Journal of Ecosystem & Ecography
ISSN: 2157-7625

Bajigo et al., J Ecosys Ecograph 2015, 5:1
DOI: 10.4172/2157-7625.1000157

Research Article | Open Access

Estimation of Carbon Stored in Agroforestry Practices in Gununo Watershed, Wolayitta Zone, Ethiopia

Aklilu Bajigo[1]*, Mikrewongel Tadesse[2], Yitebitu Moges[3] and Agena Anjulo[4]

[1] *Jigjiga University College of Dry Land Agriculture (Natural Resource Management Department) Jigjiga, Ethiopia*
[2] *Mekelle University College of Dry Land Agriculture and Natural Resources, Mekele, Ethiopia*
[3] *National REDD+ coordinator, Addis Ababa, Ethiopia*
[4] *Arbaminch University Academic and Research, Vice President, Ethiopia*

Abstract

This study was conducted in Gunugo watershed at Wolayitta zone to estimate the amount of carbon stored in traditional agroforestry practices and along different elevation gradients. Dominant agroforestry practices (home garden, parkland and woodlot) were used, and the elevation gradient was stratified in to upper, middle and lower altitudes. With three replications, a total of 27 sampling points were used. A complete measure in home garden, 50 m × 100 m quadrates in parklands, and 10 m × 10 m quadrates for woodlot were used and DBH and height was measured. At every sampling point in a 20 × 20 m plot, soil samples were taken from top and sub soil at each corner and at center. One composite sample was taken from each sampling point at each soil depths, to have a total of 54 soil samples. Then, above ground and below ground tree carbon, total tree biomass carbon, soil organic carbon and total carbon in agroforestry practices and along elevation gradient was determined at $p<0.05$. From the agroforestry practices, woodlot was significantly higher in above ground tree carbon (106.47 Mg/ha), total tree biomass carbon (133.09 Mg/ha) and total carbon (448 Mg/ha) followed by home gardens and parklands. However, there was no significant difference in soil organic carbon among agroforestry practices even though higher concentration was observed under home garden. Despite no significant differences was seen between elevation gradients for above ground tree carbon, total biomass tree carbon, soil organic carbon and total carbon. It had the order of lower>middle>upper elevation, suggesting that more plantations are needed in upper and middle elevation for better carbon storage. Lower elevation was dominated by high density Eucalyptus woodlot, had better total carbon stock. However, Eucalyptus woodlot would create drought, so that it needs to be replaced by other fast growing trees such as Gravillea Robusta.

Keywords: Biomass; Home garden; Organic matter; Parkland; Soil; Woodlot

Introduction

An agroforestry system consists of one or more agroforestry practices that are practiced extensively in a given area; usually have biological, ecological and economic interactions among the components [1,2]. The major components of agroforestry systems are trees or shrubs (woody perennials, including bamboos). These are deliberately retained or planted on the farmland [1] to provide multiple products and services such as carbon sequestration and litter fall which improve soil structure and reduce erosion hazards.

In many studies estimation of woody species biomass have been done by whole tree method. However, it is an old approach and have cost. Therefore, woody species biomass is determined using allometric equations with different measured variables such as DBH, height and others [3]. The structure and composition of vegetation (tree species, size, and height, density etc.) affects the above ground carbon stock [4,5]. Belowground biomass is also the major pool of carbon. However, determination of belowground biomass is comparatively difficult than above ground biomass of carbon [3].

Most of carbon in trees and shrubs is accumulated in above ground biomass (AGB) and 50% of the total biomass is taken as carbon stock. Aboveground carbon stock is the amount of carbon that is assumed to be 50% of the total vegetation biomass made up by carbon [3,6]. The belowground biomass of vegetation is considered as a fraction that take about 25-30% of above ground biomass depending on the nature of plant, its root system and ecological conditions [3,6]. Total biomass of carbon is the sum of above and below ground vegetation carbon [3].

For trees used in the various systems Sub-Saharan Africa, the above ground woody biomass carbon was estimated to be 6, 13, or 23 Pg C, while the below ground carbon biomass and carbon in the soil store 8 to 54 Pg carbon [5]. In tropical agroforestry system it ranges from 0.29 to 15.21 Mg/ha/year [3] in sub Saharan Africa [5].

Soils are the largest pool of terrestrial carbon and its loss can significantly affect the global carbon budget. The soil carbon pool comprise organic or inorganic carbon and it can be either sequestered directly i.e. inorganic chemical reactions that convert CO_2 into soil inorganic carbon compounds such as calcium and magnesium carbonates. It can also be indirectly C fixation through photosynthesis [6]. The majority of carbon enters in the ecosystem is by photosynthesis which would be accumulated in the above ground biomass. However, more than half of this carbon would enter to soil through litter decomposition, root growth, turnover, and root exudates [6]. The soil carbon stock of various agroforestry system and species are described by [3,6].

Different agroforestry practices have different potential to store carbon and depending on their species composition and different

***Corresponding author:** Aklilu Bajigo, Jigjiga University College of Dry Land Agriculture (Natural Resource Management Department), Jigjiga, Ethiopia, Tel: +251 344 40 40 05; Fax:+251-344-40-1090; E-mail: bajigoaklilu05@gmail.com

Received April 27, 2015; **Accepted** May 23, 2015; **Published** May 25, 2015

Citation: Bajigo A, Tadesse M, Moges Y, Anjulo A (2015) Monitoring of Seasonal Variation in Physicochemical Water Parameters in Nalasopara Region. J Ecosys Ecograph 5: 157. doi: 10.4172/2157-7625.1000157

ecological and environmental variables [3,5-10]. Along elevation gradients, carbon stock is higher in the lower elevations than upper elevations because of better soil depths, lower soil surface erosion and higher stand density in the lower slopes [11,12]. On the other hand, biomass carbon can be high in upper elevations due to high stand structural parameters (size, height, etc.) [4].

Gununo watershed was selected for that it is prone to land degradation and resource depletions such as soil erosion, flooding, and loss of biodiversity [13,14] due to high population pressure and density [15]. Despite of this, the local people have been using different traditional agroforestry practices as strategies to combat the problems through its protective and productive roles. However, studies concerning carbon storage potential of traditional agroforestry practices, specifically estimating total carbon stored in traditional agroforestry practices in the watershed at different elevation gradient was lacking. And this has also global carbon balance meaning.

General objective was to estimate the amount of carbon stored in traditional agroforestry practices in Gununo watershed. Specifically, to determine above ground and below ground tree carbon, total tree biomass carbon, soil organic carbon and total carbon among agroforestry practices and along elevation gradients.

Materials and Methods

Study area description

Wolayitta zone is in southern nations, nationalities and peoples (SNNP) region of Ethiopia with a total land area of 4537.5 square kilometers is located between 6°4´N to 7°1´N latitudes and 37°4´E to 38°2´E longitudes. It is located 22 km from Sodo town and about 330 km from Addis Ababa. The watershed has an area of about 544 hectare with three rural Kebeles namely: Demba Zamine (middle elevation), Doge Hunchucho (lower elevation) and Chew kare (upper elevation).

Gununo watershed has plain lands, plateaus, hills and rugged mountains topography with an altitude ranging from 1937 to 2100 meter above sea level. The mean annual temperature of the site is 19.2°C and the mean annual rainfall is 1335mm with bimodal rain pattern [15,16].

Soil of the watershed is Eutric Nitosol according to FAO/UN classification system (Belay, 1992). Soil erosion in watershed is severe due to conversion of natural forests to other land uses. The study area has high population pressure i.e. around 450 person per km^2 [16], and an average land holding is about 0.25 ha per household and drive farmers to cultivate slope lands [14]. Agroforestry is one of the major land uses at the area. Different species (tree crops and woody species) such as Enset ventricosum Musa accuminata, Moringa oleifera and Brassica oleracea serve as primary food source while Croton macrostachyus and different Acacia species are the dominant trees in the degraded natural forest of Wolayitta [16].

Sampling procedures and data collection

The topography of the watershed has steep slopes and undulating landscapes. This heterogeneous landscape was stratified in to three different homogeneous transects after delineating topographic map of the watershed. Consequently, from upper (2006 to 2040), middle (1972 to 2006) and lower zone (1937 to 1971) meters above sea level (m.a.s.l.) representative samples were taken. At each zone, the middle point was chosen for horizontal transect walk i.e. at 2023, 1989 and 1954 m.a.s.l. for upper, middle and lower transect respectively. These transect lines thatches all the three Kebeles that the watershed contains. The distance of each transect line was measured from the delineated watershed map and sampling points were distributed proportionally. Accordingly, at each horizontal transect line the first sampling point was randomly selected i.e. some distance away from initial standing point. Then the next sampling point (quadrate) was allocated systematically at every two kilometer by using GPS.

To estimate the carbon stored in woody components of agroforestry species, no quadrates were used in home garden; rather a complete measure of woody species was used [17]. In parklands, woody species data was collected from 50 m × 100 m sample size quadrates [18] and for woodlot 10 m × 10 m sample quadrates were taken [19]. All the woody species in each sample plot greater than or equal to 5 cm DBH (diameter at breast height) was taken [17]. Height less than 1.5 m was considered as seedlings while height between 1.5 and 3 m was taken as sapling and height greater than 3 m was taken as tree [19]. The average height of woody species was used for home gardens (average of upper and middle story). At every sampling point, number of individuals per plot, DBH, height, and crown diameter was measured and recorded by using measuring tape, caliper, and hypsometer.

The spatial analogue approach [20,21] which is important to study the effect of different land use on soil properties was used to take soil samples for organic carbon determination. At every sampling point from selected agroforestry practices along each elevation gradient, 20 × 20 m square plot was taken for soil sampling from each corner and at center of the plot. From the top (0-15 cm) and sub soil (15–30 cm) soil depths, samples were taken by using auger. Two samples were taken from each sampling point after compositing the same depths together to get one representative sample. Three elevation level * three agroforestry practices * three replication * two soil depth, and hence total of 54 soil samples were taken. The soil samples were analyzed in Melka Werer Agricultural Research Center soil laboratory. Then the soil organic carbon was determined following the wet digestion method [22], and the percent organic matter was computed from the percent organic carbon using a conversion factor of 1.724.

Data analysis

All trees>5 cm DBH were considered for determining above ground biomass. Accordingly, aboveground total biomass determination equation developed for Tropical Agroforestry [23] was used: $\ln Y = -3.375 + 0.948 \times \ln(D^2 \times H)$ Where; Y=Aboveground total biomass per tree (kg), D=DBH (cm) and H=Height (m). The above ground carbon stock was considered as 50% of above ground biomass and belowground carbon stock was considered as 25% of above ground carbon stock [3,24]. The soil organic carbon was determined following [25] SOC (t/ha)=BD (g/cm^3) × depth (cm) × carbon%. Where BD is bulk density and SOC is soil organic carbon. Total carbon is the sum of vegetation carbon and soil carbon. Two way ANOVA was carried out at $P<0.05$ with the help of (SPSS versions 16), to carbon stock data analyze on agroforestry practices and elevation gradients. Least significance difference (LSD) test was used to separate the means.

Results

Soil carbon concentration

The top and sub soil organic carbon (OC) and organic matter (OM) in the agroforestry practices had the order of homegardens>parkland>woodlot (Table 1). However, the soil organic carbon (OC) and organic matter (OM) have not shown significant difference for the agroforestry practices at $P<0.05$.

Note: OC refers to organic carbon, OM refers to organic matter and similar letter shows no significant difference between means.

Across elevation gradient, the top soil carbon concentration was higher in the lower elevation followed by middle and upper elevation at surface and sub-surface soil. However, at $P<0.05$ there was no significant difference observed in soil carbon concentration (Table 2).

Note: OC refers to organic carbon, OM refers to organic matter. These parameters were transformed in to square root basis for comparison during analysis. Similar letter shows no significant difference.

Carbon stocks in soil and woody biomass

From the agroforestry practices, woodlot was significantly highest in above ground tree carbon (106.47 Mg/ha), total tree biomass carbon (133.09 Mg/ha) and total carbon (448 Mg/ha); followed by home gardens and parklands (Table 3). However, there was no significant difference in soil organic carbon among agroforestry practices even though higher concentration was observed under homegarden (Table 3).

Note: AGC/ha refers to above ground carbon per hectare, TBC/ha refers to total biomass carbon per hectare, SOC/ha refers to soil organic carbon per hectare and TC refers to total carbon. Similar letters show no significant difference.

Across elevation gradient, the above ground tree carbon, total biomass tree carbon, soil organic carbon and total carbon have shown the order of lower>middle>upper elevation. However, there was no significant difference seen between these elevation gradients for above ground tree carbon, total biomass tree carbon, soil organic carbon and total carbon (Table 4).

Agroforestry practice	Top soil (0-15 cm)		Sub soil (15-30 cm)	
	OC (%)	OM (%)	OC (%)	OM (%)
Home garden	1.5 ± 0.05a	2.59 ± 0.09a	1.84 ± 0.3a	3.16 ± 0.5a
Parkland	1.38 ± .069a	2.37 ± 115a	1.48 ± 0.03a	2.55 ± 0.06a
Woodlot	1.29 ± .027a	2.22 ± 0.04a	1.47 ± 0.06a	2.54 ± 0.1a

Table 1: Soil carbon and organic matter variation among agroforestry practices in Gununo Watershed.

Elevation	Top soil (0-15cm)		Sub soil (15-20cm)	
	OC (%)	OM (%)	OC (%)	OM (%)
Lower	1.67 ± 0.3a	2.87 ± 0.45a	1.45 ± 0.090a	2.49 ± 0.158a
Middle	1.64 ± 0.2a	2.82 ± 0.30a	1.43 ± 0.071a	2.47 ± 117a
Upper	1.48 ± 0.08a	2.56 ± 0.14a	1.3 ± 037a	2.24 ± 067a

Table 2: Soil carbon and organic matter variation along elevation gradients in Gununo Watershed.

Agroforestry Practices	AGC/ha (Mg/ha)	TBC/ha (Mg/ha)	SOC/ha (Mg/ha)	TC (Mg/ha)
Home garden	6.63 ± 2.2b	8.29 ± 2.8b	61.57 ± 11a	86.4 ± 20b
Parkland	0.57 ± 0.13c	0.7 ± 0.1c	49.05 ± 2.1a	51 ± 0.7b
Woodlot	106.47 ± 8.5a	133.09 ± 10.6a	48.57 ± 0.3a	448 ± 43a

Table 3: Carbon stock variation among agroforestry practices in Gununo Watershed.

Elevation	AGC/ha	TBC/ha	SOC/ha	TC
Lower	46.17 ± 20.2a	57.71 ± 25.3a	57.61 ± 8.9a	231 ± 145a
Middle	37.43 ± 17.8a	46.79 ± 22.3a	57.07 ± 6.2a	197 ± 129a
Upper	30.07 ± 14.8a	37.58 ± 18.5a	44.50 ± 2.4a	157 ± 106a

Table 4: Carbon stock variation along elevation gradient in Gununo Watershed.

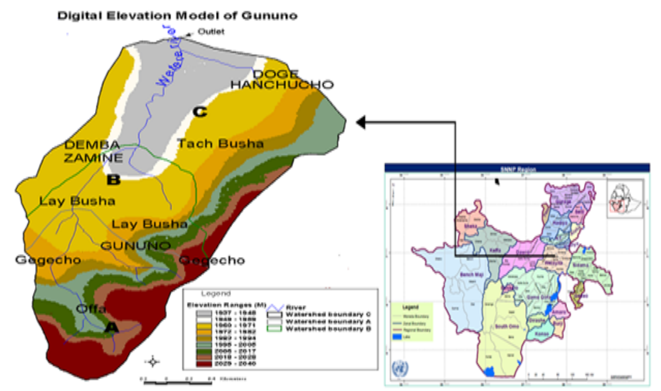

Figure 1: Map of Wolayitta Zone and Gununo watershed, Southern Ethiopia [15].

Note: AGC/ha refers to above ground carbon per hectare, TBC/ha refers to total biomass carbon per hectare, SOC/ha refers to soil organic carbon per hectare and TC refers total carbon. Similar letters show no significant difference.

Discussion

Carbon concentration

The variation in soil organic carbon among agroforestry practices and relatively highest value in home garden can be linked with high litter accumulation and species diversity in home garden. Relatively higher result of OC/OM on home garden than parkland and woodlot can be associated with better species diversity in home garden and management given for homegarden; the interaction effect of use of crop residue and high accumulation of surface litter fall from diverse species. As a result, the biomass carbon is returned into soil [26]. The litter fall will be decomposed in soil to release organic matter/organic carbon [2,21]. Difference in soil organic carbon among different agroforestry practices was studied by [7-10,27]. In addition, [28] has reported a variation of SOC between home garden and other land uses.

There is no crop resides on woodlot; this would be the reason for lower value of OC/OM than home garden and parkland. Also the management of burning can have an effect on carbon availability as burning remove carbon to atmosphere [29,30] and may result in lower value of OC/OM on woodlot than parkland. In other hand, tillage given on parkland can break down soil aggregates, exposes soil to raindrop impact, and releases soil organic matter and loss of soil carbon to atmosphere as CO_2 [27] and resulted in lower OC and OM in parkland than home garden. Therefore, the result has shown that home gardens are relatively better in accumulating OM/OC than other agroforestry practices.

At lower elevation an increase in OC and OM could be due to the effect of soil erosion [29]which caused SOC and SON pools to leached and eroded down from upper to deposition sites or lower elevation contour i.e. offsite effect [26,14,31] has found higher OM at lower elevation contour. Therefore, the result is consistent with the claim of higher OM/OC in the lower elevations than upper elevation.

Carbon stock

The highest value of above ground tree carbon, total tree biomass carbon, and total carbon on woodlot is associated with high stand density/number of individuals per hectare and associated structural parameters such as basal area and crown cover. In addition, this could be attributed with high efficiency of eucalyptus in carbon sequestration than native species as it is faster in its growth [32]. Similar result was observed in Western Kenya that fast growing woodlots were highest in above ground tree carbon stock than other agroforestry practices [9,8]. has also reported that above ground carbon can be varied among agroforestry practices. The above ground tree carbon of the study area was higher than small holders farms of Vihiga district (36.9 Mg/ha) in Western Kenya and lower than small holders farm of Siaya district (115.9 Mg/ha) in Western Kenya [9] these difference could be attributed to variation in structure, composition and age of agroforestry practices as compared to the study area.

The above ground tree carbon, total tree biomass carbon and total carbon which was higher on the lower elevation (though no significant difference among elevation level) could be linked with high total number of individuals and most of the structural parameters were highest [4]. Also described that the stand structural parameters such as size and height has significant positive relationship with aboveground C stocks. Therefore, high number of tree plantation is needed in order to increase the carbon stock of the study area especially in upper and middle elevation. However, the result was opposite to the claim of [4]. Accordingly, they reported that species diversity has a significant positive relationship with aboveground carbon. The species diversity of the study area was higher in the upper elevation but aboveground and total biomass of carbon was lower in upper elevation. Therefore, the result indicated that the number of individual in the study area have a great impact in increasing the carbon stokes than species diversity. Further, the highest value of soil organic carbon in the lower and middle slope is attributed to bulk density since bulk density was higher in the lower and middle slope than upper slope. In addition, the effect of leaching and erosion (sheet and rill erosion in the site) could wash the SOC from the upper slope and accumulate toward deposition sites/foot/lower slope i.e. offsite effect [12,11] similarly observed a reduction of SOC when altitude is increasing.

Therefore, the result has revealed eucalyptus woodlot has a great significance in increasing the carbon stock of watershed than other agroforestry practices though it is harmful in drought enhancement effect. Consequently, it is suggested that eucalyptus woodlot need to be changed by other fast growing tree e.g. Grevillea. This replacement will reduce the harmful effect of eucalyptus and also very helpful in carbon storage of the area due to its fast growth next to eucalyptus.

Conclusion and Recommendation

The study has shown that the dominant agroforestry practices in Gununo watershed are differently important in storing carbon in the system. Consequently, the total tree biomass carbon, above ground tree carbon, and total carbon was significantly higher on woodlots than parklands and home gardens. However, Eucalyptus which is dominant species in woodlot would create drought, so that it needs to be replaced by other fast growing tree such as Gravillea. The total tree biomass carbon and above ground tree carbon was highest in lower elevation suggesting that more tree plantations are needed in upper and middle elevation for better carbon storage of the area. Therefore, promotion of agroforestry practices and technologies in Gununo watershed can be potential activity in carbon storing. However, eucalyptus is much important for household economy (due to its fast growth) than Grevillea, and it is not easy for farmers to replace eucalyptus by Grevillea. Therefore, different training for awareness creation by extension agents and other stakeholders is needed to be given for the people in the watershed.

References

1. World Agroforestry Centre (ICRAF) (2006) Agroforestry for improved livelihoods and Natural resources conservation. An Agroforestry Policy Brief.
2. Nair PKR (1993) An introduction to agroforestry. Kluwer Academic publisher with cooperation ICRAF 489.
3. Kumar BM, Nair PKR (2011) Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges. Springer Science+Business Media 8: 326.
4. Weifeng W, Xiangdong L, Zhihai M, Kneeshaw DD, Changhui P (2011) Positive Relationship between Aboveground Carbon Stocks and Structural Diversity in Spruce-Dominated Forest Stands in New Brunswick, Canada 57: 506-515.
5. Unruh JD, Houghton RA, Lefebvre PA (1993) Carbon storage in agroforestry: an estimate for sub-Saharan Africa. Climate Research. Clim Res 3: 39-52.
6. Nair PKR, Kumar BM, Vimala DN (2009) Agroforestry as a strategy for carbon sequestration. J Plant Nutr Soil Sci 172: 10-23.
7. Wardah BT, Zulkhaidah (2011) Carbon Stock of Agroforestry Systems at Adjacent Buffer Zone of Lore Lindu National Park, Central Sulawesi. J Trop Soils 16: 123-128.
8. Yadava AK (2011) Potential of agroforestry systems in carbon sequestration for mitigating climate changes in Tarai region of central Himalaya. Nature and Science 9.
9. Henry M, Tittonell P, Manlay RJ, Bernoux M, Albrecht A, et al. (2009) Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agriculture, Ecosystems and Environment 129: 238-252.
10. Isaac ME, Gordon AM, Thevathasan N, Oppong SK, Quashie-Sam J (2005) Temporal changes in soil carbon and nitrogen in west African multistrata agroforestry systems: a chronosequence of pools and fluxes. Agroforestry Systems 65: 23-31.
11. Olsson MT, Erlandsson M, Lundin L, Nilsson T, Nilsson Å, et al. (2009) Organic carbon stocks in Swedish Podzol soils in relation to soil hydrology and other site characteristics. Silva Fennica 43: 209-222.
12. Schroth G, Sinclair FL (2003) Trees, Crops and Soil Fertility Concepts and Research Methods. CABI Publishing. 451.
13. Sheleme B (2011) Characterization of Soils along a Toposequence in Gununo Area, Southern Ethiopia. Journal of Science and Development 1: 31-41.
14. Tilahun A, Takele B, Endrias G (2001) Reversing the Degradation of Arable Land in the Ethiopian Highlands. Managing Africa Soils. No 23.
15. Mowo J, Adimassu Z, Masuki K, Lyamchai C, Tanui J, et al. (2011) The Importance of Local Traditional Institutions in the Management of Natural Resources in the Highlands of Eastern Africa.Working Paper No 134. World Agroforestry Centre, Nairobi.
16. WZFEDD (2008) Zonal Basic Socio-Ecnomic & Demographic Information. Wolaita Soddo.
17. Motuma T, Zebene A, Mulugeta L, Erik K (2008) Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. Agriculture, Ecosystems and Environment 128: 52-58.
18. Nikiema A (2005) Agroforestry Parkland Species Diversity: Uses and Management in Semi-Arid West Africa (Burkina Faso). PhD thesis.
19. Feyera S, Demel T, Bert-Ake N (2002) Native woody species regeneration in exotic tree plantations at Munessa-Shashemene Forest, southern Ethiopia. New Forests 24: 131-145.
20. Mulugeta L, Mats O, Erik K (2004) Comparison of soil attributes under Cupressus lusitanica and Eucalyptus saligna established on abandoned farmlands with continuously cropped farmlands and natural forest in Ethiopia. Forest Ecology and Management 195: 57-67.
21. Young A (1989) Agroforestry for soil conservation. International Council for Research in Agroforestry. C A B International 318.
22. Walkley A Black CA (1934) An examination of the Degtjareff methods for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37: 29-38.
23. Steffan-Dewenter I, Kessler M, Barkmann J, Boss M, Buchori D, et al. (2007)

Tardeoffs between income, biodiversity and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. PNAS 104: 4973-4978.

24. MacDicken KG (1997) A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock International, Arlington, Virginia 622.
25. Subedi BP, Pandey SS, Pandey A (2010) Forest carbon measurement: Guidelines for measuring carbon stock in community managed forest: Ansab/Fecofun/Icimod/Norad.
26. Kimble JM, Rice CW, Reed D, Mooney S, Follett RF, et al. (2007) Soil carbon management: economic, environmental and societal benefits. CRC Press Taylor and Francis Group 280.
27. Kaur B, Gupta SR, Singh G (2000) Soil carbon, microbial activity and nitrogen availability in agroforestry systems on moderately alkaline soils in northern India. Applied Soil Ecology 15: 283-294.
28. Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J (2006) Soil organic carbon dynamics, functions and management. Agricultural Systems 94: 13-25.
29. Blanco H, Lal R(2008) Principles of Soil Conservation and Management. Springer Science 626.
30. Hazelton P, Murphy B (2007) Interpreting soil test results. What do all the numbers mean? Second editioin. Csiro Publishing, p. 169.
31. Prasad NR (2002) Agroforestry intervention on soil fertility management under the Nepalese hill farming systems. 17th WCSS 14-21.
32. Gil L, Tadesse W, Tolosana E, López R (2010) Eucalyptus farming in Ethiopia: The case of Eucalyptus farm and Village Woodlots in Amhara Region. Eucalyptus Species Management, History, Status and Trends in Ethiopia. Proceedings from the Congress held in Addis Ababa.
33. Schjønning P, Elmholt S, Christensen BT (2004) Managing Soil Quality. Challenges in Modern Agriculture. CAB International 353.
34. Schroeder P (1993) Agroforestry systems: integrated land use to store and conserve carbon. Clim Res 3: 53-60.