Carbon stocks in the Oak and Pine Forests in Salyan District, Nepal

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Forests play an important role in absorbing atmospheric carbon dioxide. Broadleaf Forests absorb more carbon as compared to the Pine Forests. Quantification of carbon in any vegetation and soil type is a basic step for evaluating the carbon sequestration potential of an ecosystem. To quantify the vegetation and soil carbon stocks in Oak and Pine Forests, above and below-ground biomass of both forests were estimated using stratified random sampling. Individual trees in the sample plots of both forest types were measured. Above-ground biomass of trees and saplings were estimated by using different models, while the biomass of grass, herb and litter were calculated directly from field measurements. To determine the soil carbon stock, soil samples from three depth levels (0–10 cm, 10–20 cm, and 20–30 cm) of each soil profile were collected for each sample plot laid out in both forest types. Total vegetation carbon stocks in Oak and Pine Forests were 90.37 and 24.82 Mg C ha^{-1}, respectively. Similarly, the soil carbon stocks in the Oak and Pine Forests were 60.82 and 46.12 Mg C ha^{-1}, respectively.

Key words: Carbon sequestration, soil organic carbon, vegetative biomass, forest types

Forests play an important role in the global carbon cycle. They can be both sources and sinks of carbon, depending on the specific management regime and activities (IPCC, 2000). The goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al.*, 1996). Forest vegetation and soils share almost 60% of the world's terrestrial carbon (Winjum *et al.*, 1992). Vegetation and soils are viable sinks of atmospheric carbon (C) and may significantly contribute to mitigation of global climate change (Bajracharya *et al.*, 1998; Lal, 2004). Estimating C stock under existing forest land, and their distribution within the soil profile, provides baseline data to enable us to project C sequestration over time (Shrestha and Singh, 2008). The carbon stock in a forest ecosystem can be broadly categorized into biotic (vegetative carbon) and pedologic (soil carbon) components. As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases, the atmospheric carbon dioxide (CO_2) is mitigated. About 43–50% of the dry biomass of trees is carbon (Malhi *et al.*, 2002; Negi *et al.*, 2003). Soil contains the major part of carbon in terrestrial ecosystems. Trees, both above and below-ground, continue to accumulate carbon until they reach maturity; at that point about half of the average tree's dry weight will be carbon (Anonymous, 2004). On the other hand, trees are long-lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, forests can capture and retain large amounts of carbon over long periods. These stocks are dynamic, depending upon various factors and processes operating in the systems, the most significant being land use, land-use changes, soil erosion, and deforestation (IPCC, 2000).

The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand (Van Noordwijk *et al.*, 1997). Estimates of the biomass contained within forests are critical aspects of determination of the carbon loss associated with a wide range of land use and land-cover change processes. In order to assess the impact of deforestation and re-growth rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for

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different forest types. The above-ground biomass and below-ground root biomass both need to be measured to enable better calculations of total forest carbon (Hamburg, 2000). 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. Most studies on carbon sequestration have focused on carbon stocks in different land uses (Gautam, 2002; Shrestha and Singh, 2008). Others have focused only on organic carbon stocks in different forest soils of Nepal (Awasthi *et al.*, 2002; Shrestha *et al.*, 2004; Sitaula *et al.*, 2004). Nepal is a member of Forest Carbon Partnership Facility (FCPF), an innovative approach to financing efforts to combat climate change. Nepal is now preparing REDD Strategy. Carbon sequestration potential of different forest types under different management regimes need to be explored. This study quantified forest biomass C stocks as well as soil C stocks in Oak and Pine Forests of Salyan District. It provides baseline data for implementation of the REDD+ mechanism.

Materials and methods

Study area

The study was carried out in Gerupani Oak (*Quercus* spp.) Forest and Pakhapani Pine (*Pinus roxburghii*) Forest of Salyan District, Nepal. Gerupani Oak Forest and Pakhapani Pine Forest are located in Kotmaula Village Development Committee (VDC) Ward Number 7 of Salyan District. The areas of the Gerupani Oak Forest and Pakhapani Pine Forest are 16.91 ha and 25.85 ha respectively. The Gerupani Oak Forest is natural while the Pakhapani Pine Forest is man-made planted in 1997. The Pakhapani Pine Forest has been handed over to the local community whereas the Gerupani Oak Forest has not been formally handed over to the local community so far but, this forest is conserved and managed by the local community since 1993. The Gerupani Oak Forest is situated on moderate to steep slopes with altitude ranging from 1,950–2,100 m above mean sea level whereas the Pakhapani Pine Forest is situated on moderate to steep slopes with altitude ranging from 1,800–1,960 m. The Gerupani Oak Forest mostly lies on northern aspect whereas the Pakhapani Pine Forest is situated on the southern aspect. The soil type varies from sandy-loam to clay-loam and is mostly brown in color. The management activities undertaken in both the forests are cleaning, thinning and pruning.

Data collection and analysis

Sampling design and biophysical measurement

Simple random sampling with 0.6% sampling intensity was used to measure the forest biomass and carbon. Both the forests were found to vary with tree sizes and density. Permanent circular nested plots were laid out in each selected forest type. Within the main plot, 8.92 m radius was taken to measure above-ground tree biomass {diameter at breast height (dbh) $\geq$ 5 cm}, nested-plots with 5.64 m radius for above-ground sapling biomass (1–5 cm dbh), 1 m radius for regeneration (less than 1 cm dbh) and 0.56 m radius for litter, herb, grass and soil organic carbon were laid out for collecting biophysical data (MFSC, 2010). The dbh and total height of all the trees $\geq$ 5 cm dbh were measured. Regeneration within 1 m radius plot were counted. All the litters, herbs and grasses inside the 0.56 m radius plot were clipped and collected, and the fresh weights of the samples were recorded and representative sub-samples were taken to the labouratory for oven drying.

Biomass and carbon pool estimation

Above-ground tree biomass and carbon

The total above-ground tree biomass was calculated using the equations (models) developed by Chave *et al.* (2005).

For moist forest stand,

$$AGTB = 0.0509 * \rho D^2 H \quad \text{.................. (i)}$$

where,
AGTB = above-ground tree biomass (kg);
ρ = wood specific gravity (g cm^{-3});
D = tree diameter at breast height (cm);
H = tree height (m).

Above-ground sapling biomass and carbon

The following regression model was used to calculate biomass of saplings:

$$\log(AGSB) = a + b \, \log(D) \quad \text{........................ (ii)}$$

where,
log = natural log (dimensionless);

AGSB = above-ground sapling biomass (kg);
a = intercept of allometric relationship for saplings (dimensionless);
b = slope allometric relationship for saplings (dimensionless); and
D = over bark diameter (cm) at breast height (measured at 1.3 m above-ground).

Leaf litter, herb, and grass (LHG) biomass

In the case of herbs, grass, and litter, the amount of biomass per unit area was calculated by using the formula:

$$LHG = \frac{W_{field}}{A} \times \frac{W_{subsample,\ dry}}{W_{subsample,\ wet}} \times \frac{1}{10000} \text{ .... (iii)}$$

where,

LHG= biomass of leaf litter, herbs, and grass (t ha^{-1});

W_{field} = weight of the fresh field sample of leaf litter, herbs, and grass, destructively sampled within an area of size A (g);

A = size of the area in which leaf litter, herbs, and grass were collected (ha);

$W_{subsample,dry}$ = weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the labouratory to determine moisture content (g); and

$W_{subsample,wet}$ = weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the labouratory to determine moisture content (g).

The carbon content in biomass (above-ground tree, sapling, leaf litter, herb and grass) was calculated by multiplying the respective biomass with the IPCC (2006) default carbon fraction of 0.47.

Below-ground biomass

The following relationship was used to estimate the root biomass developed by MacDicken (1997).

Below-ground biomass = 0.15 × above-ground biomass ....(iv)

The carbon content in below-ground biomass (BB) was calculated by multiplying BB with the IPCC (2006) default carbon fraction of 0.47.

Soil sampling and estimating soil organic carbon (SOC)

Soil samples were taken from 0.56 m radius plot. Profile was dug out at the centres of all the plots up to 30 cm depth. For the purpose of estimating bulk density, three individual soil samples of approximately 100 cm^3, one each from three depths (0–10 cm, 10–20 cm, and 20–30 cm) were collected with the help of a standardized 100 cm^3 metal Soil Sampling Corer. Soil samples from three different depths were collected. Similarly, one composite sample was collected mixing soils from all the three layers in order to determine concentrations of organic carbon and then weighed at a precision of 0.1 g. Around 100 g of composite samples were collected from one plot.

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 (Mg C 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 density of rock fragments was assumed to be 2.65 g cm^{-3} (Pearson *et al.*, 2005). The carbon stock density of soil organic carbon is calculated as (Pearson *et al.*, 2007):

$$SOC = p \times d \times \%C \text{ .... (v)}$$

where,

SOC = soil organic carbon stock per unit area (Mg ha^{-1}),

p = soil bulk density (g cm^{-3}),

d = the total depth where the sample was taken from (cm), and

%C = carbon concentration (%).

Total carbon stock density

The carbon stock density of a stratum was calculated by summing the carbon stock densities of the individual carbon pools of that stratum except carbpn in dead wood and stumps using the following formula:

$$C(LU) = C(AGTB)+C(AGSB)+C(BB)+C(LHG)+C(DWS)+ SOC \text{ .... (vi)}$$

Where,

C(LU) = carbon stock density of a stratum (Mg C ha^{-1}), C(AGTB) = carbon in above-ground tree biomass ($Mg\ C\ ha^{-1}$),

C(AGSB) = carbon in above-ground sapling biomass ($Mg\ C\ ha^{-1}$),

C(BB) = carbon in below-ground biomass ($Mg\ C\ ha^{-1}$),

C(LHG) = carbon in litter, herb and grass ($Mg\ C\ ha^{-1}$),

C(DWS) = carbon in dead wood and stumps ($Mg\ C\ ha^{-1}$), and

SOC = soil organic carbon ($Mg\ C\ ha^{-1}$)

Results and discussion

Vegetation carbon stock

Above-ground vegatation and carbon stock

Biomass of trees varies in different plots within same forest and 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 the Gerupani Oak Forest was found to be 167.21 $Mg\ C\ ha^{-1}$ which was higher than in the Pakhapani Pine Forest (45.7 $Mg\ C\ ha^{-1}$) (Table 1). Similarly, the LHG biomass in the Gerupani Oak Forest was found to be higher than that in the Pakhapani Pine Forest. However, the above-ground sapling biomass was found to be a little higher in the Pakhapani Pine Forest than that in the Gerupani Oak Forest.

Carbon stocks in above-ground vegetation in the Gerupani Oak Forest and the Pakhapani Pine Forest was found to be 78.58 and 21.37 $Mg\ C\ ha^{-1}$ respectively (Table 1). 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). The above-ground carbon stock was found to be higher in the Gerupani Oak Forest than that in the Pakhapani Pine Forest due to function of age, vegetation type, density of stand and larger-sized trees. Shrestha and Singh (2008), Oli and Shrestha (2009), Shrestha *et al.* (2009), Baral *et al.* (2009) and Khanal *et al.* (2010) found more or less similar above-ground carbon stocks in the Mid-hills forests.

Table 1: Above-ground vegetation biomass and carbon stock (Mean ± SE, $Mg\ C\ ha^{-1}$)

Forest	AGTB	Carbon	AGSB	Carbon	LHG biomass	Carbon	Total AB biomass	Carbon in AB vegetation
Gerupani Oak Forest	164.24 ± 1.63	77.19 ± 1.12	0.49± 0.26	0.23± 0.16	2.48± 0.60	1.17 ± 0.41	167.21	78.58
Pakhapani Pine Forest	43.58 ± 3.49	20.48 ± 2.39	0.55 ± 0.18	0.26± 0.18	1.34 ± 0.40	0.63 ± 0.28	45.47	21.37

Carbon stocks in below-ground vegetation (roots)

Biomass and carbon stocks in below-ground vegetation (root) is shown in table 2. Below-ground vegetation carbon stocks in the Gerupani Oak Forest and the Pakhapani Pine Forest was found to be 11.79 ± 0.43 and 3.21 ± 0.93 $Mg\ C\ ha^{-1}$ respectively. Shrestha *et al.* (2009) found similar root carbon in the community-managed *Schima-Castanopsis* Forests in Palpa District. Khanal *et al.* (2010) also found more or less similar root carbon stocks in the community-managed forests in the Mid-hills of Nepal.

Table 2: Below-ground biomass and carbon stock (Mean ± SE, $Mg\ C\ ha^{-1}$)

Forest	Below-ground biomass	Carbon stock in below-ground biomass
Gerupani Oak Forest	25.08 ± 0.63	11.79 ± 0.43
Pakhapani Pine Forest	6.82 ± 1.36	3.21 ± 0.93

Soil carbon stock

Bulk density

The bulk density (BD) depends on several factors such as compaction, consolidation and amount of SOC present in the soil, but it is highly correlated to the organic carbon content (Morisada *et al.*, 2004). There was a large variation in the BD with respect to the forest types. Similarly, there was a gradual increase in the BD with increase in soil depth in both the forests, but it did not differ significantly across the layers of the soil profile (p>0.05). The range of bulk density in both the forests based on the profile (0–30 cm) depths is shown in figure 1. The mean BD value ranged from 0.64 to 1.13 g cm^{-3}. The minimum BD (0.64 ± 0.04 g cm^{-3}) was found at the top soil (0–10 cm) in the Gerupani Oak Forest while the maximum BD (1.13 ± 0.05 g cm^{-3}) at the depth of 20–30 cm in the Pakhapani Pine Forest (Fig. 1).

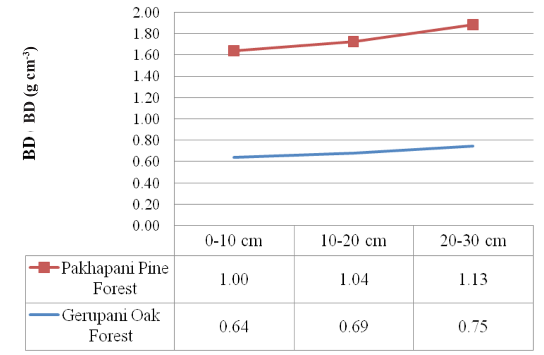

Fig. 1: Bulk densities in different depth of forests

Shrestha *et al.* (2004) in their study from the Mid-hill forest of the Mardi Watershed of Kaski District, 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 the similar forest types of the Mid-hills. Khanal *et al.* (2010) and Shrestha (2009) found similar bulk density values in their studies carried out in Palpa District, Nepal.

Soil organic carbon

Amount of soil organic carbon depends upon various biotic and abiotic factors such as microclimate, 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 (SOC) was found to be higher at the upper layers and gradually decreased as soil depth increased (Fig. 2). The SOC stocks in different soil profiles of both the forests are presented in table 3. The total mean carbon stocks in the surface soil (0–10 cm) of the Gerupani Oak Forest was found to be the highest (23.17 ± 1.28 Mg C ha^{-1}); the lowest mean carbon stock was found in the deeper soil layer (20–30 cm) of the Pakhapani Pine Forest (12.0 ± 1.55 Mg C ha^{-1}). The carbon stock in each layer of the soil profile differed significantly in both the forests ($p \leq 0.05$). The mean carbon stock in each soil layer of both the forests also differed significantly ($p \leq 0.05$). The results indicated that with increase in soil depth, bulk density was found to be in increasing order while the SOC was found to be in decreasing order. Similar results were obtained by Khanal *et al.* (2010) and Shrestha (2009). The soil organic carbon stock in this study was comparable with the soil organic carbon pool values reported by Shrestha and Singh (2008). Shrestha and Singh (2008) also found lower soil carbon pool in Pine-mixed forest than in other forest types.

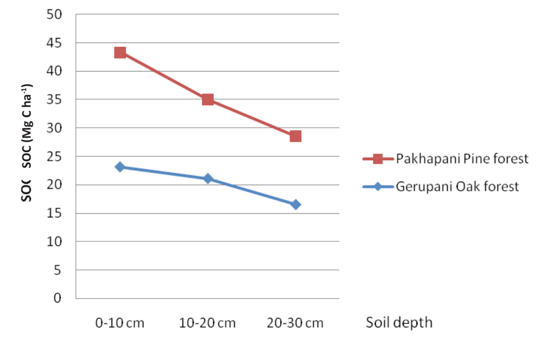

Fig. 2: SOC in different depth of forests

Table 3. SOC stock in different depths of Oak and Pine Forests (Mean ± SE, Mg C ha^{-1})

Soil depth	Gerupani Oak Forest	Pakhapani Pine Forest
0–10 cm	23.17 ± 1.28	20.19 ± 1.83
10–20 cm	21.12 ± 1.30	13.9 ± 1.52
20–30 cm	16.53 ± 1.29	12.03 ± 1.55
Total	**60.82**	**46.12**

Total carbon stock

Total carbon stock is the sum of above-ground vegetation carbon, root carbon and soil organic carbon. The total carbon stocks in both the forests are shown in table 4. The total carbon stocks in the Gerupani Oak Forest and the Pakhapani Pine Forest were found to be 151.19 Mg C ha^{-1} and 70.70 Mg C ha^{-1} respectively. Shrestha and Singh (2008) have reported that the total carbon stock (vegetation plus soil) in the Mid-hill forests is 139 Mg C ha^{-1}. Similarly, Shrestha (2009) found the total carbon stock in the *Schima-Castanopsis* forest of Palpa District as 178.5 Mg C ha^{-1} and Khanal *et al.* (2010) found the total carbon stock in the two community-managed forests of Palpa

District as 168.48 Mg C ha^{-1} and 146.16 Mg C ha^{-1} respectively. These results were slightly different due to difference in site quality, stand structure and intensity of management.

Table 4: Total carbon stock in Oak and Pine Forests

Carbon stock	Gerupani Oak Forest (Mg C ha^{-1})	Pakhapani Pine Forest (Mg C ha^{-1})
Above-ground carbon	78.58 (52 %)	21.37 (30 %)
Root carbon	11.79 (8 %)	3.21 (5 %)
Soil Carbon	60.82 (40 %)	46.12 (65 %)
Total	**151.19**	**70.70**

The total carbon stocks in the Gerupani Oak Forest was found to be 40% in soil, 52% in the above-ground and 8% in root (Table 4). Similarly, the total carbon stock in the Pakhapani Pine Forest was found to be 65% in soil, 30% in above-ground and 5% in root (Table 4). Shrestha (2009) reported that the total carbon stock in the *Schima-Castanopsis* Forests of Palpa District as 74% in soil, 20% in above-ground and 6% in root.

Conclusion

Soil offers a more promising sink for carbon over longer time period under forest cover. Total carbon stock in forest vegetation varies depending on forest types. The vegetation carbon stock was higher in the Oak Forest than in the Pine Forest due to the presence of larger sized trees, age and density of stand. The share of under-growth vegetation carbon was very low. The soil organic carbon in 0–10 cm, 10–20 cm, 20–30 cm soil depths were found to be different. The soil organic carbon was higher in Oak Forest than in the Pine Forest due to higher amounts of leaf litter and under storey biomass. With the increase in soil depth, bulk density was found to have increased, whereas, the carbon content was found to have decreased. The average soil carbon comprised 52.5% of the total carbon. Both the forests seem to be good for vegetation and soil carbon stocks.

References

Anonymous, 2004. Forest Carbon Sequestration. *CATALYST, the magazine of the union of concerned scientist* **3:** 1–4.

Awasthi, K. D., Sitaula, B. K., Singh, B. R. and Bajracharya, R. M. 2002. Land use changes and morphometric analysis using GIS for two mountain watersheds of western Nepal. *Land Degradation and Development* **13:** 1–19.

Bajracharya, R. M., Lal, R. and Kimble, J. M. 1998. Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position. In: *Soil Processes and the Carbon Cycle* (eds.) Lal, R., Kimble, J., Follett, R. and Stewart, B. A. CRC Press, Boca Raton, Florida, 353–367.

Baral, S. K., Malla, R. and Ranabhat, S. 2009. Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari* **19 (2):** 10–14.

Brown, S., Sathaye, J., Cannell, M. and Kauppi, P. E. 1996. Mitigation of carbon emissions to the atmosphere by forest management. *Commonwealth Forestry Review* **75 (1):** 80–91.

Chave, J., Andalo, C., Brown, S., Cairns, M. A. Chambers, J. Q. and Eamus, D. 2005. Tree allometry and improved estimation of carbon stocks. *Oecologia* **145 (1):** 87–99.

Gautam, K. R. 2002. Carbon Sequestration in Agroforestry and Annual Cropping System in Inner Terai, Central Nepal. M. Sc. Thesis. Agricultural University of Norway, Aas, Norway.

Hamburg, S. P. 2000. Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. *Mitigation Adaptation Strategy Global Change* **5 (1):** 25–37.

IPCC. 2006. Good Practice Guidelines for National Greenhouse Gas Inventories. Switzerland: Intergovernmental panel on climate change.

IPCC. 2000. **The Intergovernmental Panel on Climate Change, Special Report on Land Use, Land-Use Change and Forestry.** Cambridge University Press, Cambridge, UK.

Khanal, Y. M., Sharma, R. P. and Upadhyaya, C. P. 2010. Soil and vegetation carbon in two community forests of Palpa District, Nepal. *Banko Janakari* **20 (2):** 34–40.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma* **123 (1–2):** 1–22.

MacDicken, K. G. 1997. **A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects.** Forest Carbon Monitoring Programme, Winrock International Institute for Agricultural Development, Littlerock, Arkansas, USA.

Malhi, Y., Meir, P. and Brown, S. 2002. **Forests, Carbon and Global Climate.** Phil. Trans. R. Soc. Lond. A 360, 1567–1591

MFSC. 2010. Forest Carbon Estimation Guideline, 2010. Ministry of Forests and Soil Conservation, Singhdurbar, Kathmandu, Nepal.

Morisada, K., Ono, K. and Kanomata, H. 2004. Organic carbon stocks in forest soils in Japan. *Geoderma* **119:** 21–32.

Negi, J. D. S., Manhas, R. K. and Chauhan, P. S. 2003. Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. *Current Science* **85 (11):** 1528–1531.

Oli, B. N. and Shrestha, K. 2009. Carbon status in forests of Nepal: An overview. *Journal of Forest and Livelihood* **8 (1):** 62–66.

Pearson, T. R., Brown, S. and Ravindranath, N. H. 2005. **Integrating Carbon Benefit Estimates into GEF Projects: Guidelines.** Capacity Development and Adaptation Group, Global Environment Facility, United Nations Development Programme, New York, USA.

Pearson, T. R., Brown, S. L. and Birdsey, R. A. 2007. **Measurement guidelines for the sequestration of forest carbon.** Northern Research Station, Department of Agriculture, USA.

Shrestha, B. M. and Singh, B. R. 2008. Soil and vegetation carbon pools in a mountainous watershed of Nepal. *Nutrient Cycling in Agroecosystems* **81:** 179–191.

Shrestha, B. M., Sitaula, B. K., Singh, B. R. and Bajracharya, R. M. 2004. Fluxes of CO and CH in soil profiles of a mountainous watershed of Nepal as influenced by land use, temperature, moisture and substrate addition. *Nutrient Cycling in Agroecosystems* **68:** 155–164.

Shrestha, B. P. 2009. Carbon sequestration in *Schima-Castanopsis* forest: A case study from Palpa District. *The Greenery (A Journal of Environment and Biodiversity)* **7 (1):** 34–40.

Shrestha, B. P., Awasthi, K. D. and Bajracharya, R. M. 2009. Variation in Carbon Stock in Community Forests of Mid-hills of Nepal: A case study from Palpa district. The Natural Resource Management: Reviews and Research in the Himalayan Watershed (Special Publication of NUFU HIMUNET Project): 18–29.

Sitaula, B. K., Bajracharya, R. M., Singh, B. R. and Solberg, B. 2004. Factors affecting organic carbon dynamics in soils of Nepal/ Himalayan region- a review and analysis. *Nutrient Cycling in Agroecosystems* **70:** 215–229.

Van Noordwijk, M., Cerri, C., Woomer, P. L., Nugroho, K. and Bernoux, M. 1997. Soil carbon dynamics in the humid tropical forest zone. *Geoderma* **79 (1–4):** 187–225.

Winjum, J. K., Dixon, R. K. and Schroeder, P. E. 1992. Estimating the global potential of forest and agro-forestry management practices to sequester carbon. *Water Air Soil Pollution* **64 (1–2):** 213–227.