Proceedings of the International Academy of Ecology and Environmental Sciences, 2023, 13(3): 126-138

Article

Total carbon stock from biomass and soil in agroforestry system of two different ecological regions of western Nepal

Shashi Kafle
Tribhuvan University, Kathmandu, Nepal
E-mail: shashi.kafle@trc.tu.edu.np

Received 30 March 2023; Accepted 8 May 2023; Published online 25 May 2023; Published 1 September 2023

Abstract

Nepal, where more than 80% people are still living in the countryside and their main profession is based on agriculture and its relevant sectors are exercising different mode of agroforestry system for their daily livelihood activities. Carbon sequestration through agroforestry system is an emerging strategy to cope with the immediate and long-term impacts of climate change in all its coping options such as adaptation, mitigation and resilience. Realizing these facts, this paper aimed to determine the carbon stock in agroforestry system especially on regards to home garden in two different ecological regions of western Nepal. Two different ecological regions were selected namely Terai and Mid-hills of western Nepal. The result found that average total biomass was significantly greater ($p<0.05$) in Terai (21.314 t/ha) than in Mid-hills (11.203 t/ha). The mean of total biomass carbon stock was found to be 10.255 t/ha and 5.24 t/ha for Terai and Mid-hill respectively. The soil carbon stock was found 61.17 t/ha in Terai and 67.608 t/ha in mid-hills whose bulk density found 1.38 g/cm^3 in Terai and 1.076 g/cm^3 in Mid-hills region. However, there was no significant difference ($p>0.05$) found in the total carbon stock (biomass and soil) between two ecological regions i.e., 71.433 t/ha in Terai and 72.856 t/ha in Mid-hills. This study can be helpful in providing insight in adaptation of various trees to mitigate the effect the climate change.

Keywords agroforestry system; home garden; Terai region; Mid-hills; biomass carbon stock; soil carbon stock.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

The impacts of climate change have become highly visible affecting different aspects of human society and ecosystem across the globe. The Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has reported that human induced climate change has caused adverse impact on nature and people. Some irreversible impacts have been observed as natural and human systems are pushed beyond their ability to adapt. Climate changes including increases in frequency and intensity of extremes have reduced the food and water security. It also reported that overall agricultural productivity has been increased but the growth over the past 50 years has been slowed down due to climate change. IPCC has also alerted about the risk in the near term (2021-2040). If the global warming would reach 1.5°, it would cause multiple climate hazards and present multiple risks to the ecosystem and humans (IPCC, 2022).

Agroforestry system provides ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape (Jose, 2009). There are various environmental benefits of agroforestry as it enhances biodiversity, nutrient absorption and water economy. It is also used as a tool to reduce wildfires incidents and carbon sequestration (Pantera, 2021). Agroforestry systems are believed to have a higher potential to sequester carbon than pastures or field crops (Pokhrel et al., 2013). Carbon storage in both living biomass and in the soil is a key ecosystem services provided by forests and agroforests (Beenhouwer et al., 2016). Considering only the tree component of agroforestry systems, estimates based on growth rates and wood. The potential of agroforestry systems to accumulate C is estimated to 0.29–15.21 Mg ha^{-1} $year^{-1}$ (Dyani, 2020).

Nepal has experienced direct impacts of climate change and is one of the most vulnerable countries to climate change in the world. The data trend from 1975 to 2005 shows that the mean annual temperature has been increasing by 0.06°C while the mean rainfall has been decreasing by 3.7 mm (-3.2%) per month per decade (MoPE, 2016, as cited in CBS, 2017).The impact of climate change in agriculture has directly affected economy and lives of people in Nepal. The national climate change impact survey conducted in 2016 have reported the higher percentages of households in tropical, sub-tropical and temperate zones are mostly affected by disease, drought, windstorm, hailstorm, and cold wave in last five year due to climate change (CBS, 2017).

Until 90s, the studies on agroforestry were more focused on livelihood aspects such as contribution of agroforestry in household economy profitability of agroforestry over agriculture-based farming system. However, a paradigm shift has occurred in agroforestry research and a more focus has been laid on the carbon sequestration and potential role of agroforestry in climate change mitigation. Agroforestry is relatively new name for the age-old practice of growing trees and shrubs with crops and/or animals in interacting combinations on the same unit of land (Pokhrel et al., 2013)**.** In a developing country like Nepal where the per capita landholding is less than one hectare (0.96 ha) and which continue to further decrease because of land fragmentation followed by the population growth agroforestry practice could be a viable option from both the livelihood and climate change mitigation point of view (as cited by Dhakal et al., 2012). Dhakal et al. (2022) has mentioned agroforestry practices as an opportunity in the present socio-economic context of Nepal, where farmers are forced to leave their farmlands fallow due to labor scarcity resulting from youths out-migrating for jobs. This study aimed to determine the carbon stock in biomass and in soil in agroforestry systems especially in home garden maintained in two different ecological regions namely Terai and Mid-hills of western Nepal.

2 Study Area and Methodology

2.1 Study area

The study was conducted in Anandaban village development committee (V.D.C.) of Rupandehidistrict (province 5) and Hemja V.D.C. of Kaski district (province 4) of western Nepal.

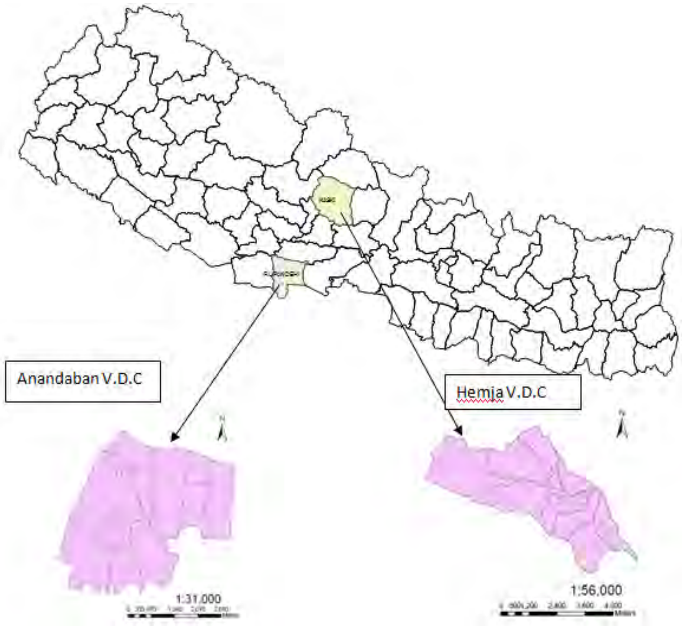


Fig. 1 A map showing the study areas.

Anandaban V.D.C. lies on the right side of the Siddhartha Highway while from Bhairahawa to Butwal covers an area of 14.7 km^2. It is situated at an altitude of 134 m above mean sea level (msl) with longitude 83^{0}27'35.83"E and latitude 27^{0}37'48.19"N. Major ethnic groups residing in the area were Brahmin, Chettri, Gurung, Magar and Tharu. The vegetations of the area were dominated by *Dalbergia sissoo, Shorearobusta, Leucaena leucocephala, Artocarpus lakoocha.*

Climatologically, the area experiences the hot and humid climate during the summer and cold during the winter. For the period of 1981-2010, the highest average maximum temperature was 36.4^{0}C and the lowest average minimum temperature was 8.8^{0}C while, the highest average rainfall was 545.6 mm in the month of July (Fig. 2).

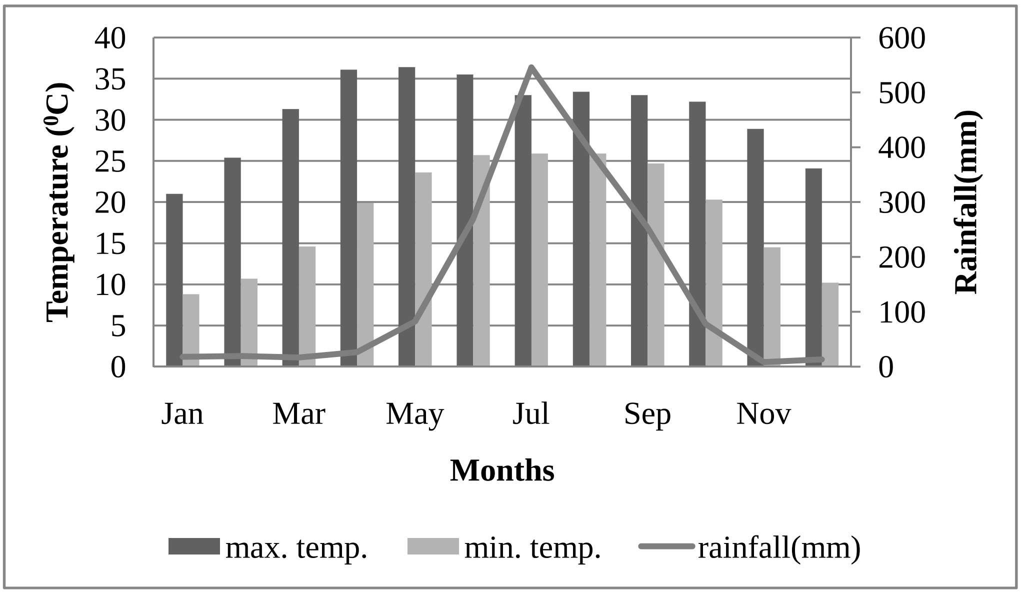


Fig. 2 Average minimum-maximum temperature and rainfall (1981-2010) of Bhairahawa (Rupandehi) airport (Source: Department of Hydrology and Meteorology).

Hemja V.D.C. lies on western Mid-hills scattered on both sides of Pokhara-Baglung highway and covers an area of 19.71 km^2. It is situated at an altitude of 840-1471 m above mean sea level (msl) with longitude $83^0$52'46"E to $83^0$58'18"E and latitude $28^0$14'48"N to $28^0$18'05"N. Major ethnic groups inhabiting in the area were Brahmin, Cheetri, Magar, Gurung, Newar, Gharti, Kami, Damai and Sarki. Major vegetations include *Schimawallichi, Castanopsis indica, Myrica esculenta, Alnus nepalensis, Madhuca longifolia* in and around the study site.

Climatologically, it experiences the temperate type of climate. For the period of 1981-2010, the highest average maximum temperature was 30.6^0C and the lowest average minimum temperature was 7.1^0C while, the highest average rainfall was 940.3 mm in the month of July (Fig. 3).

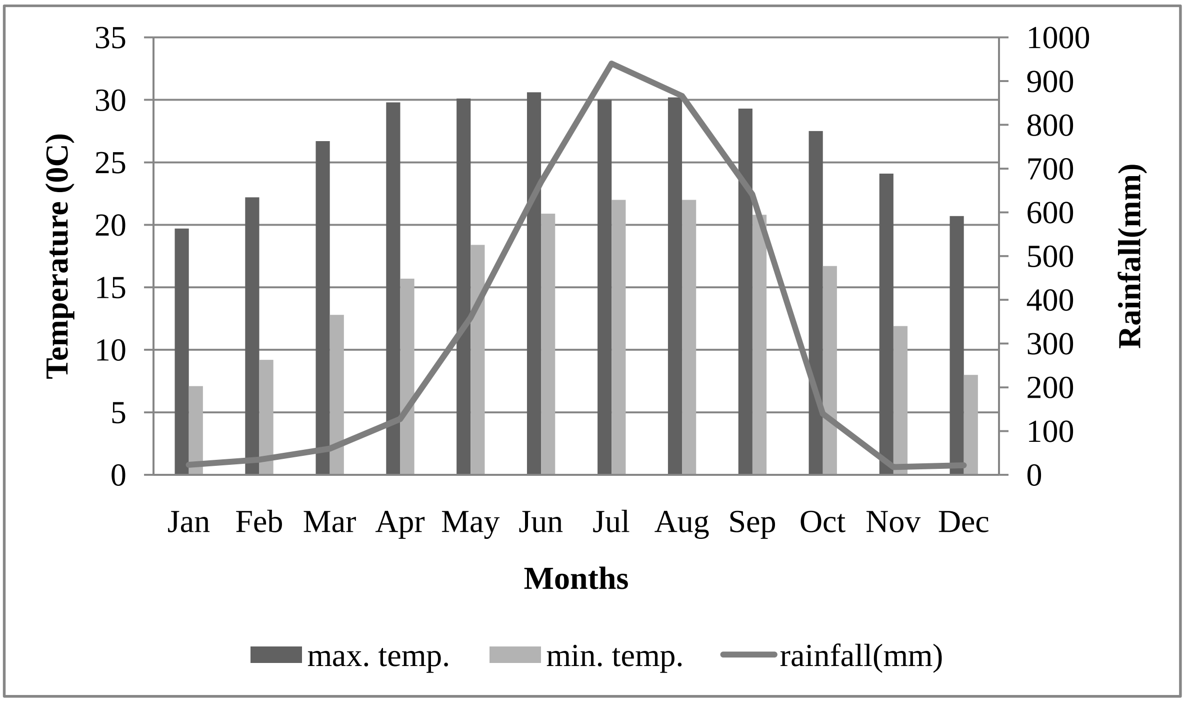


Fig. 3 Average minimum-maximum temperature and rainfall (1981-2010) of Pokhara (Kaski) airport (Source: Department of Hydrology and Meteorology).

2.2 Data collection

2.2.1 Household survey

A survey was conducted with open ended questionnaires. 30 households from Terai region and 50 households from Mid-hills region were interviewed for the study purpose.

2.2.2 Biomass carbon stock assessment

Carbon stock assessment was carried out in home garden and nearby area where number of trees were grown for various purposes. 30 home gardens from Terai region and 50 home gardens from Mid-hills region were selected purposively from the study area. Plots of the quadrat size 20 m × 20 m were set in the home garden or the nearby area of each household. The name and number of trees inside the plots were listed with the help of the information given by the respondents. Girth measuring tape was used to measure the girth at breast height (1.30 m from the ground level) of the individual trees inside the plot and later converted it to its diameter (DBH) equivalent using the equation:

$Diameter\ (cm) = circumference\ (cm)/\pi.$

where $\pi = 3.1416$ (Labata et al., 2012).

The biomass was estimated by using allometric equation models given by Chave et al. (2005):

$$Above\ ground\ biomass\ (AGB) = 0.0509 \times \rho\ (dbh)^{2} H$$

where, ρ = wood specific gravity (g/cm^3), dbh = expressed in cm, and H= height of the plants in m.

The value of ρ was obtained from the secondary data source of Zanne et al. (2009). But, the above ground biomass (AGB) of plants with dbh<10 cm (called sapling) were estimated using global equation given by Zianis (2008). The equation is:

$AGB = a\ (dbh)^{b}$ (Zianis, 2008)

where, a=0.1424 and b=2.3679

Above ground biomass tons per hectare (t/ha) was calculated as:

$$AGB = \frac{sum\ of\ AGB\ of\ the\ plot\ x\ 100\ x\ 100}{20\ x20}\ X\ \frac{1}{1000}$$

The root-shoot ratio was used to estimate below ground biomass (BGB) as an inventory could calculate root biomass as not less than 10 or 15% of above-ground biomass (Mac Dicken, 1997).

$BGB = AGB \times 0.15$

Below ground biomass tons per hectare (t/ha) was calculated as:

$$BGB = \frac{sum\ of\ BGB\ of\ the\ plot\ x\ 100\ x\ 100}{20\ x20}\ X\ \frac{1}{1000}$$

The carbon stock in living biomass ($C.S_B$) was estimated by multiplying the sum of dry biomass (i.e. $T.B = AGB + BGB$) by 0.47 which is the default carbon fraction in dry biomass given by IPCC (2006, as cited by Shirish, 2012):

$C.S_B = T.B \times 0.47$ kg

Finally, the carbon stock in the biomass was converted into tons per hectare (t/ha) as:

$$Carbon\ stock\ in\ biomass = \frac{sum\ of\ biomass\ carbon\ stock\ of\ the\ plot\ x\ 100\ x\ 100}{20\ x20}\ X\ \frac{1}{1000}$$

2.2.3 Soil carbon stock assessment

The soil samples were collected from same home gardens of study sites i.e., 30 samples from Terai region and 50 samples from Mid-hill samples. Soil samples were collected from 20cm depth with the help of the digger at almost about the center of the quadrat which had been already fixed for the biomass carbon stock assessment. The soil samples from Terai were mixed in a single bulk and similarly the soil samples from Mid-hills were also mixed in another single bulk. The soil samples were air dried separately for one week in shade and stored in air tight zipper plastic bags. Samples of soil were brought to Ecology Laboratory in the Central Department of Botany, Tribhuvan University for further analysis of various parameters to determine carbon stock in soil.

The soil carbon stock was estimated by applying the relation given by Winrock International as REDD Methodological Module 2009. The relation was given as:

$$C_{SOCsp,i,t=0} = C_{SOC\ sample,sp,i,t=0} \times BD_{sample,sp,i,t=0} \times Dep_{sample,sp,i,t=0} \times 100$$

$C_{SOCsp,i,t=0}$ = Carbon stock in soil organic carbon for sample plot *sp*, stratum *i*, at time t=0; t C ha^{-1}

where $C_{SOC\ sample,sp,i,t=0}$ = soil organic carbon of the sample in sample plot *sp*, stratum *i*, at time t=0, determined in the laboratory in g C/100 g soil (fine fraction <2 mm); $BD_{sample,sp,i,t=0}$ = bulk density of fine (<2 mm) fraction of mineral soil in sample plot *sp*, stratum, at time t =0, determined in the laboratory in g fine fraction cm^{-3} total sample volume; $Dep_{sample,sp,i,t=0}$ = depth to which soil sample is collected in sample plot in stratum *i* at time t=0, sp = 1, 2, 3 … Pi sample plots in stratum *i*, i = 1, 2, 3 … M strata. t= 0, 0 years elapsed since the start of the project activity.

The bulk density of soil was determined as described by Gupta (2000) as:

$$Bulk\ density = \frac{Mass\ of\ the\ soil(g)}{Volume\ of\ soil(cm^3)}$$

Similarly, Walkey and Black's rapid titration method (Gupta, 2000) was referred to estimate the soil organic carbon of the soil samples.

2.2.4 Total carbon stock

The total carbon stock of the sampled plots was ultimately calculated by summing up the carbon stock due to biomass and carbon stock due to the soil:

Total carbon stock (t/ha) = Carbon stock in biomass (t/ha) + Carbon stock in soil (t/ha)

2.3 Statistical analysis

All data were subjected to the test of normality. Mann-Whitney U-test was used for the comparison of mean and Pearson correlation was performed to correlate the variables. Linear regression was carried out to observe the pattern between the variables. Statistical package SPSS 16.0 (SPSS Inc.2007) and R were used for the statistical analysis. The relevant data were analyzed and presented in their respective forms inferential and descriptive statistics.

3 Results and Discussion

3.1 Biomass carbon stock assessment

Mean and standard deviation measurement of various parameters for biomass carbon stock assessment has been given in Table 1.

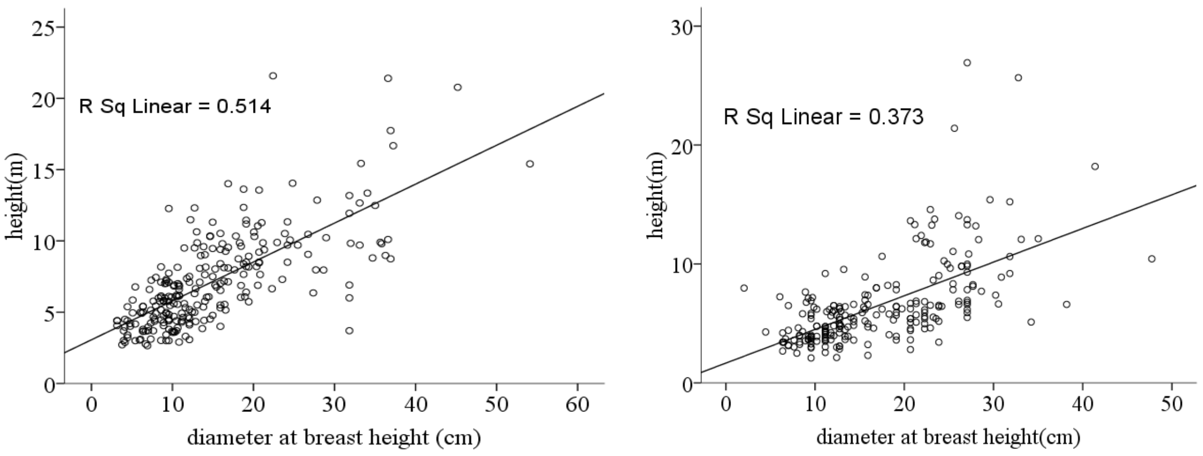
Table 1 Parameters for biomass carbon stock assessment in two ecological regions.

Parameters	**Terai** (mean ± sd)	**Mid-hill** (mean ± sd)
*Diameter at breast height (dbh)(cm)	14.91 ± 8.69 (n= 248)	17.1853 ± 7.81 (n= 228)
*Tree height(m)	7.13 ± 3.3316 (n= 248)	6.54 ± 3.618 (n= 228)
Basal Area(m^2/ha)	4.788 ± 3.188 (n= 30)	3.1725 ± 1.819 (n= 50)
Tree stem volume(m^3/ha)	23.95 ± 1.98 (n= 30)	13.574 ± 1.26 (n= 50)
Above ground biomass(t/ha)	18.97 ± 1.506 (n= 30)	9.741 ± 9.415 (n= 50)
Below ground biomass(t/ha)	2.745 ± 2.306 (n= 30)	1.456 ± 1.411 (n= 50)
Total biomass(t/ha)	21.0502 ± 1.76 (n= 30)	11.1603±1.082 (n= 50)
Biomass carbon stock (t/ha)	10.255 ± 8.14 (n= 30)	5.24 ± 5.0874 (n= 50)

(n= number of plots, for *dbh and *height, n= number of plants).

The diameter at breast height and the height of the plants in both Terai and mid-hill regions showed statistically significant positive linear relationship (Fig. 4a and 4b). It showed a strong relationship i.e., the study found that the height increased proportionately with the increasing dbh. Pearson correlation test also revealed the higher correlation between dbh versus total height and basal area versus above ground biomass in Terai than in mid-hill (Table 2). Day et al. (2021) evaluated different correlation regression models for predicting tree-height and DBH. Their study also showed a positive and significant relationship between DBH and height in *Acacia auriculiformis*. Another study in boreal forest also found strong correlation between DBH and heightand further reported that the strong correlation makes it possible to model the DBH-height relationship with relatively high accuracy without considering growing conditions (Chen et al., 2020).

The mean of biomass carbon stock was found to be 10.255 t/ha for Terai and and 5.24 t/ha Mid-hill respectively (Table 1, Fig. 6) which was found to be significantly higher in Terai (Mann-whitney U test, p=0.001). In Terai region, there is higher temperature and humid condition which is considered a favorable situation for the metabolism of micro-organisms. There was higher litter fall and also the rate of decomposition was higher in Terai due to which large number of carbons released is stored in biomass not in soil. Betemariyam et al. (2020) reported 27.4 ± 16.9 Mg C ha^{-1} biomass carbon stock in home garden of Ethiopia. Another study of agroforestry in Northern Ethiopia reported the biomass carbon stock to be 13.8 Mg ha^{-1} (Gebremeskel et al., 2021). The study of agroforestry in mid-hill Nepal has also reported the total biomass carbon stock to be 15.05 ± 3.934 Mg C ha^{-1} (Paudel et al., 2022).



(a) (b)

Fig. 4 Fitted linear regression line between height and diameter at breast height of plants in (a) Terai and (b) mid-hill region.

Table 2 Pearson correlation test result.

Parameters	**Value of r (Mid-hills)**	**Value of r (Terai)**
dbh- Total height	0.611	0.717
Basal area - Above ground biomass	0.891	0.942

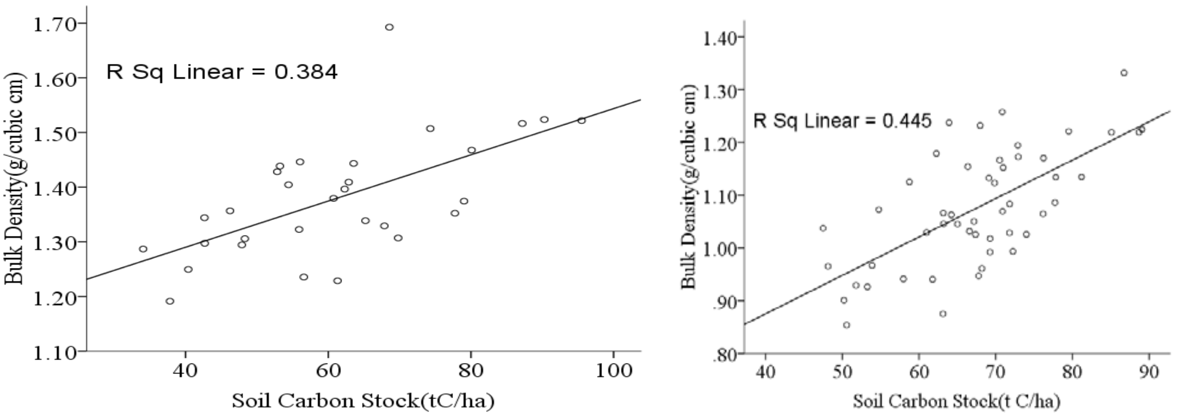
3.2 Soil carbon stock assessment

Mean and standard deviation measurement and correlation of various parameters for soil carbon stock assessment has been given in Table 3.

Table 3 Parameters for soil carbon stock assessment in two ecological regions.

Measurement	Parameters	Region	
		Terai	Mid-hill
mean ± sd	Soil bulk density(g/cm^3)	1.38 ± 0.107 (n= 30)	1.076 ± 0.11062 (n= 50)
	Soil carbon stock (t/ha)	61.17 ± 15.808 (n= 30)	67.608 ± 10.121 (n= 50)
Correlation coefficient (r)	Soil bulk density Vs Soil organic carbon	0.620	0.667
	Biomass carbon stock Vs Soil carbon stock	0.085	-0.50

The mean of soil bulk density of Terai was significantly higher (Mann Whitney U test, $p<0.05$) which was found to be 1.38 g/cm^3 and that of mid-hill was found to be 1.076 g/cm^3. However, the mean of soil carbon stock was significantly higher (Mann Whitney U test, $p=0.025$) in mid-hill (67.608 t/ha) than in Terai (61.17 t/ha). The correlation coefficient between soil bulk density and soil organic carbon were found to be significantly positive ($p<0.05$) in both regions (Table 3). However, the correlation between biomass carbon stock and soil carbon stock was found to be negative (Table 3) in mid-hill. Though, positive correlation in Terai, it was not significant ($p=0.655$). Linear regression showed statistically significant linear positive pattern between bulk density and soil carbon stock in both regions (Fig. 5 a, b). The result of the study was comparable to the mean of soil carbon stock in Karahiya community forest of Rupandehi district, Nepal (Shirish, 2012). Likewise, the finding was 1.3 times greater than the soil organic carbon stock in the farm with trees in Kanchanpur district, Nepal (Baral et al., 2013). Also, the mean soil carbon stock of this work was 1.24 times greater than that in Jarneldhara community forest and 2.06 times more than that in LipindeviThulopakho community in Palpa district, Nepal (Khanal et al., 2010). Also, the study in Chitwan and Gorkha showed soil carbon stock in the Hill CF (111.4 t ha^{-1}) was found to be more than the that in the Terai CF (95.1 t ha^{-1}) (Pandey and Bhusal, 2016). Another study conducted in Ethiopia also gave the similar result for the soil carbon stock with the value 64.18 Mg C/ha (Gebre, 2018). According to Sakin (2012), very strong relationship was determined between soil organic carbon stock and soil textural groups. Moreover, few studies have focused on the effects of bulk density methods on soil organic carbon stock and the accuracy of the different methods worldwide. Best estimator method of bulk density gives good estimation on carbon stock (Gebre, 2018). The result is comparable to the soil carbon in Dry semi-deciduous forest of Ecudorian coast which was 63.28 Mg C per hectare (Macias et al., 2017). SOC content and bulk density are the two main factors defining SOC stock. The distribution of SOC contents and stocks reflected the large variation in soil type, climatic and altitudinal conditions. The good accuracy of the bulk density prediction models is achieved by the combination both of the variability of bulk density values for every soil type and within Andosols samples (Allo et al., 2020). SOC changes were correlated with decreased erosion and increased mineralizable carbon. The regression analysis revealed that SOC changes from cover cropping correlated with improvements in soil quality (Jian et al., 2020). Soil organic carbon (SOC) stock in farms with *Rhamnus prinoides* intercropping was found to be 121.9 ± 29 Mg ha^{-1} (Gebremeskel et al., 2021).



(a) (b)

Fig. 5 Fitted linear regression line between soil carbon stock and soil bulk density of sampled soil of (a) Terai and (b) mid-hill regions.

The mean of total carbon stock obtained from the biomass carbon stock and soil carbon stock was found to be 71.433 t/ha in Terai and 72.856 t/ha in Mid-hills (Fig. 6) but the difference was not statistically significant (Mann Whitney U test, p=0.409). Paudel et al., 2022 also found that the total carbon stock between the two practices -improved and traditional was insignificant. The finding is however, 3.75 times less than the Karahiya community forest of Rupandehi district, Nepal (Shirish, 2012). The range of total carbon stock was also comparable to the study on Dry Deciduous Forest which was 69.62 Mg of carbon per hectare and 123.05 Mg of carbon in dry semi deciduous forest of Ecudorian coast (Macias et al., 2017). The total carbon stocks in the Gerupani Oak Forest and the Pakhapani Pine Forest were151.19 Mg C ha^{-1} and 70.70 Mg C ha^{-1} respectively (Shrestha and Devkota, 2013). Shrestha and Singh (2008) have reported that the total carbon stock 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. The total C stocks in home garden of Ehiopia was found to be 157.77 ± 29.20 Mg C ha^{-1} (Betemariyam et al., 2020).Total carbon stock in home garden in Makwanpur district of Nepal was reported to be 10.32 t/ha (Ghimire and Bolakhe, 2020).

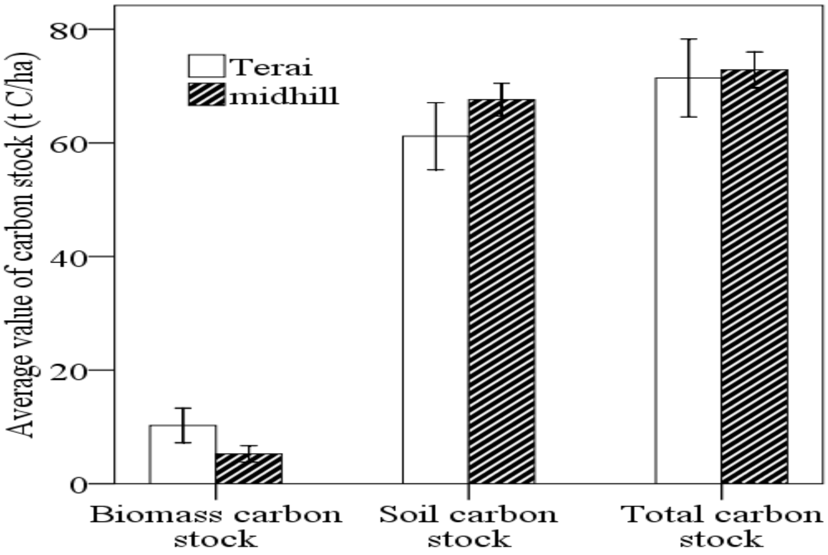


Fig. 6 Carbon stock in biomass and carbon stock in soil and the total carbon stock in the sampled plots of Terai and Mid-hill regions. Columns represent average values with vertical bars as standard error of the mean.

4 Conclusion

Agroforestry can store the large amount of carbon from the atmosphere. People are exercising different mode of agroforestry system for their daily livelihood activities. Home garden is common type of agroforestry system being adopted since long. Carbon sequestration through agroforestry system is an emerging strategy to cope with the immediate and long-term impacts of climate change in all its coping options such as adaptation, mitigation and resilience.

The result found that the mean of total biomass carbon stock was found to be 10.255 t/ha and 5.24 t/ha for Terai and Mid-hill respectively. The soil carbon stock was found 61.17 t/ha in Terai and 67.608 t/ha in mid-hills whose bulk density found 1.38 g/cm^3 in Terai and 1.076 g/cm^3 in Mid-hills region. However, there was no significant difference (p>0.05) found in the total carbon stock (biomass and soil) between two ecological regions i.e., 71.433 t/ha in Terai and 72.856 t/ha in Mid-hills.

Study concludes soil has larger capacity to store organic carbon than the vegetation that grows in agroforestry system because soil formed in a place for million years and reserve large amount during the period. Also, higher biomass contents in Terai's home garden have lower carbon constituent in the soil where as the result is just opposite in Mid-hills region where higher amount of soil carbon grows lesser amount of tree biomass in the farmers' home garden because of climatic region but not of the difference in composition and pattern that the people practicing agroforestry systems in these two different ecological regions of western Nepal.

Acknowledgement

I am heartily thankful to the respondents of the study area. I also express my gratitude to my supervisor Professor Dr. Ram Kailash Prasad Yadav for this support and my family.

References

Allo M, Todoroff P, Jameux M, Stern M, Paulin L, Albrecht A. 2020. Prediction of tropical volcanic soil organic carbon stocks by visible-near-and mid-infrared spectroscopy. Catena, 189

Baral SK, Malla R, Khanal S, Shakya R. 2013. Trees on farms: diversity, carbon pool and contribution to rural livelihoods in Kanchanpur district of Nepal. Banko Janakari, 3(1)

Beenhouwer MD, Geeraerta L, Mertensa J, Geela M Van, Aertsa R, Vanderhaegenb K., Honnaya O. 2016. Biodiversity and carbon storage co-benefits of coffee agroforestry across a gradient of increasing management intensity in the SW Ethiopian highlands. Agriculture, Ecosystems and Environment, 222: 193-199

Betemariyam, M, Negash, M, Worku, A. 2020. Comparative Analysis of Carbon Stocks in Home Garden and Adjacent Coffee Based Agroforestry Systems in Ethiopia. Small-scale Forestry. Small-scale Forestry, 19: 319-334

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Earnus D, Folster H, Fromard F, Higuchi N, Kira T, Leacure JP, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T. 2005 Tree allometry and improved estimation of carbon stocks and balance in Tropical forests. Oecologia, 145(1): 87-99

Chen J, Yang H, Man R, et al. 2020. Using machine learning to synthesize spatiotemporal data for modelling DBH-height and DBH-height-age relationships in boreal forests. Forest Ecology and Management, 466: 118104

Dey T, Ahmed S, Islam MA. 2021. Relationships of tree height-diameter at breast height (DBH) and crown diameter-DBH of *Acacia auriculiformis* plantation. Asian Journal, 5: 71-75.

Dhakal A, Cockfield G, Maraseni TN. 2012. Agroforestry based farming system, farm characteristics and climate change: A study of Dhanusha District, Nepal. Disseratation, University Of Southern Queensland, Queensland, Australia

Dhakal A, Maraseni TN, Timsina J. 2022. Assessing the potential of agroforestry in Nepal: socio-economic and environmental perspectives. In: Agriculture, Natural Resources and Food Security: Lessons from Nepal. 375-394, University of Southern Queensland, Australia

Dyani SK, Ram A, Newaj R, Handa AK, Dev I. 2020. Agroforestry for carbon sequestration in tropical India. In: Carbon management in Tropical and Sub-Tropical Terrestrial Systems. 313-331, Springer

Gebre AB. 2018. Comparison of bulk density methods in determining soil organic carbon storage under different land use types. Journal of Soil Science and Environmental Management, 9(1): 13-20

Gebremeskel D, Birhane E, Rannestad MM, et al. 2021. Biomass and soil carbon stocks of Rhamnus prinoides based agroforestry practice with varied density in the drylands of Northern Ethiopia. Agroforestry Systems, 95: 1275-1293

Ghimire P, Bolakhe S. 2020. Agroforestry systems: Biodiversity, carbon stocks and contribution to rural livelihood. Journal of Agriculture and Forestry University, 4(1): 197-205

Gupta PK. 2000. Methods in environment analysis water, soil and air. Agrobios, India. http://www.dhm.gov.np/uploads/climatic/657898146NORMAL%20FILE.pdf

Jian J, Du X, Reiter MS, Stewart RD. 2020. A meta-analysis of global cropland soil carbon changes due to cover cropping. Soil Biology and Biochemistry, 143: 107735

Jose S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76(1): 1-10

Khanal Y, Sharma RP and Upadhyaya CP.2010. Soil and vegetation carbon pools in two community forests of Palpa District, Nepal. Banko Janakari, 20(2): 34-40

Labata MM, Aranico EC, Tabaranza ACE, Patricio JHP, Amparado RF Jr. 2012. Carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines. Advances in Environmental Sciences, 4(1): 5-11

MacDicken KG. 1997. A Guide To Monitoring Carbon Storage In Forestry and Agroforestry Projects. Winrock International Institute for Agricultural Development, USA

Macias CAS, Orihuela JCA, Albad SI. 2017. Estimation of above-ground live biomass and carbon stocks in different plant formations and in the soil of dry forests of the Ecuadorian coast. Food and Energy Security

National Climate Change Impact Survey: A Statistical Report. 2017. Central Bureau of Statistics, Kathmandu, Nepal

Pandey HP, Bhusal M. 2016. A comparative study on carbon stock in Sal (*Shorearobusta*) forest in two different ecological regions of Nepal. Banko Janakari, 26: 1

Pantera A, Mosquera-Losada MR., Herzog F, et al. 2021. Agroforestry and the environment. Agroforest Syst 95: 767-774

Paudel D, Tiwari KR, Raut N, et al., 2022. Species Composition and Carbon Stock in Different Agroforestry Practices in the mid-hills of Nepal. Journal of Sustainable Forestry, DOI: 10.1080/10549811.2022.2123350

Pokhrel CP, Sharma S, Yadav RKP. 2013. Agroforestry and ecosystem services. International Journal of Science Innovations and Discoveries, 3(1)

Portner HO, Roberts DC, Adams H, Adler C, Aldunce P, Ali E, Begum RA, Betts R, Kerr RB, Biesbroek R, Birkmann J. 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. IPCC, Geneva, Switzerland

REDD Methodological Module Estimation of carbon stocks in the soil organic carbon pool Version 1.0. 2009. REDD

Sakin E. 2012. Organic carbon organic matter and bulk density relationships in arid-semi arid soils in Southeast Anatolia region. African Journal of Biotechnology, 11(6):1373-1377

Shrestha BM and Singh BR. 2008. Soil and vegetation carbon pools in a mountainous watershed of Nepal. Nutrient Cycling in Agroecosystems, 81: 179-191

Shrestha BP, Devkota BP. 2013. Carbon stocks in the Oak and Pine Forests in Salyan District, Nepal. Banko Janakari, 23(2): 30-36

Shrestha BP. 2009. Carbon sequestration in Schima-Castanopsis forest: A case study from Palpa District. The Greenery, 7(1): 34-40

Shrish O. 2012. Carbon stock of selected tree species of Karahiya community forest, Rupandehi District, Nepal. MSc Dissertation, Central Department of Botany, Tribhuvan University, Kathmandu, Nepal

Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, and Chave J. 2009. Global wood density database. Dryad identifier. Accessed from http://Hdl.Handle.Net/10255/Dryad.235

Zianis D. 2008. Predicting mean aboveground forest biomass and its associated variance. Forest Ecology and Management, 256(6): 1400-1407