International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(6): 1792-1798

Received: 14-09-2018
Accepted: 18-10-2018

Prabhat Tiwari
Teaching Associate, RLBCAU, Jhansi Uttar Pardesh, India

KS Pant
Professor, Deptt. Of SAF, Dr. Y.S. Parmar, UHF, Nauni, Solan Himachal Pradesh, India

Ranjeet Singh
Ph.D Scholar, Dr. Y.S. Parmar, UHF, Nauni, Solan Himachal Pradesh, India

Correspondence
Prabhat Tiwari
Teaching Associate, RLBCAU, Jhansi, Uttar Pardesh, India

Biomass apprisal of pasture based agroforestry systems in North-Western Himalaya, India

Prabhat Tiwari, KS Pant and Ranjeet Singh

Abstract
Our objective to observed the crop composition of pasture based agroforestry systems and their influence on biomass production in North-Western Himalaya under Sirmaur district of H.P. The study area had four prevailing pasture based agroforestry systems viz. agri-silvi-pasture, silvi-pasture, pastoral-silviculture and pastoral-silvi-horticulture system at three altitudinal zones representing three categories of farmers. The results showed that maximum above ground biomass (23.01 t ha^{-1}) and below ground biomass (6.63 t ha^{-1}) were accumulated by silvi-pasture (SP) system under zone I. Medium farmers category recorded highest biomass production as compare to marginal and small farmers categories due to better management of tress and pastures.

Keywords: biomass, agri-silvi-pasture; silvi-pasture; crop composition; medium farmers

Introduction

Agroforestry is one of the potential options to increase yields, productivity, food security, and resilience. The role of agroforestry in improving and maintaining soil productivity and sustainability is well documented (Shibu 2009) [44]. As are the positive effects on nitrogen in the soils in the tropics (e.g. Nair and Latt, 1997; Young, 1997; Buck *et al*., 1998; Schroth and Sinclair, 2003) [30, 49, 2, 41]. And water infiltration into the soil (Nyamadzawo *et al*., 2008) [34]. Agroforestry also contributed to increase biomass and ultimately carbon sequestration to overcome Global warming. Globally the number of people practicing agroforestry is estimated at 1.2 billion (Dawson *et al*., 2013) [8].

The deliberate introduction of trees into agricultural or pasture lands, in an agroforestry format (low density of trees with crops and/or animals), has resulted in diversified products and ecosystem services (Jose 2009; Nair 2011) [18, 28]. These ecosystem services are derived mainly as a result of integrating the perennial tree component into the agro-ecosystems (Thevathasan *et al*. 2014) [46]. Agroforestry systems have the potential to combine agricultural production, the supply of woody biomass and the provision of numerous environmental services, such as carbon storage, conservation of biodiversity and soil protection (Jose 2009) [18]. Aboveground woody biomass playsa decisive role considering the economic value of the agroforestry systems as well as the carbon storage (Huber *et al*. 2014) [14].

One of the commodities in agroforestry is well suited to producing is biomass for bio-power and bio-fuels (Jose *et al*. 2012) [18]. Vegetation biomass is a crucial variable for understanding the potential future changes of the climate system. Depending on the quantity of biomass, vegetation cover can have a direct influence on local, regional, and even global climate, particularly on air temperature and humidity (Bombelli *et al*. 2009) [3]. Biomass and carbon storage in forest ecosystems play an important role in the global carbon cycle (Li *et al*. 2013; Zhao *et al*. 2014) [23, 50]. Soil carbon, whereas, depends on the aboveground input received from plant litter and on the decomposition of fine roots belowground (Rasse *et al*. 2006) [39]. The aboveground tree biomass and belowground root biomass both need to be assessed to enable better estimations of total carbon (Hamburg 2000) [13].

The incorporation of trees or shrubs on farms or pastures can increase the amount of biomass compared to a monoculture field of crop plants or pasture (Sharrow and Ismail 2004; Iirby and Potvin 2007) [42, 15]. In addition to the significant amount of aboveground biomass, agroforestry systems can also store belowground biomass. Several other factors such as quality of C input, climate, and soil physical and chemical properties further determine the rate of decomposition and thus stabilization of soil organic carbon in a particular ecosystem. Since modernization of agriculture in the 19th-century, soil carbon pool has gradually depleted because of several

Factors such as deforestation, intensive cropping and biomass removal, soil erosion, and unsustainable agricultural practices. Most of the decline in soil organic matter has been observed in regions under intensive crop production such as continuous row cropping or monocropping. Depletion of soil carbon has been documented to result in decreased productivity, poor soil physical and chemical proper- ties, and negative secondary environmental impacts. It has been well documented that conversion of degraded agricultural soils into agroforestry systems can rebuild soil productivity.

Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity (Pandey *et al*. 2010) [36]. In the agroforestry systems the amount of biomass stored is determined by the structure and function of systems which to a great extent, are determined by vegetation pattern viz. tree species and system management (Albrecht & Kandji 2003; Pandey *et al*. 2010; Rajput *et al*. 2015) [1, 36, 38].

Himalayan region has a long custom of pasure land under agroforestry system, based on people's needs and site-specific distinctiveness numerous native agroforestry systems have been developed over the years (Chinnamani 1993; Yadav & Bisht 2014) [6, 48]. The vast potential of smallholder agroforestry system for biomass storage remains underexploited and proper utilization, management and innovative policies can make this an effective approach for carbon sink besides fulfilling the diverse needs of rural livelihoods (Nath & Das 2012; Yadav & Bisht 2013) [31, 47]. Therefore, the present study was designed to estimate crop composition of agroforestry system and their role in above ground as well as below ground biomass production in identified pasture based agroforestry systems in the North-Western Himalaya.

Material and Methods

The study was carried out in Sirmaur district of H.P., bounded by latitude 30°22'30"–31°01'20"N and longitude 77° 01'12"–77°49'40"E having elevation range from < 1000 m to >2000 m in Sirmaur district of North West Himalaya (Himachal Pradesh), India. The climate of Sirmaur district is sub-tropical to temperate depending upon the elevation. Three major seasons that is the winter season extends from November to February, summer season from March to June followed by the monsoon period extending from July to September end. Maximum precipitation in the form of rain occurs during July to September. Average annual rainfall in the district is about 1405 mm, out of which 90% occurs during monsoon season. In the non-monsoon season precipitation as snowfall also occurs in the higher reaches above 1500 m. During winter period rainfall also occurs in lower hills and valleys parts. Mean maximum and minimum temperature of 30°C and below 0°C respectively.

The entire study area was delineated into three altitudinal zones viz. Z1 (<1000 m), Z2 (1000– 2000 m) and Z3 (>2000 m), in each zone, four sites (approximately) were selected for identification of agroforestry systems, sampling of crops and measurement of trees. All the four sites in each elevation zone were surveyed. In total, 180 households according to farmer's category representing 12 panchayats were surveyed. Out of 180 households, 60 was marginal category (< 1 ha), 60 was small category (1-2 ha) and 60 was medium category (2-5 ha)**.** In each altitudinal range, three agroforestry systems viz. agri-silviculture, agri-horticulture and agri-silvi-horticulture were selected. This experiment was laid out as randomized block design (factorial experiment).

Estimation of vegetation biomass

The grasses biomass was harvested by laying out quadrat of size 50 cm × 50 cm. The soil was gently removed by tapping. Roots of different species were segregated and stored in different paper bags. All plant samples were oven dried at 70°C till a constant weight was achieved. The dried samples of root and shoot of each species were weighed to determine aboveground and belowground biomass of each species.

The estimation of above ground tree biomass was done by non-destructive method using local volume equation developed by (FSI 1996) [9]. For the biomass study, the tree falling in the plot (30×10 m^2) were enumerated. The diameter at breast height (dbh) was measured with the help of tree caliper and height was measured with Ravi's multimeter (Chaturvedi & Khanna 2013) [4]. The above ground biomass was calculated by multiplying stem wood volume with wood density and biomass expansion factor (BEF). Total above ground biomass of trees were calculated by using the formula given by (Deb *et al.* 2015) [7].

$$\text{Total above ground biomass} = \text{Stem wood volume} \times \text{Wood density} \times \text{BEF}$$

Local volume equation developed for specific tree species, specific gravity of tree species and biomass expansion factor (BEF) were undertaken from available literature.

Belowground biomass of a particular tree species was calculated by multiplying its aboveground with the root-shoot ratio. Root-Shoot ratio of different tree species were collected from available literature. In unavailability of the root-shoot ratio, using the simple default value of 25% (for hard wood species) and 21% (for soft wood species) to the total above ground biomass recommended by (Simon *et al*. 2006) [45]. The sum of aboveground and belowground was taken as total biomass of tree.

$$\text{Below ground biomass} = \text{above ground biomass} \times \text{Root: Shoot}$$

The data obtained were subjected to statistical analysis as per the procedure suggested by Gomez & Gomez (1984) [10].

Results and Discussion

Crop Composition

In altitudinal zones four pasture based agroforestry systems have been identified among different farmers category. These systems were Agri-silvi-pasture (ASP), Pastoral-silviculture (PS), Silvi-pasture (SP) and Pastoral-silvi-horticulture (PSH), Outh of these systems, Agri-silvi-pasture (ASP) system was absent in altitudinal zones II and III. In each agroforestry systems, crop composition are shown in Table-1, 2 & 3.

Under pasture components in altitudinal zone I (<1000 m) among all farmers category were *Chrysopogon martinii*, *Heteropogon contortus, Chrysopogon montanus*, *Dichanthium annulatum*, *Panicum coloratum* and *Panicum maximum* etc. Under horticulture and forestry components *Mangifera indica*, *Citrus Limon, Psidium guajava, Citrus sinesnis, Litchi sinensis, Citrus aurantifolia, Carica papaya, Juglans regia, Toona ciliata, Bauhinia variegata, Acacia catachu, Morus Alba, Terminalia bellerica, Grewia optiva, Eucalyptus spp., Anogeissus latifolia, Shorea robusta, Melia azedarach etc.* were mainly consisted in altitudinal zone I (Table-1).

Table 1: Crop composition of Sirmaur District under altitudinal zone I (<1000m)

Agroforestry systems	Crop composition		
	Pasture/ Crops		Tree species
	Crops	Pastures	
Agri-silvi-pasture system(ASP)	Maize, sesame, turmeric, chili, Wheat, barley, mustard, potato, garlic, onion, cauliflower	*Heteropogon contortus, Chrysopogon montanus, Cymbopogon martinii, Panicum coloratum*	*Toona ciliata, Shorea robusta, Eucalyptus spp. Celtis australis, Bombax ceiba, Anogeissus latifolia*
Silvi- Pastoral(SP)	-	*Chrysopogon montanus, Dichanthium annulatum, Panicum coloratum, Chrysopogon martinii*	*Anogeissus latifolia, Butea monosperma, Melia azedarach, Celtis australis, Eucalyptus spp., Diospyros melanoxylon, Shorea robusta, Leucaena leucocephala*
Pastoral-silviculture system(PS)	-	*Chrysopogon martinii, Heteropogon contortus, Chrysopogon montanus, Dichanthium annulatum, Dichanthium annulatum, Panicum coloratum, Panicum maximum*	*Diospyros melanoxylon, Butea monosperma, Terminalia bellerica, Celtis australis, Shorea robusta, Anogeissus latifolia, Melia azedarach, Eucalyptus spp.*
Pastoral-silvi-horticulture system(PSH)	-	*Chrysopogon martinii, Heteropogon contortus, Chrysopogon montanus, Cymbopogon martinii, Dichanthium annulatum, Panicum coloratum, Panicum maximum*	*Psidium guajava, Leucaena leucocephala, Bauhinia variegata, Mangifera indica, Eucalyptus spp., Anogeissus latifolia, Grewia optiva, Melia azedarach, Citrus limon, Butea monosperma*

Table 2: Crop composition of Sirmaur District under altitudinal zone II (1000-2000m)

Agroforestry systems	Crop composition	
	Pasture	Tree species
Silvi-Pastoral(SP)	*Heteropogon contortus, Cymbopogon martinii, Dichanthium annulatum, Apluda mutica, Heteropogon contortus*	*Anogeissus latifolia, Albizia lebback, Pinus roxburghii, Ficus palmata, Quercus leucotrichophora, Bauhinia variegata, Moringa oleifera, Eucalyptus spp.*
Pastoral-silviculture system(PS)	*Chrysopogon montanus, Dichanthium annulatum, Apluda mutica, Heteropogon contortus, Cymbopogon martinii*	*Celtis australis,Pinus roxburghii, Bauhinia variegata, Eucalyptus spp., Moringa oleifera, Sapindus mukorossi, Ficus palmata, Quercus leucotrichophora*
Pastoral-silvi-horticulture system(PSH)	*Themada anathera, Cymbopogon martinii, Chrysopogon montanus, Heteropogon contortus, Apluda mutica, Dichanthium annulatum*	*Anogeissus latifolia, Bauhinia variegata, Ficus palmata, Psidium guajava, Juglans regia, Leucaena leucocephala, Grewia optiva, Pinus roxburghii, Citrus limon, Eucalyptus spp.*

Table 3: Crop composition of Sirmaur District under altitudinal zone III (>2000m)

Agroforestry systems	Crop composition	
	Pasture	Tree species
Silvi-Pastoral (SP)	*Ischaemum aristatum, Cymbopogon martinii, Apluda mutica, Ischaemum spp., Themada anathera, Arundinella nepalensis*	*Ficus palmata, Bauhinia variegata, Pinus roxburghii, Cedrus deodara, Quercus leucotrichophora, Celtis australis, Bombax ceiba, Quercus dilatata*
Pastoral-silviculture system(PS)	*Apluda mutica, Ischaemum spp., Themada anathera, Arundinella nepalensis, Ischaemum aristatum, Cymbopogon martinii*	*Pinus roxburghii, Cedrus deodara, Rhododendron arboreum, Quercus dilatata, Ficus palmata, Picea smithiana, Quercus leucotrichophora, Bauhinia variegata, Celtis australis*
Pastoral-silvi-horticulture system(PSH)	*Apluda mutica, Ischaemum spp., Themada anathera, Arundinella nepalensis, Ischaemum aristatum, Cymbopogon martinii*	*Bauhinia variegata, Quercus leucotrichophora, Juglans regia, Bombax ceiba, Prunus armeniaca, Pinus roxburghii, Prunus domestica, Cedrus deodara, Ficus palmata, Malus domestica, Quercus dilatata, Juglans regia*

In the altitudinal zone II (1000-2000 m), the crop composition under pasture components in all farmers category were *Apluda mutica, Heteropogon contortus, Cymbopogon martinii, Chrysopogon montanus* and *Dichanthium annulatum,* where as under horticulture and forestry components *Prunus domestica, Prunus persica, Pyrus communis, Prunus armeniaca, Litchi sinensis, Psidium guajava, Citrus limon, Juglans regia, Toona ciliata, Bauhinia variegata, Morus alba, Grewia optiva, Eucalyptus spp., Celtis australis, Anogeissus latifolia, Bombax ceiba, Leucaena leucocephala, Salix alba etc.* (Table-2).

The crop composition in altitudinal zone III (>2000 m), irrespective of all farmers category under pasture components were *Arundinella nepalensis, Ischaemum aristatum, Cymbopogon martinii*, *Apluda mutica*, *Ischaemum spp.* and *Themeda anathera.* Under horticulture components *Prunus domestica, Malus domestica, Pyrus communis, Prunus armeniaca and Juglans regia* were identified as functional units. The forestry components in this altitudinal zones consisted of *Grewia optiva, Toona ciliata, Bahunia variegata, Morus Alba, Celtis australis, Bombax ceiba, Populas deltoides, Ficus Palmata* etc. (Table-3).

The Sirmaur district of Himachal Pradesh has highly diverse agro-ecological conditions due to wide altitudinal range, accompanied by variation in properties of edaphic strata viz. soil pH, fertility, soil structure, slope, aspect etc., therefore these agroforestry systems may be attributed. Kumari *et. al.* (2008) [22] who has reported that the traditional agroforestry practices to some extent have helped people in meeting their diverse needs viz. food, fodder, fuel wood and timber. Further, they identified prevalent AFS in Lahaul & Spiti and Kinnaur District (H.P). *viz.* AH, AS, Agri-silvi-pature (ASP), PS, PH. Rajput (2010) [37] reported Silvi-pasture system (Grewia, Chir pine, Bauhinia and grasses) in Kullu valley of Himachal Pradesh. Nayak *et al*. (2011) [32]. In Lahaul & Spiti area identified and categorized different types of agroforestry systems. These identified agroforestry systems were agri-silvi-pastoral, silvi-pastoral and horti-pastoral. Results were also close conformity with the findings of Murthy *et al.* (2013) [27].

Biomass production (t ha^{-1})

Above ground biomass among three altitudinal zones and three farmers category (t ha^{-1})

Figure-1 reveals that maximum above ground biomass production under pasture based agroforestry systems was recorded in the SP system (20.31 t ha^{-1}) while as minimum was found in PS system (13.54 t ha^{-1}). The maximum biomass in SP system is associated with structure and composition of vegetation (tree species, size, and height, density etc.) which affects the above ground biomass (Nair *et. al.*, 2009) [29]. Tree based pastoral agroforestry systems have been reported to produce more biomass as compared to pasture based system (Sanneh, 2007; Minj, 2008; Gupta and Chib, 2011 and Khaki and Wani, 2013) [40, 26, 12, 20]. Above ground biomass of pastoral agroforestry systems in three different altitudinal zones were observed significantly decreasing trend from zone I (17.21 t ha^{-1}) to zone II (14.04 t ha^{-1}) and there after it showed increasing trend with increasing altitude, zone III (18.14 t ha^{-1}). Altitude zone III recorded higher above ground biomass due to this zone attributed large trees mostly conifers. The result was closely comparable to the findings of Masoodi (2010) [25] and Mahato (2013) [24]. Interaction between pastoral agroforestry systems and altitudinal zones has a significant effect on the above ground biomass production. The maximum above ground biomass of pastoral agroforestry systems was noticed in SP with zone I (23.01 t ha^{-1}) and minimum was recorded in PS with zone II (12.74 t ha^{-1}). Different agroforestry practices have different potential, depending upon their species composition and different ecological and environmental variables (Kumar and Nair, 2011 and Isaac *et al.*, 2005) [21, 16]. Along elevation gradients, biomass is higher in the upper elevations than lower because of higher stand density. Similar result was also noticed by Olsson *et. al.* (2009) [35]. Maximum above ground biomass of pastoral agroforestry systems was recorded in SP system (20.27 t ha^{-1}) and minimum above ground biomass of pastoral agroforestry systems was recorded in SP system (13.68 t ha^{-1}) (Figure-2). Increased aboveground biomass under SP system was due to more trees as compared to grasslands (Chib, 2005) [5]. Above ground biomass of pastoral agroforestry systems among three farmer categories indicated that medium farmers have a maximum above ground biomass (17.43 t ha^{-1}) which was statistically at par with marginal (16.92 t ha^{-1}) farmer category and minimum above ground biomass was observed in small farmer category (15.35 t ha^{-1}). While in interaction, between pastoral agroforestry systems and three farmer categories showed significant difference on the above ground biomass. The maximum above ground biomass was recorded in the combination SP system, marginal farmer category (23.11 t ha^{-1}) which was statistically at par with medium farmer category under SP system (22.66 t ha^{-1}) and minimum above ground biomass was recorded in PS with medium farmer category (13.09 t ha^{-1}). However, these values are much closer to finding of Sharma *et. al.* (2008) [43].

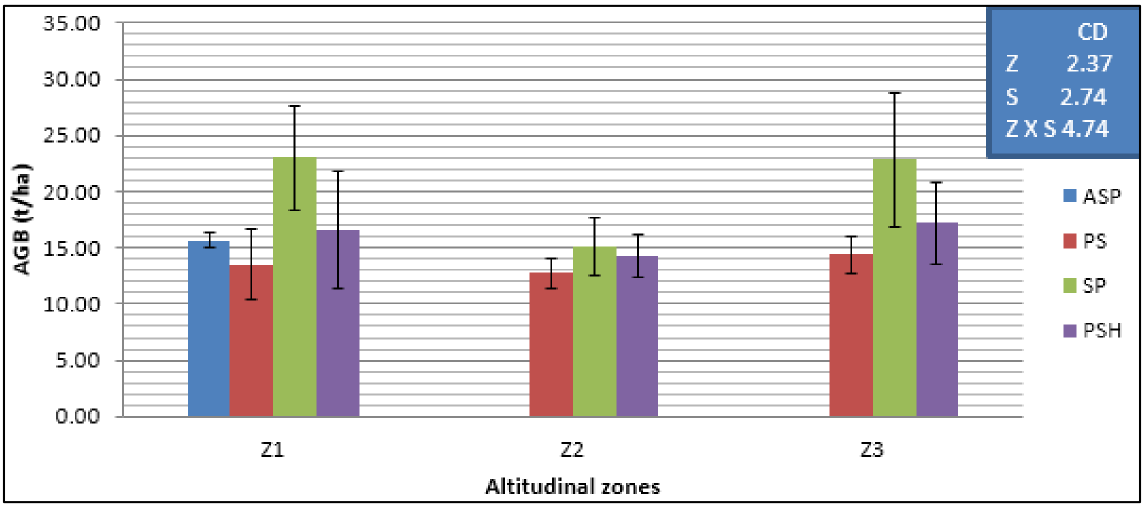

Fig 1: AGB (t ha^{-1}) of pasture based agroforestry systems at three altitudinal zones of Sirmaur District (H.P.)

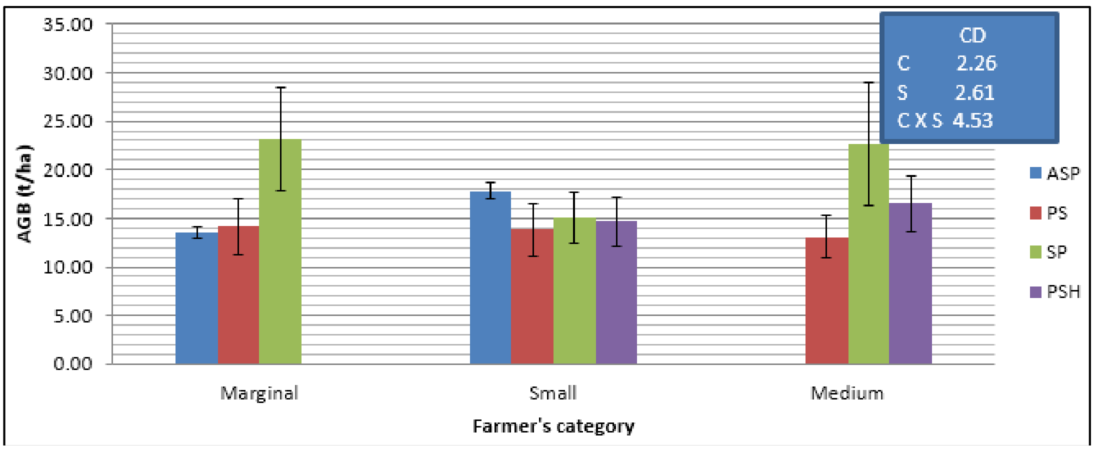

Fig 2: AGB (t ha^{-1}) of pasture based agroforestry systems among three farmers category of Sirmaur District (H.P.)

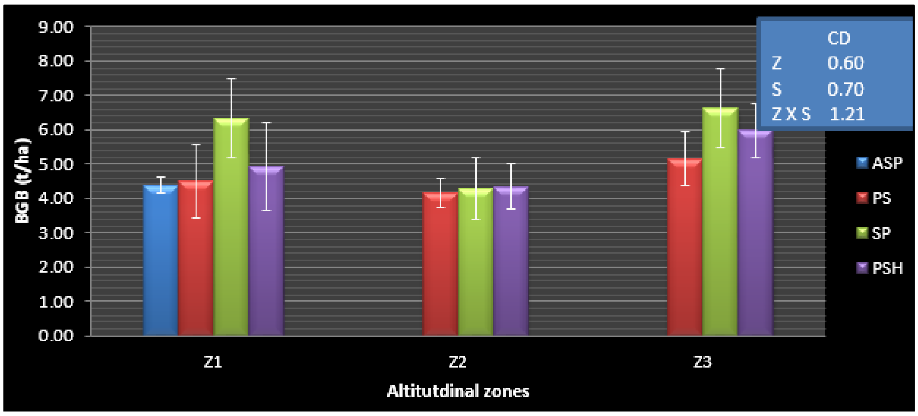

Fig 3: BGB (t ha^{-1}) of pasture based agroforestry systems at three altitudinal zones of Sirmaur District (H.P.)

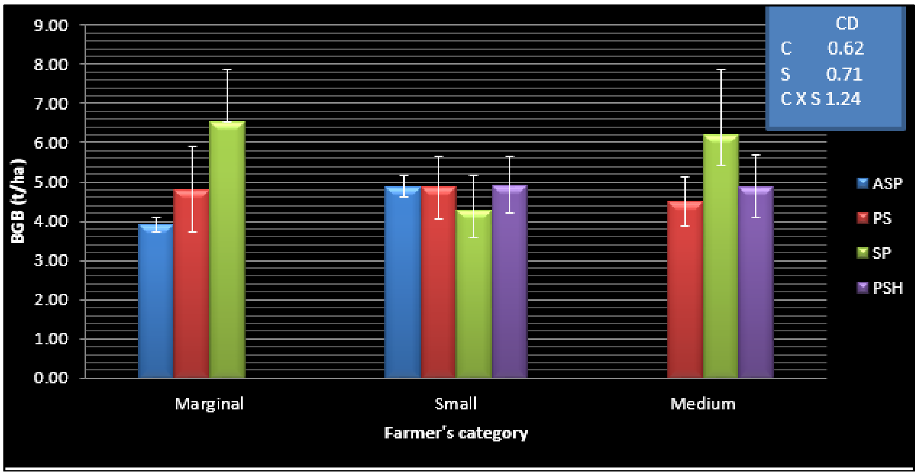

Fig 4: BGB (t ha^{-1}) of pasture based agroforestry systems among three farmers category of Sirmaur District (H.P.)

Below ground biomass among three altitudinal zones and three farmers category (t ha^{-1})

Figure-3 indicate that maximum below ground biomass was observed in the SP system (5.75 t ha^{-1}), which was statistically at par with PSH system (5.09 t ha^{-1}) and minimum was recorded in ASP system (4.40 t ha^{-1}). Maximum below ground biomass of pastoral agroforestry systems among three altitudinal zones was observed in zone III (5.92 t ha^{-1}), which was statistically at par with zone I (5.04 t ha^{-1}), while minimum in zone II (4.27 t ha^{-1}). Below ground biomass of trees was 25 per cent (for hard wood species) to the total above ground biomass recommended by (Simon *et. al.*, 2006) [45], hence followed the above ground biomass trend. However, the interaction between pastoral agroforestry systems and altitudinal zones had a significant effect on the below ground biomass. The maximum below ground biomass of pastoral agroforestry systems was recorded in SP system under zone III (6.63 t ha^{-1}), which was statistically at par with SP system, zone I (6.34 t ha^{-1}), whereas it was recorded minimum in PS system under zone II (4.17 t ha^{-1}). The biomass production depends upon a number of factors viz., growth habit of the species, site quality, soil on which trees are growing, stand age, management practices and their interactions with belowground components (Graham *et. al.*, 1992; Niu and Duiker, 2006 and Jana *et. al.*, 2009) [11,33,17].

The maximum below ground biomass was recorded in the SP system (5.68 t ha^{-1}) and it was recorded minimum in ASP system (4.40 t ha^{-1}) (Figure-4). On the other hand among three farmer categories, medium farmer category produce a higher below ground biomass (5.20 t ha^{-1}), which was statistically at par with marginal farmer category (5.09 t ha^{-1}) in pastoral agroforestry system, whereas minimum below ground biomass was found in small farmer category (4.74 t ha^{-1}). Interaction between pastoral agroforestry systems and three farmer categories significantly influenced the below ground biomass. The highest below ground biomass was noticed in the SP system under marginal (6.54 t ha^{-1}) farmer category, which was statistically at par with SP system in medium farmer category (6.22 t ha^{-1}) and minimum was noticed in ASP system, marginal farmer category (3.90 t ha^{-1}).

Conclusion

In India, North-Western Himalayan region where people's dependence on forest resources is high, agroforestry systems can play an important role in environmental and ecological sustainability. Agroforestry systems in this region can reduce the pressure on natural forests by providing the much needed fuel and fodder requirements of the peoples and can reduce a significant amount of atmospheric carbon through storage of standing biomass. In the present study, vegetation pattern and biomass in cropping system, agri-silvi-horticulture system (ASH) under zone I indicated highest biomass production both above ground and below ground. Our study reveals that a considerable amount of biomass is stored under agroforestry system, which not only fulfill the demand of people but also acts as an additional carbon sink in the region.

Acknowledgements

The authors are thankful to the Department of Science and Technology for providing financial assistance through Innovation in Science Pursuit for Inspired Research (INSPIRE) Fellowship for pursuing PhD and also grateful to the farmers of study area for providing necessary information and hospitality during research period.

Funding
This work was supported by the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.).

References

1. Albrecht A, Kandji ST. Carbon sequestration in tropical agroforestry system. Agric Ecosys Environ. 2003; 99:15-27.
2. Buck LE, Lassoie JP, Fernandez ECM. Agroforestry in sustainable agricultural systems (advances in agroecology). CRC Press, Boca Raton, FL, 1998, 416.
3. Bombelli A, Avitabile V, Balzter H. Biomass. In: di Caracalla VDT editor. Assessment of the status of the development of the standards for the terrestrial essential climate variables (T12). Global Terrestrial Observing System, Rome (*Pinus tabulaeformis*) forests. PL, 2009.
4. Chaturvedi AN, Khanna LS. Forest mensuration and biometry. 5th edition. Khanna Bandhu, Dehradun, India. 2013; 21:61-62.
5. Chib B. Performance of exotic grasses and variation in ground flora under different plantations. M.Sc. Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India, 2005. 67.
6. Chinnamani S. Agroforestry research in India: a brief review. Agrofor System. 1993; 23:253-259.
7. Deb D, Singh JP, Chaurasia RS. Biomass estimation of *Acacia catechu* using statistical modelling. Range Manag Agrofor. 2015; 36(2):151-55.
8. Dawson I, Place F, Torquebiau E, Malézieux E, Iiyama M, Sileshi W, Kehlenbeck K, *et al*. Background Paper for the International Conference on Forests for Food Security and Nutrition, 13-15 May. FAO, Rome, 2013.
9. FSI. Volume equations for forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and Forests. Govt. of India, 1996, 238.
10. Gomez KA, Gomez AA. Statistical Procedure for Agriculture Research, 2nd edition. Johan Willey and Sons, Inc. New York, 1984, 680.
11. Graham RL, Wright LL, Turhollow AF. The potential for short rotation woody crops to reduce U.S. CO2 emissions. Climate Change. 1992; 22:223-38
12. Gupta B, Chib B. Herbage dynamics under *Acacia mollissima* plantations in subtropical grasslands of north-west Himalaya. Indian Journal of Forestry. 2011; 34(3):289-96.
13. Hamburg SP. Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. Mitigation Adap Strateg Global Chan. 2000; 5:25-37.
14. Huber J, Siegel T, Schmid H, Hülsbergen KJ. Aboveground woody biomass production of different tree species in silvoarable agroforestry sytems with organic and integrated cultivation in southern Germany. Building Organic Bridg. 2014; 2:501-504.
15. Irby KR, Potvin C. Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. For Ecol Manag. 2007; 246:208-221
16. Isaac ME, Gordon AM, Thevathasan N, Oppong SK, Quashie SJ. Temporal changes in soil carbon and nitrogen in West African multistrata agroforestry systems: A chronosequence of pools and fluxes. Agroforestry Systems. 2005; 65:23-31.
17. Jana BK, Biswas S, Majumder M, Roy PK, Mazumdar A. Carbon sequestration rate and aboveground biomass carbon potential of four young species. Journal of Ecology and Natural Environment. 2009; 1(2):15-24.
18. Jose S. Agroforestry for ecosystem services and environmental benefits: An overview. Agrofor System. 2009; 76:1-10.
19. Jose S, Gold MA, Garrett HE. The future of agroforestry in the United States. Pp. 217–246. In: Nair PKR, Garrity D editors. Agroforestry: The future of global land use. Springer, the Netherlands, 2012, 541.
20. Khaki BA, Wani AA. Carbon sequestration potential of biomass under different agroforestry systems in Poanta of Himachal Pradesh. Indian Forestry Congress, New Delhi, India, 2013.
21. Kumar BM, Nair PKR. Carbon sequestration potential of agroforestry systems opportunities and challenges. Adv agrofor. 2011; 8:307.
22. Kumari A, Sehgal RN, Kumar S. Tradition agroforestry system practiced in (Lahaul and Spiti) and Kinnaur districts of Himachal Pradesh. Indian forester. 2008; 43(2):1003-09.
23. Li C, Zha T, Liu J, Jia X. Carbon and nitrogen distribution across a chronosequence of secondary lacebark pine in China. For Chron. 2013; 89(2):192-198
24. Mahato D. *Vegetation* dynamics of chirpine forests along altitudinal gradient in Giri catchment of Himachal Pradesh. PhD Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India, 2013, 247.
25. Masoodi HR. Vegetation dynamics and land use cover of 'Ga3a' micro watershed of Giririver in Solan district of Himachal Pradesh, India. M.Sc. Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India, 2010, 120.
26. Minj AV. Carbon sequestration potential of agroforestry systems- an evaluation in low and mid hills of western Himalayas. PhD Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, (H.P.), India, 2008, 124.
27. Murthy IK, Gupta M, Tomar S, Munsi M, Tiwari R, Hegde GT, *et al*. Carbon sequestration potential of agroforestry systems in India. J Earth Scie Climate Chan. 2013; 4(1):1-7.
28. Nair PKR. Agroforestry systems and environmental quality: introduction. J Enviro Qual. 2011; 40:784-90.
29. Nair PKR, Nair VD, Kumar BM, Haile SG. Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal. Environmental Scie Pol. 2009; 12:1099-1111.
30. Nair PKR, Latt CR. Directions in tropical agroforestry research. Agroforestry Systems. 1997; 38:1-249
31. Nath AJ, Das AK. Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India. Tropical Ecol. 2012; 53:287-293.
32. Nayak PD, Bawa R, Gupta T. Agroforestry Systems of Lahaul & Spiti District of Himachal Pradesh, Western Himalaya. Indian J Ecol. 2011; 38:129-31.
33. Niu X, Duiker SW. Carbon sequesteration potential by afforestration of marginal agricultural land in the mid-Western US. Forest Ecology and Management. 2006; 223(1):415-27.
34. Nyamadzawo G, Nyamugafata P, Chikowo R, Giller K. Residual effects of fallows on selected soil hydraulic properties in a kaolinitic soil subjected to conventional tillage (CT) and no tillage (NT). Agroforestry Systems. 2008; 72:161-168.

35. Olsson MT, Erlandsson M, Lundin L, Nilsson T, Nilsson A. Organic carbon stocks in swedish podzol soils in relation to soil hydrology and other site characteristics. Silva Fennica. 2009; 43:209-22.
36. Pandey U, Kushwaha SPS, Kachhwaha TS, Kunwar P, Dadhwal VK. Potential of Envisat ASAR data for woody biomass assessment. Tropical Ecol. 2010; 51:117-124.
37. Rajput BS. Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas (PhD Thesis). Nauni: Dr YS Parmar University of Horticulure and Forestry, 2010, 95.
38. Rajput BS, Bhardwaj DR, Pala NA. Carbon dioxide mitigation potential and carbon density of different land use systems along an altitudinal gradient in North-Western Himalayas. Agro for System. 2015; 89:525-536.
39. Rasse DP, Mulder J, Moni C, Chenu C. Carbon turnover kinetics with depth in a French loamy soil. American J Soil Scie Societ. 2006; 70(6):2097-2105.
40. Sanneh A. Status of carbon stock under different landuse systems in wet temperate North Western Himalaya. M.Sc. Thesis. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India, 2007, 81.
41. Schroth G, Sinclair F. Trees crops and soil fertility: concepts and research methods. CABI, Wallingford, UK, 2003, 464.
42. Sharrow SH, Ismail S. Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agrofor Syst. 2004; 60:123-130
43. Sharma CM, Gairola S, Ghildiyal SK, Suyal S. Forest resource use patterns in relation to socio-economic status: A case study in four temperate villages of Garhwal Himalaya, India. Mountain Research and Devlopment. 2009; 29(4):308-19.
44. Shibu J. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems. 2009; 76:1-10
45. Simon E, Buendia L, Miwa K, Ngara T, Tanabe K. IPCC Guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies (IGES) Publication, Japan, 2006.
46. Thevathasan N, Gordon A, Simpson J, Peng X, Silim S, Soolanayakanahally R, *et al*. Sustainability indicators of biomass production in agroforestry systems. Open Agric J. 2014; 8:1-11.
47. Yadav RP, Bisht JK. Agroforestry: A way to conserve MPTs in North Western Himalaya. Res J Agric Forestry Scie. 2013; 1:8-13.
48. Yadav RP, Bisht JK. Litter fall and potential nutrient returns from pecan nut (*Carya illinoinensis*) in agroforestry system in Indian Himalaya. Inter J Herbal Med. 2014; 2:51-52.
49. Young A. Agroforestry for soil management. 2nd edn. CABI Publishing, Wallingford, UK, 1997, 320.
50. Zhao J, Kang F, Wang L, Yu X, Zhao W, Song X, *et al*. Patterns of biomass and carbon distribution across a chronosequence of Chinese pine, 2014.