed *Schima-Castanopsis* forests of Palpa district.

Soil carbon pool

Soil properties

The soil was sandy loam with varying proportions of clay. The mean pH of surface soil (0-20 cm depth) of Jarneldhara CF was found to be 4.3 while that of Lipindevi Thulopakho CF was 4.6. This suggests that all soil types were acidic a pattern noted by Schreier *et al.* (1995) for soils in the mid-hill watersheds.

Mean soil Bulk Density (BD) at different soil depth is shown in Fig 2. Mean BD value ranged from 0.88 g cm^{-3} to 1.07 g cm^{-3}. The mean BD increased slightly with increasing soil depth, but it did not differ significantly across layers of the soil profile ($p>0.05$). Shrestha *et al.* (2004b) in their study of similar forest types of Mardi watershed of Kaski, Nepal found relatively low BD with constant value of 0.7 g cm^{-3} in each layer of soil up to 40 cm depth. However, Shrestha and Singh (2008) found slightly higher BD values than those in this study in similar forest types of the mid-hills. Shrestha (2009) found similar bulk density values for *Schima-Castanopsis* forest in Palpa district.

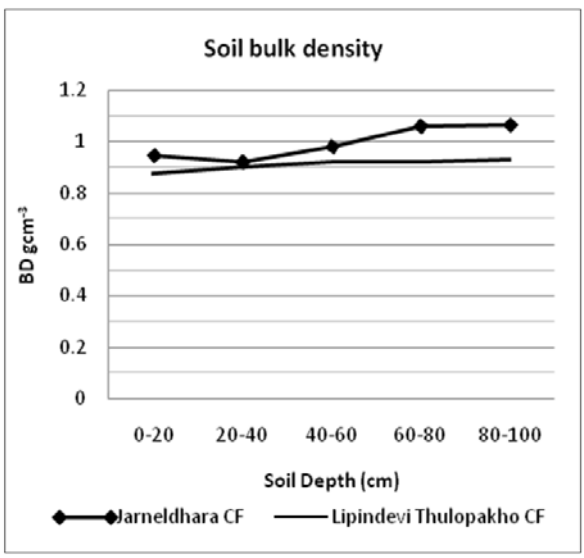

Fig 2: Soil bulk density in different soil depth

Soil organic carbon

Soil organic carbon pool in different soil profiles of each CF is shown in Table 4. Carbon content was found to be inversely related with increasing soil depth. Total mean carbon pool in the surface soil (0-20 cm) of Jarneldhara CF was found to be highest

(52.3 ± 3 t ha^{-1}); the lowest mean carbon pool was found in the deepest soil layer (80 cm - 100 cm) of Lipindevi Thulopakho CF (11.6 ± 0.5 t ha^{-1}). Carbon pool in each layer of soil profile differed significantly in both the CFs ($p<0.05$). Mean carbon pool in each soil layer of both the CFs also differed significantly ($p<0.05$). The results indicated that with increase in soil depth, bulk density was found to be in increasing trend while the SOC was found to be in decreasing trend. Almost similar results were obtained by Shrestha (2009).

Table 4: Carbon stock in different soil profile

Soil depth (cm)	Organic carbon (Mean ± SE, t ha^{-1}) Jarneldhara CF	Lipindevi Thulopakho CF
0-20	52.3 ± 3.0	31.6 ± 2.0
20-40	32.5 ± 1.8	21.8 ± 1.3
40-60	27.5 ± 1.4	19.2 ± 1.1
60-80	30.7 ± 0.2	13.9 ± 0.6
80-100	19.5 ± 2.7	11.6 ± 0.5

Amount of soil organic carbon depends upon various biotic and abiotic factors such as micro-climate, faunal diversity, land use and management. Leaf litter and root litter inputs play major roles in forest soil carbon dynamics (Shrestha and Singh, 2008). The soil organic carbon pool in this study was comparable to the soil organic carbon pool values reported by Shrestha and Singh (2008) and Shrestha (2009). Shrestha and Singh (2008) in their study (up to 70 cm soil depth) in the mid-hill watershed found SOC density as 103 t ha^{-1} whereas Shrestha (2009) found slightly higher SOC density as 131.43 t ha^{-1} (up to 1 m soil depth) than that found in this study (121.3 t ha^{-1} up to 1 m soil depth) for *Schima-Castanopsis* forest.

Total carbon pool

Total carbon pool in the two community forests is shown in Figure 3. The mean carbon pool (soil plus vegetation) in Jarneldhara CF was slightly higher than that in Lipindevi Thulopakho CF, although vegetation carbon pool was found to be higher in Lipindevi Thulopakho CF. Due to the presence of large-size trees in Lipindevi Thulopakho CF, there was higher vegetation carbon pool compared to Jarneldhara CF. Similarly, higher soil bulk density and organic carbon content in the soil of Jarneldhara CF has resulted in the higher soil carbon pool. Low soil carbon pool in Lipindevi Thulopakho CF was also attributed to the presence of Chir pine (*Pinus roxburghii*) trees which attract frequent forest fire due to longer decomposition period of their needles. Every year, there are occurrences of forest fires in Lipindevi Thulopakho CF which could be a possible reason for low carbon content in its soil. Shrestha and Singh (2008) also found lower soil carbon pool in pine mixed forest than in other forest types.

The mean of the total carbon pool from the two CFs is comparable to that of Shrestha and Singh (2008) and Shrestha (2009) in *Schima-Castanopsis* forest in the mid hills of Nepal. Shrestha and Singh (2008) reported total carbon pool (vegetation plus soil) of 139 t ha^{-1}, which was slightly lower than that found in this study, which might be due to the use of soil carbon up to 70 cm soil depth in their study, as well as the difference in site quality and stand structure.

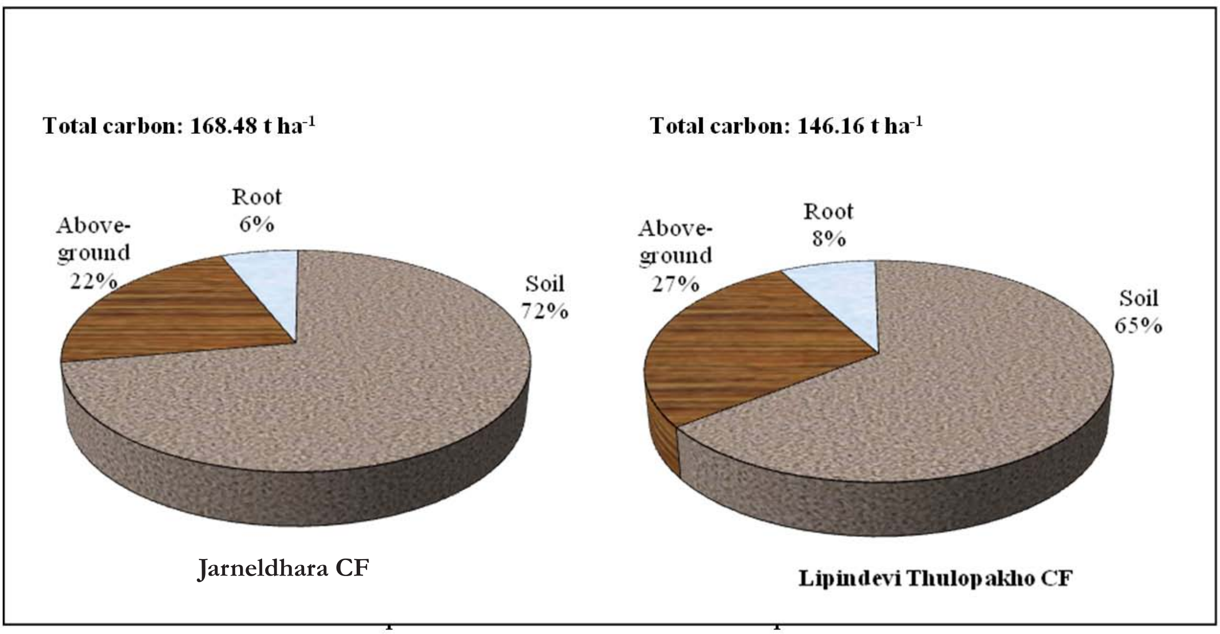

Fig 3 : Total carbon pool in two CFs

Similarly, Shrestha (2009) found total carbon pool as 178.5 t ha^{-1} which is slightly higher than the one uncovered in this study which might be due to different stand structures, site quality and intensities of management.

Conclusion

Vegetation carbon of Jarneldhara CF was found to be lower than that of Lipindevi Thulopakho CF due to the presence of smaller-size trees. The share of under-growth vegetation carbon was very low on total above-ground vegetation carbon. Soil organic carbon pool in 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm soil depths were found to be different. Similarly, soil organic carbon pool in each depth of the soil profile of the two CFs were also different. With the increase in soil depth, bulk density was found to have increased whereas C content was found to have decreased. Both soil organic carbon content and bulk density of Jarneldhara CF were higher than those of Lipindevi Thulopakho CF, and this contributed to the higher soil organic carbon stock in Jarneldhara CF. Total carbon stock in Jarneldhara CF was higher than in Lipindevi Thulopakho CF. On average, soil organic carbon contributed about 68 % in total carbon stock of community forests. However, this study has demonstrated that CFs help to offset a portion of the carbon emissions thereby contributing to climate change amelioration through the sequestration of atmospheric C to soil and vegetation and by acting as a natural carbon sink.

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