Agro-forestry Systems as a Means to Achieve Carbon Co-benefits in Nepal

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Abstract: Land management regimes and forest types play an important role in the productivity and accumulation of terrestrial carbon pools. While it is commonly accepted that forests enhance carbon sequestration and conventional agriculture causes carbon depletion, the effects of agro-forestry are not well documented. This study investigated the carbon stocks in biomass and soil, along with the selected soil properties in agro-forestry plots compared to community forests (CF) and upland farms in Chitwan, Gorkha and Rasuwa districts of Central Nepal during the year 2012-2013. We determined the total above ground biomass carbon, soil organic carbon (SOC) stocks and soil properties (bulk density, organic carbon per cent, pH, total nitrogen (TN), available phosphorus (P), exchangeable potassium (K), and cation exchange capacity (CEC)) on samples taken from four replicates of 500 m^2 plots each in community forests, agro-forestry systems and agricultural land. The soil was sampled in two increments at 0-15 cm and 15-30 cm depths and intact cores removed for bulk density and SOC determination, while loose samples were separately collected for the laboratory analysis of other soil properties. The mean SOC percent and corresponding soil carbon stocks to 30 cm depth were generally highest in CF (3.71 and 3.69 per cent, and 74.98 and 76.24 t ha^{-1}, respectively), followed by leasehold forest (LHF) (2.26 and 1.13 per cent and 40.72 and 21.34 t ha^{-1}, respectively) and least in the agricultural land (3.05 and 1.09 per cent, and 63.54 and 19.42 t ha^{-1}, respectively). This trend was not, however, observed in Chitwan, where agriculture (AG) had the highest SOC content (1.98 per cent) and soil carbon stocks (42.5 t ha^{-1}), followed by CF (1.8 per cent and 41.2 t ha^{-1}) and leasehold forests (1.56 per cent and 35.3 t ha^{-1}) although the differences were not statistically significant. Other soil properties were not significantly different among land use types with the exceptions of pH, total N, available P and CEC in the Chitwan plots. Typically, SOC and soil carbon stocks (to 30cm depth) were positively correlated with each other and with TN and CEC. The AGB-C was expectantly highest in Rasuwa district CF (ranging from 107.3 to 260.3 t ha^{-1}) due to dense growth and cool climate, followed by Gorkha (3.1 to 118.4 t ha^{-1}), and least in Chitwan (17.6 to 95.2 t ha^{-1}). The highest C stocks for agro-forestry systems in both above ground and soil were observed in Rasuwa, followed by Chitwan district. Besides forests, agro-forestry systems also hold good potential to store and accumulate carbon, hence they have scope for contributing to climate change mitigation and adaptation with co-benefits.

Key words: Above ground biomass, soil carbon stock, leasehold forest, community forest

INTRODUCTION

Agro-forestry systems are land management approaches that incorporate perennial plant species in combination with annual crops. Typically, some trees, either fruit or fodder species, are grown in and around cereal or vegetable crops on agricultural land in order to optimize and diversify production. In view of the impending climate change scenarios, agro-forestry systems offer a unique opportunity to address climate change adaptation and mitigation while securing the livelihoods of the rural communities in mountain regions of Nepal (Kumar and Nair 2011; Leakey 2012; Pachauri 2012). With the increased uncertainty of precipitation, spread of pests and diseases, and unpredictability of severe weather events, diversification and a mixed cropping approach offers a buffer against production risks. Moreover, the combination of different types of crops with varying tolerances to climate, soil, nutrient and water conditions allows for complementary and synergistic effects regarding productivity while enhancing carbon capture and storage (Montagnini and Nair 2004; Akinnifesi *et al*. 2009; Garrity 2012).

While forests are regarded as the best means for enhancing carbon capture and sequestration in terrestrial ecosystems (Ranabhat *et al.* 2000; Lal 2005; Bhattarai *et al.* 2012; Dahal and Kafle 2013), agro-forestry also offers potential for carbon accumulation while also providing income and livelihood benefits (Regmi 2003; Khanal 2011; Kumar and Nair 2011). Neupane *et al.* (2002) noted that the farmers were likely to adopt agro-forestry practices if they kept high numbers of livestock such as goats and cattle. This finding was supported by Regmi (2003) who observed that agro-forestry improved farm household livelihoods by providing fodder self-sufficiency for livestock through which income was augmented. Pandit *et al.* (2014) observed that cultivation of agro-forestry species including medicinal plants on private land in Kavre district of Central Nepal led to economic benefits and livelihood security for farmers. Likewise, in Liberia, Fouladbash and Currie (2015) noted that agro-forestry practices provided income diversification and enhanced food security thus offering local people an improved climate change adaptive capacity.

Farming on hill slopes poses problems related to soil erosion, water availability and micro-climatic variability. Slope areas often tend to have shallow, and less developed soils with low nutrient and water retention characteristics. Also, such lands are subject to excessive and uncontrolled runoff during heavy rain events leading to severe soil erosion and land degradation. Thus, the use of these sloping lands have traditionally been contingent upon the application of conservation practices to prevent their degradation, such as, terracing, ditches for safe water disposal, vegetative or non-living barriers to prevent uncontrolled overland flow of water or to trap eroded sediment. Apart from physical or structural measures to conserve soil and water in order to prevent land degradation, cropping patterns and combinations of plant types can also serve as an effective approach to achieve conservation goals while simultaneously enhancing productivity and improving rural livelihoods (Tacio 1993; Nuberg *et al.* 2009). In this respect, agro-forestry systems hold considerable promise for enabling multiple benefits to farming communities in the hill areas of Nepal (The Glacier Trust 2011; Synnot 2012).

Acharya and Kafle (2009) pointed out that agro-forestry practices such as planting of multipurpose trees on farm land helps to reduce land degradation on steep slopes in the hills of Nepal. Moreover, these practices offer other benefits like biodiversity conservation, soil improvement, nutrient cycling and carbon sequestration (Khanal 2011; Obeng and Aguilar 2015). Yadav *et al.* (2010) found that under tree-based traditional agro-forestry systems in Rajasthan, India, soil biological activity increased significantly leading to enhanced microbial biomass carbon, nitrogen and phosphorus. Similar results of significantly higher soil organic carbon (SOC), nitrogen (N), phosphorus (P), potassium (K) mean weight and diameter of soil aggregates and microbial biomass carbon were reported by Ramesh *et al.* (2013) under 26 year old multipurpose trees in Meghalaya, India, compared to control plots with no trees. Pandit *et al.* (2012) estimated that for agro-forestry systems in Rasuwa district, 48.6 tons carbon were accrued over 20 years providing good potential for climate change mitigation and carbon trading benefits to local farmers.

In view of the influence of land use and forest management types on carbon stocks in the terrestrial ecosystems, this study was carried out to assess the effect of agro-forestry systems on total biomass and soil carbon stocks as well as other selected soil properties compared to community forests and conventional upland agriculture in central Nepal.

METHODS

Study Area

Three watersheds in Gorkha, Chitwan and Rasuwa districts of Nepal were selected for the study (Figure 1). The three study sites were located in 3 different eco-regions among the 200 Global eco-regions. Betrawati watershed of Rasuwa district represents the temperate forest at higher altitudes (1500-1600 m) within the Middle Mountains region. Ludikhola watershed of Gorkha district represents the mixed hill Sal (*Shorea robusta*) forest of the lower mid-hills ranging in altitude from 900-1000 m. Kayarkhola watershed of Chitwan district comprises of the low altitude (200-300 m) forest of the foot hills of Nepal dominated by *Shorea robusta* and associated species. Community forests within each watershed were selected for comparison with agro-forestry and agricultural land use systems.

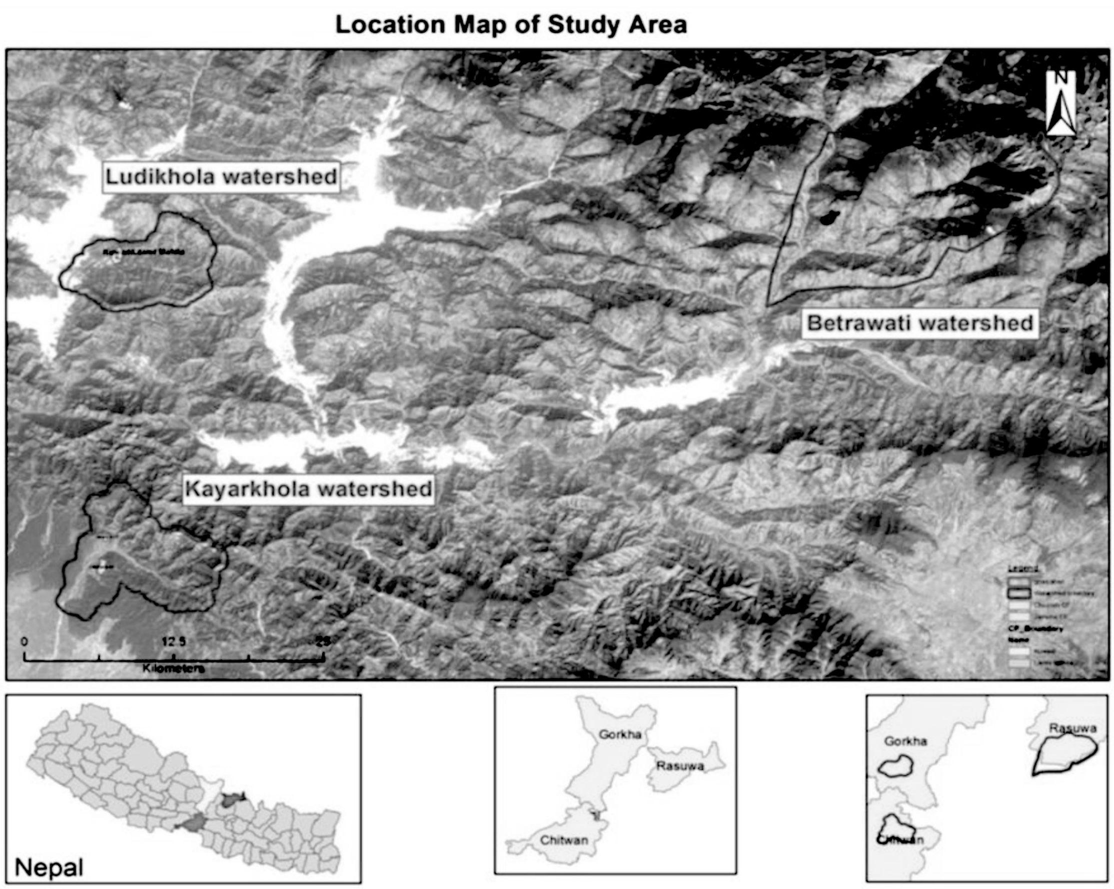

Figure 1. Map Showing the Location of the Study Watersheds in Central Nepal

Carbon Stock Quantification

Field Sampling and Measurement

For the sampling of biomass and soil carbon, random sampling was carried out in four replicate plots in each of the three land management types, namely, Community Forests, agro-forest and agricultural land. The biomass and soil sampling was done from autumn 2012 to spring 2013, and subsequent carbon stock calculations were done using standard methods commonly used as described below.

Above Ground Tree Biomass

The diameter at breast height (DBH) of 1.3 m along with the height of all trees having DBH greater than 0.1 m were measured by using a diameter-tape and clinometer, respectively, in a randomly laid-out concentric forest plots of 500 m^2 area by delineating a circle of 12.56 m radius. For the general characteristics of the plot, crown density was also measured using a **densitometer**. The allometric equation as suggested by Chave *et al.* (2005) was used for Above Ground Tree Biomass (AGTB) calculation as the study areas do not lie in the heavy rainfall region. Allometric equations are established in a purely empirical way on the basis of exact measurements from a relatively large sample of typical trees (Hairiah *et al.* 2010). The AGTB (in t ha^{-1}) was calculated using DBH (in cm), height (in m) and wood-specific gravity (in g/cm^3) of the trees according to equation 1 below:

AGTB= 0.059*δD2H ………………… (1)

Where,

δ = wood specific gravity (g cm^{-3})

D= tree diameter at breast height (cm)

H= height of the tree (m)

Leaf-litter, Herbs and Grass Biomass

To get the Leaf-litter, Herbs and Grass Biomass (LHGB), all the litter (dead leaves, twigs, and so forth) within the 1 m^2 sub-plots are collected and weighed. Approximately 100 g of evenly mixed sub-samples were brought to the laboratory to determine their moisture contents, from which total dry mass was calculated. Likewise, herbs and grass (all non woody plants) within the plots are collected by clipping all the vegetation down to ground level, weighing them, placing in the weighing bag sample and bringing them to the laboratory to determine the oven dry weight of the biomass.

For the forest floor (herbs, grass, and litter), the amount of biomass per unit area is given by equation 2 (Chave *et al.* 2005) below:

$$LHGB = \frac{\text{Wfield}}{A} \cdot \frac{\text{Wsubsample dry}}{\text{Wsubsample wet}} \times 1000 \ldots (2)$$

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 (gm);

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

$W_{subsample\ dry}$= weight of the oven dried sub-sample of leaf litter, herbs, and grass (gm)

The carbon contents in both AGTB and LHGB were calculated by multiplying LHGB with the IPCC (2006) default carbon fraction of 0.47.

Below-ground Biomass

Below-ground biomass (BGB) estimation is much more difficult and time consuming than estimating above-ground biomass. Destructive sampling of the plots to determine BGB was not possible. Hence, as an approximation, the recommended root-to-shoot ratio value of 1:5 was used as recommended by MacDicken (1997).

Soil Organic Carbon

The soil samples were collected from the center of each demarcated plot in the forest and agro-forestry plots. They were taken randomly from the agriculture fields at depth ranges of 0-15cm, 15 – 30cm, 30-60 cm and 60-100cm or until bed rock was encountered. Core samples extracted using a steel ring and corer of 4.7 cm diameter and 6 cm height were used for determination of the bulk density (according to Blake and Hartge 1986) and SOC, while other properties were determined using loose soil samples. The samples were sealed in plastic bags, transported to the laboratory, and oven dried (at 105^{o} C) until a constant weight was gained to determine their water content. The percent carbon content of soils was determined using the loss-on-ignition (dry combustion) method as described in Neslon and Sommers (1982).

The carbon stock density of SOC was calculated according to Pearson *et al.* (2007):

SOC= ∂*d* per cent C……….………… (3)

Where,

SOC= soil organic carbon stock per unit area [t ha^{-1}],

∂ = soil bulk density [g cm^{-3}],

d= the total depth at which the sample was taken [cm], and per cent C= carbon concentration [per cent].

Total Carbon Stock Density

To determine the overall carbon stocks in a given forest, the calculated per plot AGTB was multiplied by the total area in hectares of the forest and expressed as tons of carbon per hectare. Similarly, the carbon content in BGB was then calculated by multiplying above-ground biomass carbon by 0.2 (for the root shoot ratio) and also extrapolated to the entire area of the forest and expressed in tons per hectare. Likewise, the LHGB weights were subsequently converted into tonnes of carbon per ha for each land use type and SOC also extrapolated to the tonnes of carbon per ha by summing up the depth-wise carbon stocks. The total carbon stock density for a given land use type was then determined as the sum of the AGTB, BGB, LHGB and SOC for that land use. The calculations were done according to commonly used methods as given by Hairiah *et al.* (2010), IPCC (2006) and Chave *et al.* (2005).

Baseline Soil Properties

Other general baseline soil properties including soil texture, pH, total N, available P, exchangeable K and Cation Exchange Capacity (CEC) were determined using standard methods as given in the Methods of Soil Analysis (USDA Monograph No. 9). The soil texture, that is, particle size distribution, was determined using the soil hydrometer method (Gee and Bauder 1986), while soil reaction was measured using a glass-calomel probe with digital pH meter in a 1:1 soil:water mixture (McLean 1982). Total N of the soil samples were determined using the Kjeldahl method (Bremner and Mulvaney 1982), available P by a modified Olsen method (Olsen and Sommers 1982), exchangeable K by ammonium acetate extraction (Knudsen *et al.* 1982), and CEC by ammonium acetate/potassium chloride extraction (Rhodes 1982).

RESULTS AND DISCUSSION

The soils at the study locations varied in texture from sandy loam in Gorkha district to silty clay and sandy clay in Chitwan district. Despite of a wide variation in textural classes, most of the soils belonged to the silt loam, silty clay loam and clay loam classes across all districts (data not shown). A notable trend was, however, the agricultural soils in all three districts were higher in clay, being mostly silty clay loams and sandy clay loams while the soils in forested areas tended to be of lighter texture, namely, loam, sandy loam or silty loam. The fact that agricultural soils were of higher clay content was likely due to the selection of upland farm (e.g., *bari*) soils which generally had eroded top soils and exposed subsoils with higher clay contents. On the other hand, forested areas with leaf litter and ground vegetation cover usually have higher water infiltration and percolation leading to leaching of clay particles down to subsurface layers. Soils in the lower foothills and valleys of Chitwan were more developed, hence generally are called Alfisols, whereas, those of Rasuwa district above 1500 m were less weathered with fewer developmental features, thus, typically Inceptisols. The soils studied in Gorkha district were intermediate to those in Chitwan and Rasuwa.

The SOC contents were generally highest in CF for all the three districts as seen from Figure 2. Agro-forestry systems (e.g., leasehold forest (LHF)) did not have consistently high SOC per cent, however, in Rasuwa district values were comparable with CF. Other workers have also noted that forest soils tend to have high SOC, especially in the topsoil (Shrestha *et al.* 2004; Lal 2005; Dahal and Kafle 2013). Agricultural land has similar SOC contents to that of leasehold agro-forestry with the exception of Rasuwa district. It should be noted, however, that SOC was statistically and significantly different only in Gorkha district (Table 1) owing presumably to a high variability of the data.

Soil bulk density (BD) was not significantly different among districts (Table 2) although there was an observed trend of somewhat higher values in Chitwan district likely due to a combination of low organic matter levels and coarse-sandy textured soils (Figure 2).

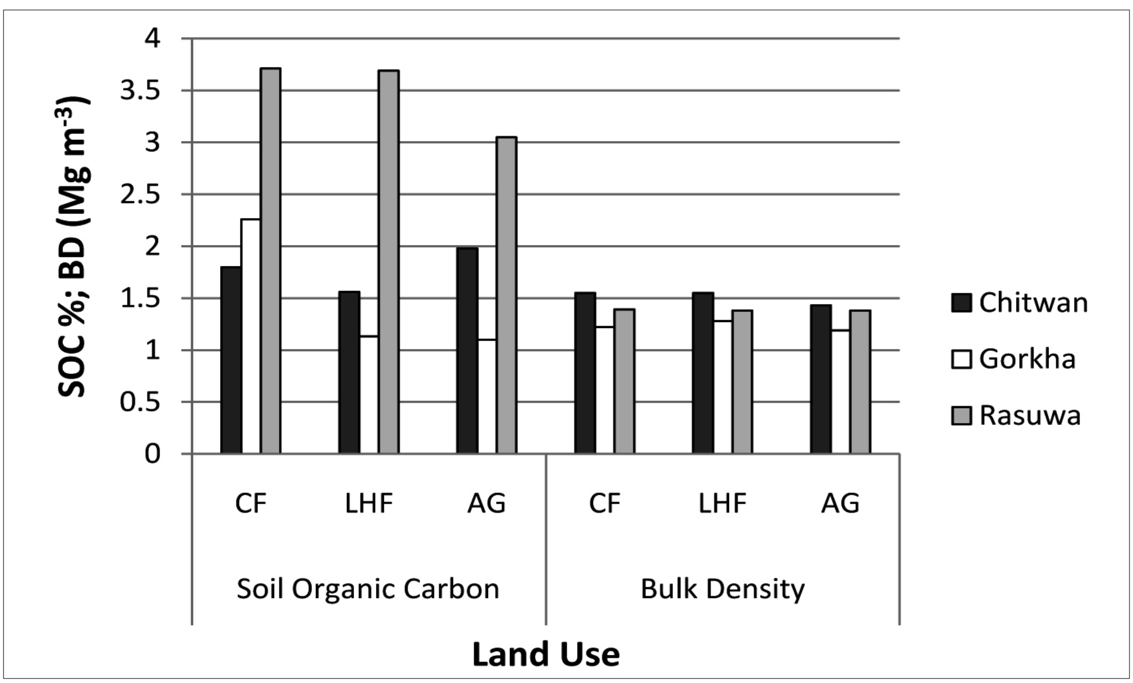

Figure 2. Mean Values of SOC per cent and Bulk Density for Three Land Uses in the Study Districts

CF = Community Forest, LHF = Lease-hold Agro-forest, AG = Agricultural Land

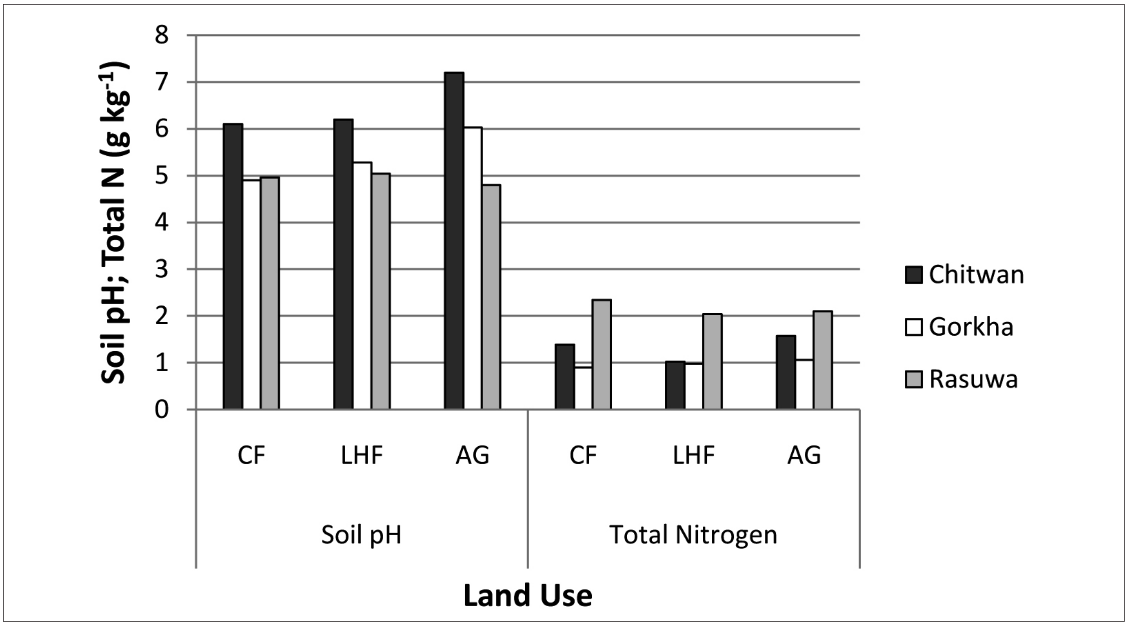

Figure 3. Mean Values of Soil pH and Total Nitrogen in Three Land Uses of the Three Study Districts

CF = Community Forest, LHF = Lease-hold Agro-forest, AG = Agricultural Land

The soils were mostly slightly acidic to strongly acidic with the exception of agricultural land in Chitwan district, which was neutral (Figure 3). Soil pH differed significantly among land use types in Chitwan and Gorkha but not in Rasuwa district (Table 1). The higher pH values in agricultural land in Chitwan and Gorkha could be attributed to the application of agricultural lime. The status of soil pH and nutrients tends to be influenced either by geology and parent material or by the application of fertilizers and lime by farmers (Atreya *et al.* 2008; Bajracharya and Sherchan 2009). While the rocks and parent materials leading to soil formation in the hills generally tend to be acidic, deposits in the lowland areas may be less acidic or near neutral. On agricultural land, however, the application of amendments such as fertilizers can lead to increased acidity, while application of lime increases the pH of soils.

Total N followed a trend similar to that of SOC per cent with highest values in Rasuwa district and not statistically non-significant differences among land use types (Figure 3, Table 1). This is evident by a high correlation between SOC and total N as seen in Table 2.

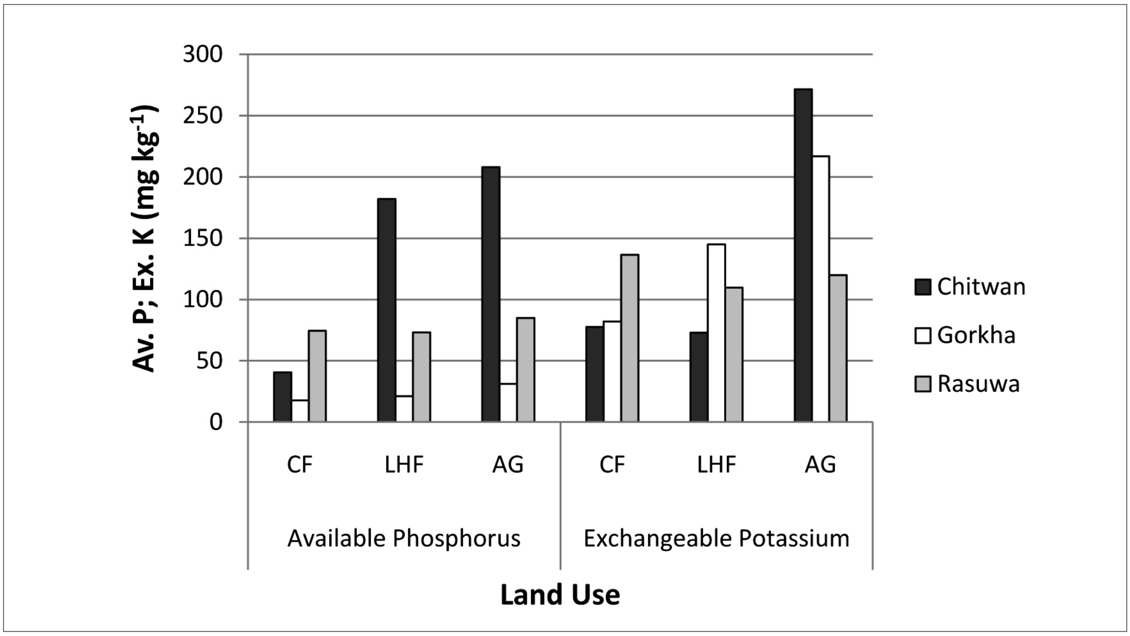

Figure 4. Mean Values of Available P and Exchangeable K in Three Land Use types of the Study Districts

CF = Community Forest, LHF = Lease-hold Agro-forest, AG = Agricultural Land

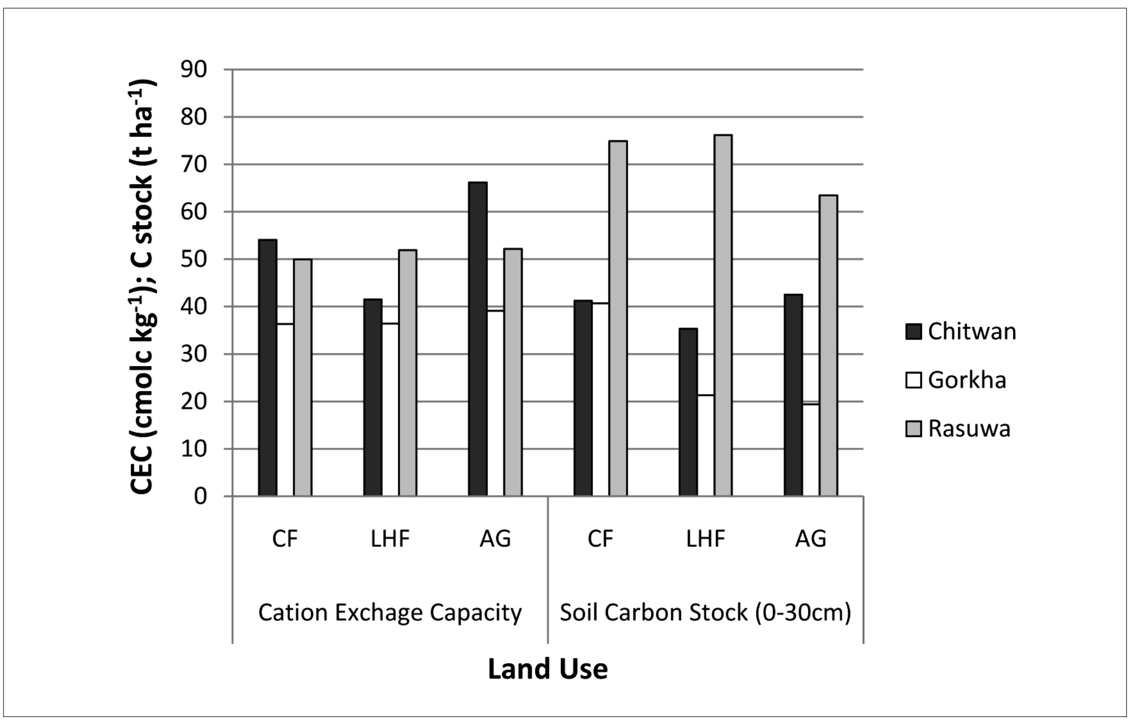

Figure 5. Mean CEC and Soil Carbon Stocks in Three Land Uses of the Study Districts

CF = Community Forest, LHF = Lease-hold Agro-forest, AG = Agricultural Land

The plant available P was significantly higher in agro-forestry systems and agricultural land only in Chitwan district (Figure 4 and Table 1). Likewise, exchangeable K was highest in agricultural lands in all districts although no statistical significance was observed due to high variability of data. This trend was thought to be the consequence of P and K fertilizer applications on agricultural land and to a lesser extent in agro-forestry systems.

The CEC of soils did not follow any clear trend (Figure 5) and was generally not statistically or significantly different among land uses except in Chitwan district (Table 1). Nonetheless, CEC was highly correlated with SOC and soil chemical parameters, namely, pH and total N (Table 2). The soil carbon stock to 30 cm depth expectantly followed a similar trend to that of SOC per cent (Figure 5) and was also highly correlated with SOC, total N, and CEC (Table 2).

Table 1. One-way Analysis of Variance of Soil Properties According to Land Use for Each District (Agro-ecological Zone), (N = 24)

	Chitwan		Gorkha		Rasuwa	
Soil Property	**F-test value**	**Signif.**	**F-test value**	**Signif.**	**F-test value**	**Signif.**
SOC per cent	0.89	ns	12.92	***	1.66	ns
Bulk density	1.32	ns	0.81	ns	0.01	ns
Soil pH	11.86	***	6.85	**	2.41	ns
Total N	4.12	*	0.24	ns	0.72	ns
Avail. P	45.54	***	1.93	ns	0.20	ns
Exch. K	2.08	*	1.79	ns	0.60	ns
CEC	7.38	**	1.07	ns	0.14	ns
C-Stock	0.59	ns	15.28	***	1.63	ns

Note: *, **, *** indicate significance at 0.05, 0.01 and 0.001 level of P, respectively

Table 2. Peason's Correlation Matrix for Soil Properties Across all Three Districts (N = 72)

	BD	C-stock	pH	TN	AP	EK	CEC
SOC	-0.77	0.96***	-0.39**	0.75***	0.03	-0.03	0.36**
BD		0.16	0.24*	0.05	0.37**	-0.19	0.13
C-stock			-0.34**	0.77***	0.10	-0.07	0.42***
pH				-0.14	0.52***	0.34**	0.26**
TN					0.18	0.09	0.39**
AP						0.09	0.29*
EK							0.21†

Note: † indicates P < 0.10; * indicates P < 0.05; ** indicates P < 0.01; and, *** indicates P , 0.001

When considering the total above and below ground carbon stocks, including biomass and SOC, clearly, CF had the highest total carbon stocks for all of the three districts as shown in Figure 6. However, in Chitwan and Rasuwa districts, leasehold agro-forestry systems also had considerable total carbon stocks in the range of 150 to 360 t ha^{-1}. However, for agricultural land uses, the total carbon stocks reflected only the SOC, and hence were substantially lower than the other land uses (Figure 6). Nonetheless, total carbon stocks significantly differed statistically only for land uses in Gorkha district (Table 1), while they were not significantly different in Chitwan and Rasuwa, presumably due to high variability within replicate plots. Expectantly, the total carbon stocks were highly positively correlated with SOC content, total N and CEC as indicated by Pearson's correlation coefficients in Table 2.

The SOC contents and soil carbon stocks were generally higher in community forests and leasehold forests. The results are corroborated by other studies which also indicated higher SOC in forests, particularly in the topsoil (Bajracharya *et al.* 2004; 2006; Dahal and Kafle 2013). However, upland agricultural soils may also have high SOC contents and stocks due to the application of large amounts of farmyard manure and the relatively deep soils found in these farms (Shrestha *et al.* 2004; Bajracharya *et al.* 2009).

High carbon stocks and sequestration potential of forest land have been well documented by numerous researchers (Lal 2005; Bhattarai *et al.* 2012; Jati 2012; Dahal and Kafle 2013). The high SOC and biomass carbon observed in Rasuwa for all land use types was attributed to the high elevation (1700-1800m) with cool climate and slow decomposition rates. Agro-forestry systems also had total carbon stocks comparable to CF (with the exception of Gorkha district) indicating potential for climate change mitigation. Also, due to multiple benefits and diversification of crops, LHF potentially offers better adaptive capacity to climate change as noted by other workers (Neupane *et al.* 2001; Zomer *et al.* 2007; Garrity 2012). Moreover, agro-forestry can lead to enhanced livelihoods of farmers when combined with high-value crops, Medicinal Aromatic Plants (MAPs), and livestock (Thorne and Tanner 2002; Regmi 2003; Nuberg *et al.* 2009).

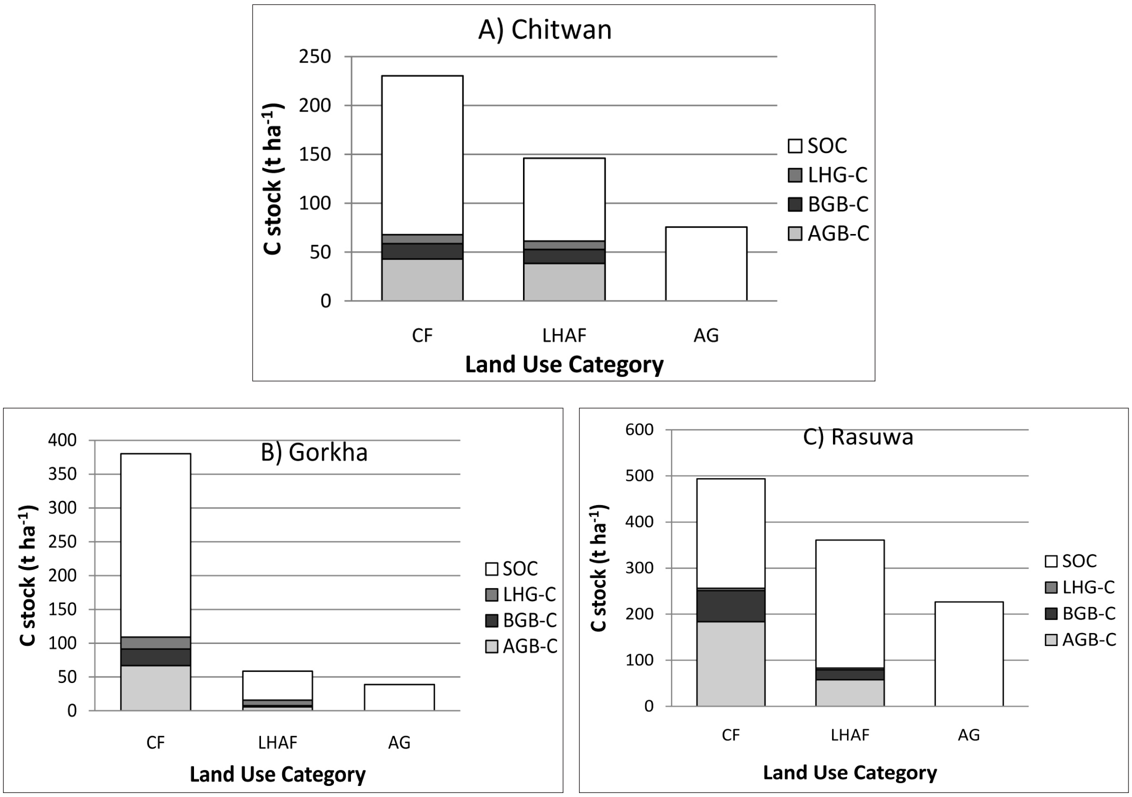

Figure 6. Total Carbon Stocks for Three Land Use Types in A) Chitwan, B) Gorkha, and C) Rasuwa districts.

CF = Community Forest, LHAF = Lease-hold Agro-forest, AG = Agricultural Land, SOC = Soil Organic Carbon, LHG-C = Leaf-litter, Herb & Grass Carbon, BGB-C = Below-ground Biomass Carbon, and AGB-C = Above-ground Biomass Carbon.

SUMMARY AND CONCLUSIONS

From the above results, it can be inferred that the SOC contents and soil carbon stocks were generally higher with elevation apparently due to the cool moist climate and slow organic matter decomposition rates. While the total carbon stocks were higher in all three districts under CF land use, carbon stocks for leasehold agro-forestry was also comparable. The soil carbon stock was significantly positively correlated with SOC per cent, total N and CEC, whereas, the SOC per cent was correlated positively with total N, CEC, and negatively with soil pH. The soil pH was also significantly positively correlated with the available P, exchangeable K and CEC.

Above-ground and below-ground biomass carbon followed similar trends as SOC stock with Rasuwa district having the highest values. The order of total carbon stock for the three land use types was: CF > LHF > AG. Thus, agro-forestry systems have higher total carbon stocks than conventional agriculture, and in cool agro-ecological zones, the SOC and total carbon stocks of LHF are comparable with other forests.

Hence, due to multiple benefits and diversification of crops leading to enhanced incomes and livelihoods, it can be said that agro-forestry systems potentially offers better adaptive capacity for local farming communities to climate change along with mitigation and carbon trading possibilities. Targeted policy initiatives are required to promote sustainable land management alternatives such as diversified agro-forestry practices, particularly in the hills of Nepal. Further work in different east-west regions across the Himalaya is needed to verify the carbon sequestration potential and livelihood benefits of these systems.

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