INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
16–0741/2017/19–6–1339–1349
DOI: 10.17957/IJAB/15.0410
http://www.fspublishers.org

Full Length Article

Biomass and Carbon Stocks Estimation in Chichawatni Irrigated Plantation in Pakistan

Muhammad Arif[1,3], Muhammad Khurram Shahzad[2,3], Elsamoal Elzaki Abdalla Elzaki[1,4], Amna Hussain[2], Bin Zhang[1] and Cao Yukun[1*]

[1]*Department of Forestry Economics & Management, Northeast Forestry University, No. 26-Hexing Road Harbin-150040, Heilongjiang Province, P.R. China*
[2]*College of Forestry, Northeast Forestry University, No. 26-Hexing Road Harbin-150040, Heilongjiang Province, P.R. China*
[3]*Punjab Forest Department, Government of Punjab, Lahore-54000, Pakistan*
[4]*Department of Forestry, University of Dalanj, Dalanj, Sudan*
[*]For correspondence: caoyukun.nefu@yahoo.com; cyklk@163.com

Abstract

Irrigated plantations (IPs) are a prominent component of the forest cover in Pakistan, while less research work has reported on the estimation of the carbon stock (CS) from these man-made plantations. The objective of this study was to assess the CS in biomass and soil of the Chichawatni Irrigated Plantation (CIP) a leading compact IP in Pakistan. Total CS ha^{-1} of the available species was estimated through field sample plots on a five-year interval age class basis. Study area covered 3823.20 hectares, comprised of *Dalbergia sissoo* 71.58%, *Eucalyptus camaldulensis* 18.99%, *Prosopis juliflora and P. glandulosa* 7.70% and other mix species *(Morus alba, M. nigra*, *Bombax ceiba* and *Acacia nilotica* etc.) 1.73%. Results of the study revealed that CS in biomass and soil directly corresponded to tree ages and species. Diverse biomass had different CS ha^{-1}; such as *D. sissoo*, *E. camaldulensis*, *Prosopis* species and other mix species had CS of 95.45, 139.47, 34.54 and 97.06 Mg ha^{-1}, respectively. CS available in the upper storey biomass was ranging from 120.61 ± 17.85 Mg ha^{-1} in the under storey was ranging from 2.45 ± 0.83 Mg ha^{-1} and in the soil was ranging from 29.26 ± 14.54 Mg ha^{-1}. Overall proportion of CS in upper storey under storey and soil thus came to 74.44, 1.96 and 23.60% respectively of total CS. It was concluded that upper storey biomass produced maximum CS ha^{-1}. While, *E. camaldulensis* was the leading tree species producing the highest CS ha^{-1} in the upper storey. Mix tree species produced highest proportions of CS ha^{-1} in under storey and soil. It is pertinent to mention here that this study was solely restricted to calculation of biomass and CS ha^{-1}.

Keywords: Man-made plantation; Growing stock; *Dalbergia sissoo*; *Eucalyptus camaldulensis; Prosopis cineraria*

Introduction

Global climate change has gained serious attention in the last few decades, as larger amounts of carbon have been added to the atmosphere due to man-made activities resulting in the disturbed ecosystem (Houghton *et al.*, 2009; Awan *et al.*, 2015). Forest's land cover and density of trees have been drastically reducing all over the world due to tremendous increase in population and cutting of trees for timber, fuel wood, grazing and shifting of cultivation that resulted in reduction of carbon biomass (Vgen and Gumbricht, 2012). Tree land cover and biomass can be enhanced by using appropriate land-use management, which not only augment soil fertility and food production but can also perform an influential global function in climate change mitigation and raise carbon sequestration capacity (Lal, 2001, 2004; Abaker *et al.*, 2016). Trees can play their constructive role in forest ecosystem, which is an essential part of the global carbon cycle (Masera *et al.*, 2003; Ahmad *et al.*, 2014). Existing forests in the world are stocking over 650 billion tones carbon out of which 45% lies in the soil, 44% in the biomass and 11% in the litter and dead wood (Keenan *et al.*, 2015). Tropical forests are performing a major role in the terrestrial carbon balance as about 1150 gt of carbon stock residue is in this forest ecosystem (Martin *et al.*, 2013). About 7% of the global forest area is under planted forest constituting 264 million hectares. These forests serve multidimensional purposes and carbon stock is one of them (Paquette and Messier, 2010). Carbon sequestration can be momentously improved through vigorous tree planting (Ringius, 2002) as a large amount of carbon stock stored in the tropical forest is in the form of standing vegetation (Malhi *et al.*, 2002).

The accuracy for the measurement of forest biomass has remarkably improved over recent decades and different agreements have been signed beneath the UNs Conventions

To cite this paper: Arif, M., M.K. Shahzad, E.E. A. Elzaki, A. Hussain, B. Zhang and C. Yukun, 2017. Biomass and carbon stocks estimation in Chichawatni irrigated plantation in Pakistan. *Int. J. Agric. Biol*., 19: 1339–1349

on climate-change issue (Van Camp *et al.,* 2004). Forest's restoration efforts significantly offset atmospheric carbon emissions (Laurance, 2007). However, true potential of forest biomass has been hampered by the poor understanding of forest restoration strategies (Holl and Zahawi, 2014; Kinyanjui *et al.*, 2014). Tree biomass is an expression of production, as it well correlates with climate and site factors (Madgwick, 1982). The amount of biomass productions are closely associated to annual rainfall (Lal, 2004; Sankaran *et al.*, 2005; Alam *et al.*, 2013) and other ecological factors (Hero *et al.*, 2013).

There is a conflict of findings about forest biomass between the planted forests and naturally regenerated secondary forest in the tropical forest ecosystem (Bonner *et al.*, 2013; Marin-Spiotta and Sharma, 2013). A number of studies indicated that compact plantations have more forest carbon stocks (Bonner *et al.*, 2013), while other studies have reported that naturally regenerated secondary forests had significantly more forest carbon accumulation (Chrsquo *et al*., 2011). At the same time numerous studies have supported that natural forest had higher forest carbon stock than restoration secondary planting (Baishya *et al*., 2009). However, some studies have reported that compact forests differ in forest carbon stock's potential due to mix tree stand structure (Kanowski and Catterall, 2010). Finding of every research work is considered right as each site of forest has specific variables that change the potential of the carbon accumulation. Nevertheless, carbon stock of compact forests is reported to be higher than natural regenerated forest stands provided the application of proper silvicultural management (Baishya *et al*., 2009).

Forests normally cover large areas of land and forest inventories (FIs) act as the primary source of forest data (Tomppo *et al*., 2010). Wide-range conditions of different forests across a country can only be calculated through FIs (Qureshi *et al*., 2012). Nowadays estimation of forest biomass and carbon stocks through FIs is widely recognized and accepted all over the world (Goodale *et al*., 2002; Gasparini and Cosmo, 2015). Stem volume is commonly estimated through FIs and these inventories rarely estimate tree biomass through direct measurements. For this reason, biomass expansion factor (BEF) is generally used to convert stem volume (m^3) into biomass (tons unit) (Lehtonen *et al*., 2004) but a standard parameter is still missing. IPCC guidelines also support such factors (IPCC, 2003) reason being such factors are helpful for aggregate volume calculation where forest stand have different characteristics such as tree composition, structure, site conditions, age and volume (Magalhaes and Seifert, 2015). BEF is developed locally assuming forest growing conditions, which lead to an assessment of forest growing stock over large forest areas (Jalkanen *et al*., 2005). Tree level biomass of different species and various geographic areas can also be measured through their developed models (Ung *et al*., 2008; Tabacchi *et al*., 2011).

Pakistan is a sub-tropical country comprising an area of 4.55 million ha under forest/tree cover, which is 5.1% of the total land area. Irrigated plantations have a forest cover on 0.2% area (Bukhari *et al.,* 2012). These man-made forests were created out of sub-tropical thorn forests (Ajmal, 2010). In Pakistan, forest resources have been evaluated through FIs. It is worth mentioning here that estimation of carbon stocks in IPs of Pakistan has not been carried out yet. The objectives of this study were to assess carbon stocks in biomass and soil of CIP one of the leading IPs of Pakistan. It is administrated by the Punjab Forest Department Punjab Pakistan.

Materials and Methods

Study Site

The plantation is located in southern zone Punjab Pakistan between latitudes 30º-29´-32.91´´N and 30º-33´-45.84´´N and longitudes 72º-36´-00.25´´E and 72º-46´-48.65´´E at an elevation of 153.6 to 163.7 m above sea level. The Establishment of man-made CIP was started during the year 1913. An area of 4726.73 hectares was declared as Chichawatni Reserved Forest vide Punjab Government Notification No. 4178 dated 28 Feb 1917. At present, the gross area of this plantation is 4666.8 hectares, while net area for planting stock is 3823.20 hectares. Originally, this plantation was a typical dry tropical forest and the indigenous flora was *Salvadora oleoides, Tamarix articulata, Prosopis cineraria* and *Capparis aphylla*. This plantation received its irrigation from the Lower Bari Doab Canal. Irrigation water delivered from canals to the forest by an extensive system of water courses. The system of canals distributaries and minors delivered water to small structure outlet. The outlet permits continuous flow of canal water into main, khal, passel and trench. Normally, water is provided on the basis of 0.34 m^3 per second per 400 hectares. However, this quantity is generally not made available at the diversion points.

The data about growing stock and soil for current study was collected in the plantation between January 2014 and August 2014. The climate of the plantation is mainly dry. The temperature ranges from 3°C to 46°C under shade during a year. The annual rainfall ranged from 43 mm to 516.5 mm from July 2004 to December 2013. Presently, sub-soil water level on an average is 11.27 m below the ground level (Khaggah, 2014). The existing crop comprised of *Dalbergia sissoo, P. glandulosa, P. juliflora, Eucalyptus camaldulensis*, *Morus alba, M. nigra, B. ceiba* and *Acacia nilotica.* The auxiliary species in the area included *T. articulata, C. decidua, Albizzia lebbek, A. procera and Zizyphus mauritiana.* The shrubs and undergrowth comprised of *Abutilon bidentatum, Asparagus gracilis, Calotropis procera, Chenopodium album, Plucheal anceolata* and *Solanum melongena.* The climbers comprised of *Cayratia camosa, Merremia aegyptica, Pentatropis apiralis, Pergolaria daemia, Rhynchesia minima, Rivea hypocraterifonnis, Andropogon laniger,* etc. Grasses

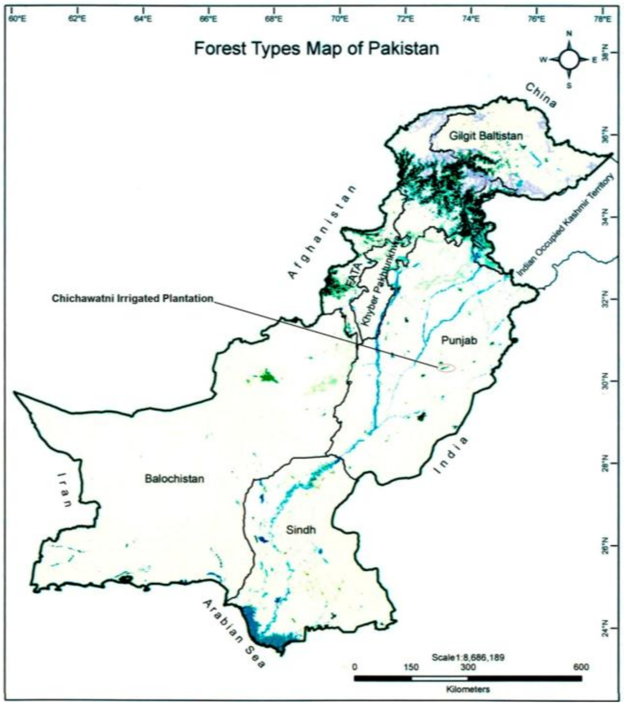

Fig. 1: Location of study area on the forest cover map of Pakistan

comprised of *Cynodon dactylon, Cyperus eleusinouides, Dichanthium annulatum, Erianthus munja, Panicaum antidotale, Saccharum spontaneum and Vetiveria zizan,* etc. The plantation is managing to obtain maximum sustained yield of quality timber, industrial wood, fuel wood and another minor forest produce and to combat the environmental pollution in line with the international commitments after attaining the normal crop in the minimum possible time. In the methods of treatments the areas received assured and adequate supplies of irrigation with good soils were included in Shisham working circle and *D. sissoo* is the principal specie. It is regenerated by planting of root-shoot cuttings at a spacing of 3 × 1.8 m (1794 plants ha^{-1}) originated from selected superior seed. The tree crop (76–100% density) was thinning in the 6th and 12th years and rotation age is 20 years. It is being managed under the system of clear felling with retention of 40–60 ha^{-1} standard trees. The areas having somewhat lesser irrigation supply and moderate soils were managed in biomass production working circle and *E. camaldulensis* is the principal specie. Regeneration is carried out through potted plants at a spacing of 3 × 1.8 m (1794 plants ha^{-1}). This working circle is being managed under the clear felling system with the rotation age of 10 years without retaining any standards. Semi-stocked and saline areas with limited supply of irrigation water and poor soils were constituted as environmental protection working circle and the indigenous flora are the principal species, where no main felling and thinning were prescribed. All cultural operations are conducted at early stages to have healthy forest crop (Fig. 1 and 2).

Sample Plots, Field Measurement and Sampling

The age and history of all tree species were recorded from 295 compartments history files and the data was collected by using variable techniques (Nath *et al*., 2010; Vesa *et al*., 2010). For upper storey biomass 43 circular plots (1 ha, 56.4 m radius) were established in the plantation covering 1–5, 6–10,11–15, 16–20, 21–25, 26–30 and 31–35 years age classes of all available tree species to ensure the chances of obtaining tree data in equal proportions. For under storey biomass 43 sample plots (4 m^2 for shrub) and (1 m^2 for grasses and herbs) were laid out at the center of each sample plot. Soil samples were collected at a depth of (0–30 cm) within the same center of each sample plot. Diameter at Breast Height (DBH) was measured by means of diameter tape and calipers, while the tree height was calculated through Abney's level and Haga altimeter for each tree in all sample plots (Saeed *et al*., 2016). *P. juliflora* and *P. glandulosa* were in shrub form in entire plantation, so these species in sample areas were felled down and volume was calculated through stacking (m^3).

Calculation of Upper Storey Growing Stock and Biomass

Tree volume was determined by using following formula (Philip, 1994; Ahmad *et al*., 2014; Saeed *et al*., 2016):

$$\text{Tree volume } (m^3) = (\pi/4) \times d^2 \times h \times f)$$

Where, π = 3.1416, d = at DBH (1.3m), h = tree height, f = form factor.

Stem biomass (t ha^{-1}) was computed from volume (m^3) and wood density (kg m^{-3}) (PARC, 1994; Haripriya, 2000) of relevant tree species by using the following relationship (Ahmad *et al*., 2014; Saeed *et al*., 2016);

$$\text{Biomass (kg)} = \text{Volume } (m^3) \times \text{Basic wood density } (kg\ m^{-3})$$

Total biomass is an aggregate volume of (leaves, twigs, branches, stem and root). Volume of leaves, twigs, branches and stem was calculated by using Biomass Expansion Factor (BEF) (Lehtonen *et al*., 2004; Somogyi *et al*., 2007; Ahmad *et al*., 2014; Saeed *et al*., 2016). The BEF values of different tree species were obtained from the source literature (Haripriya, 2000).

Calculation of Under Storey Growing Stock and Biomass

The under storey vegetation comprised of shrubs, herbs and grasses was harvested from respective sample plots. The samples weight (kg) was measured the mean weight was taken from sample plots and extrapolated it to measure existing weight of the whole sample plot. Fresh samples bags (kg) were transferred to laboratory and labeled properly. Each sample was dried for 48 h at 72°C (Roy *et*

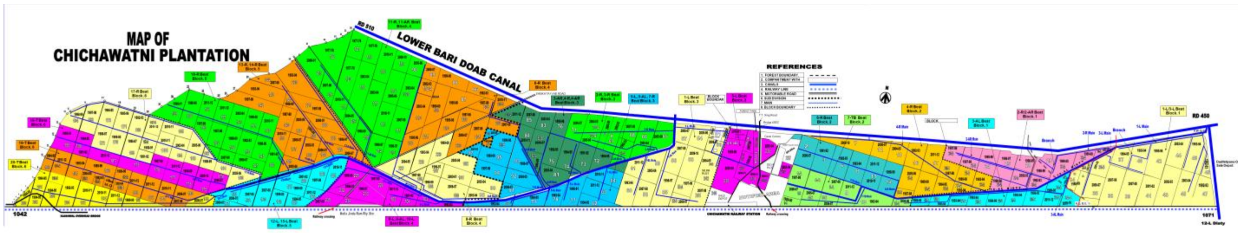

Fig. 2: Administrative map of Chichawatni irrigated plantation

al., 2001; Saeed *et al*., 2016). The dry weight (kg) of biomass was obtained from dried sample weight (kg).

Calculation of Carbon Stocks

The carbon stocks were estimated by multiplying total biomass with the conversion factor (0.5) as this value has been globally used to this purpose (Roy *et al*., 2001).

Total carbon stocks (t ha^{-1}) = Biomass (t ha^{-1}) × 0.5

Calculation of Soil Carbon

Soil samples were taken in the field and weight of each sample was recorded. In labeled bags, these samples were sent to the soil laboratory for measuring the carbon in the forest soil. Soil specimens were obtained from each plot at a level of 0–30 cm with the help of soil auger and soil cores of identified volume of 201.51 cm^3 (5.9 cm diameter and 7.25 cm height). The bulk density (gm cm^{-3}) of each sample was calculated. Soil carbon was measured through oxidizable organic method (Saeed *et al*., 2016).

Soil carbon (Mg ha^{-1}) = Soil bulk density ((gm cm^{-3}) × SOC (%) × Thickness of the horizon (cm) × 100

Calculation of Total Carbon Stocks

Total carbon stocks (Mg ha^{-1}) of Chichawatni irrigated plantation was calculated by adding all three components of carbon stocks (i.e. upper storey biomass, under storey biomass and soil carbon).

Results

Growing Stock

Dalbergia sissoo and *E. camaldulensis* were the dominant tree species covering an area of 90.57% of the whole plantation as shown in Table 1 and 2. Age classes, mean diameter (cm ha^{-1}), mean height (m ha^{-1}), basal area (m^2 ha^{-1}), mean stem density (ha^{-1}) and mean volume (m^3 ha^{-1}) of *D. sisso, E. camaldulensis, M. alba, M. nigra, B. ceiba* and *A. nilotica* and estimate out turns (m^3 ha^{-1}) of *P. juliflora* and *P. glandulosa* are shown in Table 3. The results illustrate that *D. sisso,* age classes 0-5 to 26-30 years has the mean values of diameter as 44.7 ± 11.4 (cm ha^{-1}), height as 25 ± 9.4 (m ha^{-1}), basal area as 14 ± 8.70 (m^2 ha^{-1}), stem density as 838 ± 89 (ha^{-1}) and volume as 150 ± 39 (m^3 ha^{-1}). The results show that *E. camaldulensis*, age classes 0–5 to 31–36 years, has the mean values of diameter as 26.7 ± 14 (cm ha^{-1}), height as 23.2 ± 14.6 (m ha^{-1}), basal area as 20.98 ± 13.54 (m^2 ha^{-1}), stem density as 906 ± 380 (ha^{-1}) and volume as 153.728 ± 90.167 (m^3 ha^{-1}). The other mix species (i.e. *M. alba*, *M. nigra*, *B. ceiba* and *A. nilotica)*, age classes 0–5 to 21–25 years, have the mean values of diameter as 38.3 ± 9.1 (cm ha^{-1}), height as 18.59 ± 9.14 (m ha^{-1}), basal area as 19.521 ± 12.498 (m^2 ha^{-1}), stem density as 2354 ± 183 (ha^{-1}) and volume as 213.590 ± 51.225 (m^3 ha^{-1}). *P. juliflora* and *P. glandulosa* have estimated out turn ranging over 41.5 ± 30.6 (m^3 ha^{-1}). It is evident that stem density and volume of each tree species have strong relationship with the diameter. The stem volume of tee is directly proportional to the diameter, so it has positive relationship. Stem density of trees has been inversely proportional to the diameter, so it has a negative relationship. In order to understand the relationship between tree volume (m^3 ha^{-1}) and basal area (m^2 ha^{-1}) and stem biomass and basal area (m^2 ha^{-1}) of *D. sissoo* and *E. camaldulensis*, different regression models were developed in Figs. 3 and 4. Volume (m^3 ha^{-1}) and stem biomass increases with an increase of the basal area (m^2 ha^{-1}) as volume (m^3 ha^{-1}) and stem biomass are the functions of the basal area (m^2 ha^{-1}).

Upper Storey Biomass and Carbon Stocks

Stem biomass (Mg ha^{-1}) of eight different tree species on the basis of five years age class interval was determined with the help of their average volume (m^3 ha^{-1}) and basic wood density (Kg m^{-3}) (Table 4). The maximum stems biomass of 173.71 Mg ha^{-1} was found in *E. camaldulensis.* Mean stem biomass of *E. camaldulensis* was 151.71 with a range of 173.71 ± 101.88 Mg ha^{-1}. The lowest stem biomass of 18.67 Mg ha^{-1} was found in *P. juliflora* and *P. glandulosa*, while it had mean stem biomass of 22.45 with a range of 25.19 ± 18.67 Mg ha^{-1}. Mean stem biomass of *D. sissoo* was 86.81 with a range of 122.85 ± 31.94 Mg ha^{-1}. Mean stem biomass of other mix species was 82.21 with a range of 128.15 ± 30.74 Mg ha^{-1}. The relationships among tree stem-volume and basal area and stem-biomass and basal areas were polynomial quadratic for all tree species. Mean stem biomass of complete plantation was 85.80 with a range of 151.71 ± 22.44 Mg ha^{-1}, while the mean of tree biomass was

Table 1: Ages-wise and species-wise position of growing stock in Chichawatni irrigated plantation

Age in years	Growing stock area (ha)			
	D. sissoo	*E. camaldulensis*	Others Mix Species *(M. alba, M. nigra, B. ceiba, A. nilotica, etc)*	*P. juliflora* and *P. glandulosa*
0-5	397.01	306.36	25.09	-
6-10	1131.14	10.12	23.88	4.86
11-15	465.81	27.11	6.48	-
16-20	512.35	142.45	6.88	61.51
21-25	205.99	153.79	3.24	94.30
26-30	24.28	61.11	-	96.72
31-36	-	25.09	-	37.64
Total	2736.58	726.03	65.56	295.03

Table 2: Density-wise stock position of Chichawatni irrigated plantation

Sr. No.	Species	Net planted area (ha)	Density class-wise area (ha)			
			0-25%	26-50%	51-75%	76-100%
1	*Dalbergia sissoo*	2736.58	933.23	447.20	414.41	941.73
2	*Eucalyptus camaldulensis*	726.03	89.84	138.81	159.45	337.92
3	Others Mix Species (*Morus alba, Morus nigra, Bombax ceiba , Acacia nilotica, etc*)	65.56	3.23	4.86	12.95	44.51
4	*Prosopis juliflora* & *Prosopis glandulosa*	295.03	-	-	-	295.02
Grand Total		3823.20	1026.30	590.87	586.81	1619.18

136.41 with a range of 241.21 ± 35.69 Mg ha^{-1}. Mean carbon stock in upper storey was 68.20 with a range of 120.61 ± 17.85 Mg ha^{-1}.

Under Storey Biomass and Carbon Stocks

The maximum biomass of 7.81 Mg ha^{-1} was found in shrubs and undergrowth while grasses and climbers had minimum biomass of 0.56 Mg ha^{-1}. Shrubs and undergrowth have mean biomass ranging from 4.10 ± 1.37 Mg ha^{-1}, while grasses and climbers have mean biomass ranging from 2.10 ± 0.52 Mg ha^{-1}. On the whole, calculated range of under storey biomass is 4.71 ± 2.2 Mg ha^{-1} and total carbon stock measured is ranging from 2.45 ± 0.83 Mg ha^{-1}. The maximum under storey carbon stock of 2.99 Mg ha^{-1} was found in other mix species crop; while the minimum under storey carbon stock of 0.56 Mg ha^{-1} was found in *E. camaldulensis* crop. The mean of carbon stocks in *D. sissoo*, *E. camaldulensis*, *Prosopis* species and other mix species thus worked out as 1.77, 0.83, 2.45 and 2.15 Mg ha^{-1}, respectively (Table 4).

Calculation of Soil Carbon

The maximum soil carbon of 35.51 Mg ha^{-1} was observed in *D. sissoo* crop, while minimum soil carbon of 11.15 Mg ha^{-1} was viewed in *Prosopis* species crop. The mean value of soil carbon determined in the crops of *D. sissoo*, *E. camaldulensis*, *Prosopis* species and other mix species was 24.66, 18.03, 14.54 and 29.26 Mg ha^{-1}, respectively. Range of soil carbon verified in *D. sissoo* crop was 35.51 ± 11.41 Mg ha^{-1}, in *E. camaldulensis* crop was 21.20 ± 14.41 Mg ha^{-1}, in other mix species crop was 34.51 ± 23.43 Mg ha^{-1} and in *Prosopis* species crop was 15.90 ± 11.15 Mg ha^{-1} (Tables 1–5; Figs. 3–4).

Discussion

There are five C pools in forest ecosystems: living trees under story vegetation, dead wood, litter on the forest floor, and organic soil C (Woodbury *et al*., 2007). In this study, we only estimated C stock in the three C pools (living trees, under story vegetation, and organic soil C) and C storages in dead wood and litter on the forest floor were not considered. As all saleable dead wood of CIP has disposed of through open auction, while the remaining un-saleable brushwood and debris burnt at different time intervals under prescribed management plans. In the earlier studies C flux in living trees´ accounts for 76–90% of total C storage in forest ecosystems (Liu *et al*., 2006; Woodbury *et al*., 2007). Two methods are generally used to estimate C storage in forest tree biomass. First living tree biomass was estimated using BEF or allometric biomass equations. The resulting biomass values were converted to C storage estimates using a conversion coefficient. Second C storage estimates were obtained directly using allometric C equations. In this study, we used first method depending on available information and resources. Inventory-based assessment of carbon stocks from forest biomass and soil is considered as a reliable source (Walle *et al*., 2005; Tolunay, 2011). That is the reason estimation of biomass and carbon stock in CIP was conducted through inventories. BEF of 1.59 is used to convert the growing stock of this plantation into biomass and carbon stocks, which has earlier been used by (Haripriya, 2000; Saeed *et al*., 2016).

Above and below grounds´ C stocks are important parameters for characterizing forests ecosystems, and it is needed to assess the limits to potential production from the forests. The lack of sufficient and reliable inventory data is a significant factor in limiting biomass estimates from the

Table 3: Age-classes wise mean diameter (cm ha^{-1}), mean height (m ha^{-1}), basal area (m^2 ha^{-1}), mean stem density (ha^{-1}) and mean volume (m^3 ha^{-1}) of the different tree species

Age in years	Net planted area (ha)	Mean diameter (cm)	Mean height (m)	Basal area (m^2)	Mean density (ha^{-1})	Mean volume (m^3 ha^{-1})
Dalbergia sissoo						
0-5	397.01	11.4	9.4	8.7	838	39
6-10	1131.14	19.3	14.9	11.9	410	80
11-15	465.81	27.2	18.9	12.6	225	105
16-20	512.35	33.8	21.9	13.3	148	125
21-25	205.99	39.4	23.8	13.8	114	137
26-30	24.28	44.7	25	14	89	150
Mean	-	-	-	-	-	106.00
Eucalyptus camaldulensis						
0-5	306.36	14	14.6	13.540	906	90.167
6-10	10.12	25.9	23.8	19.180	405	139.089
11-15	27.11	27.4	23.2	19.247	370	142.267
16-20	142.45	27.7	23.5	18.487	306	138.217
21-25	153.79	24.6	22.2	19.800	415	136.347
26-30	61.11	25.4	22.6	14.357	380	139.984
31-36	25.09	26.7	23.2	20.980	380	153.728
Mean	-	-	-	-	-	134.25
Others Mix Species (*Morus alba, Morus nigra, Bombax ceiba , Acacia nilotica*)						
0-5	25.09	9.1	9.14	12.498	2354	51.225
6-10	23.88	17.3	13.41	15.928	803	119.012
11-15	6.48	24.1	15.54	16.276	380	144.064
16-20	6.88	28.2	17.07	15.281	262	157.170
21-25	3.24	38.3	18.59	19.521	183	213.590
Mean	-	-	-	-	-	137.01
Prosopis juliflora & *Prosopis glandulosa* (infested area)						
0-5	0.00	-	-	-	-	0
6-10	4.86	-	-	-	-	30.6
11-15	0.00	-	-	-	-	0
16-20	61.51	-	-	-	-	34.4
21-25	94.30	-	-	-	-	39.3
26-30	96.72	-	-	-	-	38.2
31-36	37.64	-	-	-	-	41.5
Mean	-	-	-	-	-	36.80

forests, particularly from the IPs in Pakistan. In this study, tree biomass was found positively correlated to the tree density and height. The biomass stock is primarily determined by the species composition and size-frequency distribution of trees (Clark and Clark, 2000). It is established from Table 3 that tree height (m) and tree diameter (cm) have positive relationship, while tree density (ha^{-1}) and tree diameter (cm ha^{-1}) have negative relationship, which has already been reported by (Nizami, 2012; Saeed *et al*., 2016). Results from Fig. 3 and 4 clearly show the tree volume (m^3 ha^{-1}) and stem biomass have been directly proportional to the value of the basal area (m^2 ha^{-1}) (Nizami, 2012; Ahmad *et al.,* 2014; Ahmad and Nizami, 2015; Saeed *et al*., 2016).

In this study, five-year periodic long-term field measurements of living trees, under story vegetation, and organic soil allowed the quantification of total biomass C stock change and how the demographics of individual tree species contributed to the total biomass change from the forest. Our result showed that the highest C stock of mean value 139.47 Mg ha^{-1} was founded in *E. camaldulensis* followed by other mix species crop, *D. sissoo* crop and *Prosopis* species crop with values of 97.06, 95.45 and 34.54 Mg ha^{-1}, respectively. Earlier, the C stock estimated for Indian Barringtonia floodplain forest was ranging from 263 ± 11 Mg ha^{-1}. Prior studies estimated C stocks in different forest types in North East India in the range of 203 ± 16 Mg ha^{-1} (Baishya *et al*., 2009; Bora *et al*., 2013; Rabha *et al*., 2014; Borah *et al*., 2015), which is much lower than the Barringtonia floodplain forest. In a *Populus deltoides* based agroforestry system in the Terai region of central Himalaya, the reported C stock was 96 Mg ha^{-1} (Singh and Lodhiyal, 2009). The estimated C stock in mango (*Mangifera indica*) and coffee (*Coffea* sp.) based agroforestry system was 121 ± 73 Mg ha^{-1} respectively (Schmitt-Harsh *et al*., 2012). The C storage of agro-silvicultural system in the humid tropical eco-region of Southeast Asia ranges from 228 ± 12 Mg ha^{-1} (Masera *et al*., 2003). The C stock estimated of our study ranges from 139.47 ± 34.54 Mg ha^{-1}. The mean value of total carbon stock in the study area is 85.80 Mg ha^{-1}. This result is very close to the findings of another study of 85.70 Mg ha^{-1}, which was conducted for broad leave vegetation of tropical forest plantation during 2010 (Usuga *et al*., 2010). This value is in the range of mean values of 331.09 ± 9.1 t ha^{-1} received in another study for the same species in Bella forest of the district Jehlum, Punjab, Pakistan (Saeed *et al*., 2016). However, this figure is lower than the value obtained from Asian Broadleaves plantation, which is 180 t ha^{-1}

Table 4: Age class wise biomass (Mg ha^{-1}) and carbon stocks (Mg ha^{-1}) of different tree species

Age (years)	Stem biomass (Mg ha^{-1})	T. tree biomass (Mg ha^{-1})	Upper story carbon stock (Mg ha^{-1})	Understory carbon stock (Mg ha^{-1})	Soil carbon stock (Mg ha^{-1})
Dalbergia sissoo					
0-5	31.94	50.78	25.39	0.89	11.41
6-10	65.52	104.18	52.09	1.24	17.19
11-15	85.99	136.72	68.36	1.87	29.38
16-20	102.37	162.77	81.38	1.55	22.96
21-25	112.20	178.40	89.20	2.36	31.49
26-30	122.85	195.33	97.67	2.71	35.51
Mean	86.81	138.03	69.02	1.77	24.66
Eucalyptus camaldulensis					
0-5	101.88	161.99	80.99	0.83	14.41
6-10	157.17	249.90	124.95	0.76	18.63
11-15	160.76	255.61	127.80	0.71	15.42
16-20	156.18	248.33	124.16	1.14	19.58
21-25	154.07	244.97	122.49	0.94	17.67
26-30	158.18	251.51	125.75	0.56	21.20
31-36	173.71	276.20	138.10	0.89	19.27
Mean	151.71	241.21	120.61	0.83	18.03
Others Mix Species *(Morus alba, M. nigra, Bombax ceiba , Acacia nilotica)*					
0-5	30.74	48.87	24.43	1.82	25.84
6-10	71.41	113.54	56.77	1.87	23.43
11-15	86.44	137.44	68.72	2.76	29.63
16-20	94.30	149.94	74.97	2.99	32.88
21-25	128.15	203.76	101.88	2.81	34.51
Mean	82.21	130.71	65.35	2.45	29.26
Prosopis juliflora & P. glandulosa					
0-5	0.00	0.00	0.00	0.00	0.00
6-10	18.67	29.68	14.84	1.64	11.15
11-15	0.00	0.00	0.00	0.00	0.00
16-20	20.98	33.36	16.68	1.82	14.76
21-25	23.97	38.12	19.06	2.41	13.43
26-30	23.42	37.24	18.62	2.55	15.90
31-36	25.19	40.06	20.03	2.32	17.48
Mean	22.45	35.69	17.85	2.15	14.54

Table 5: Total carbon stock in the Chichawatni irrigated plantation

Carbon pools (Mg ha^{-1})	Species				Percentage
	D. sissoo	*E. camaldulensis*	Others Mix Species *(M. alba, M. nigra, B. ceiba, A. nilotica)*	*P. juliflora and P. glandulosa*	
Upper story carbon stock	69.02	120.61	65.35	17.85	74.44
Understory carbon stock	1.77	0.83	2.45	2.15	1.96
Soil carbon stock	24.66	18.03	29.26	14.54	23.60
Total	95.45	139.47	97.06	34.54	100

(IPCC, 2003). The reason behind this difference should be precisely attributed to the fact that CIP contains a major portion of growing stock as a pole crop. This observation is also confirmed by the findings of (Zhang *et al*., 2013; Ahmad *et al*., 2014) that mature and over mature trees have more tree biomass and carbon stocks than immature crop. With regards to the value of average biomass pertaining to a particular tree species, it is highest for *E. camaldulensis.* This is due to its fast rate of growth as compared to other available tree species (Sheikh, 1993). In the upper storey vegetation, *D. sisso, E. camaldulensis,* other mix species and *Prosopis* species crops have carbon stocks of 69.02, 120.61, 65.35 and 17.85 Mg ha^{-1}, which is 74.44 percent of total carbon stocks stored in the study area (Table 5). Upper storey outcomes from the study are also alike with the result of (Chhabra *et al*., 2002), which he conducted for forest crops of India, which is in the same continent. While in under storey vegetation, it is 1.96 percent of the total carbon pool with respective values of 1.77, 0.86, 2.45 and 2.15 Mg ha^{-1}. The results of upper storey vegetations lower storey vegetation and soil carbon are similar to the finding of (Saeed *et al*., 2016) as mentioned earlier.

Estimation of trees, shrubs, herbs and grasses biomass is very important as it can provide more accurate estimates of forest biomass and carbon sequestration. Methods to establish a relationship between easily obtained plant measurements and plant biomass include a technique termed dimension analysis (Whittaker and Feeny, 1971) and further its utilization in forest biomass estimation through regression analysis (Rutherford, 1979). In a study by Rana *et al*. (1989) the herbs and shrubs of each quadrat were harvested and the litter from each quadrat was placed in

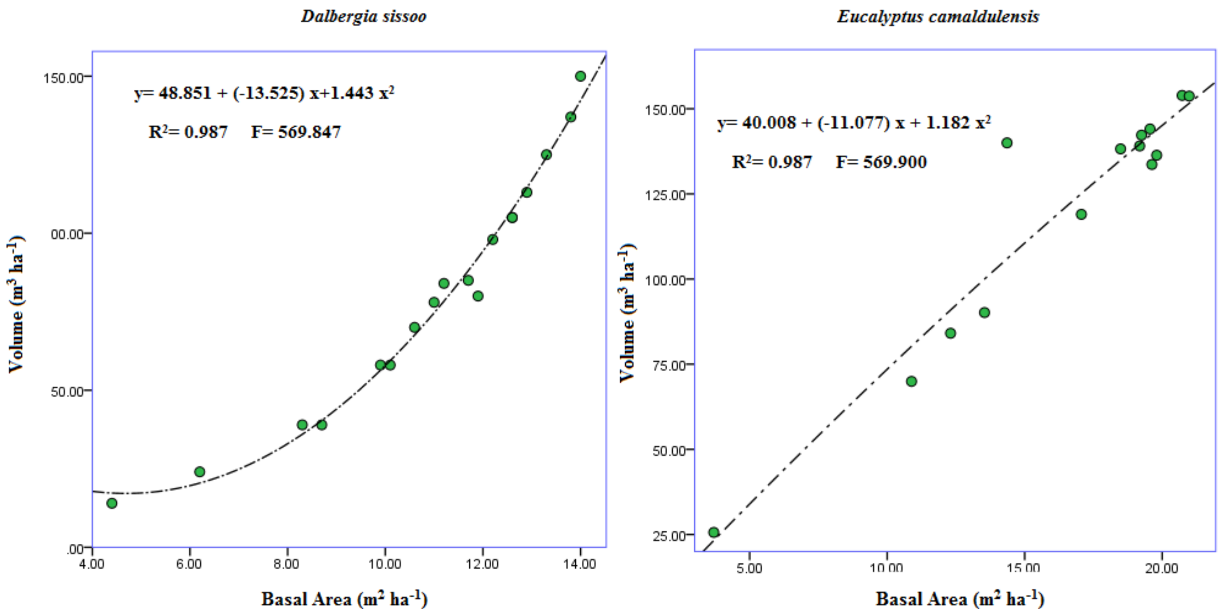

Fig. 3: Relationship between tree stem-volume (m^3 ha^{-1}) and basal area (m^2 ha^{-1})

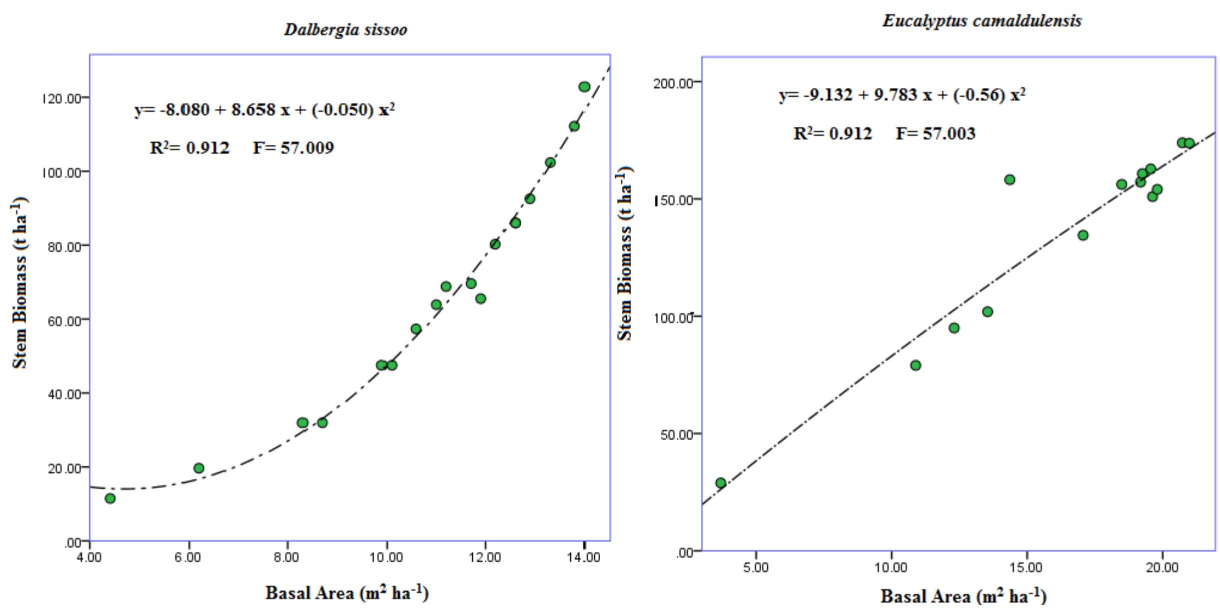

Fig. 4: Relationship b/w tree stem-biomass (Mg ha^{-1}) and basal area (m^2 ha^{-1})

paper bags and brought to the laboratory and the present results are in line with previous reports that the forest biomass can be well described with measured architectural variables such as the DBH and plant height (Foroughbakhch *et al*., 2005). The C stock estimated for Above Ground Biomass (AGB) of our study that included upper story and under story, ranges from 121.44 ± 20 Mg ha^{-1} (Table 5). The estimated AGB for different forest types in North East India ranges from 406 ± 135 Mg ha^{-1} (Baishya *et al.*, 2009; Borah *et al*., 2015). For different plantation systems the reported AGB from India was 307 ± 203 Mg ha^{-1} (Ramachandran *et al*., 2007; Singh and Lodhiyal, 2009). The reported AGB stock for tropical rain forests of Asia and Africa ranged from 450 ± 225 Mg ha^{-1} (Brown and Lugo, 1982). The estimate of AGB of the present study is remarkably lower than the biomass stock of Amazonian floodplain forests, which ranges from 325 ± 109 Mg ha^{-1} (Terakunpisut *et al.*, 2007). High biomass stock in Barringtonia forest is attributed to high tree density in the river floodplain. However, variation in biomass stock can also be due to differences in growth conditions, site quality, age and structure and management practices (Goswami *et al*., 2014).

The biomass proportion is affected by a combination of resource availability, tree species and stand age (Coyle *et al*., 2008). In this study, climate conditions, soil properties, irrigation intervals and tree ages for all the species were almost similar, so the main reason for the variation in the C storage was species-specific. The carbon concentrations of various soil samples across the plantation provided a general picture of the carbon storage in soil for different tree species. Considering the total soil carbon in the CIP the highest soil carbon storage was found in other mix species 29.26 Mg ha^{-1} followed by *D. sisso* with 24.66 Mg ha^{-1} and the lowest in *Prosopis* species 14.54 Mg ha^{-1} which outcome of 23.60% of the total carbon pool (Table 5). For the entire whole plantation soil carbon storage was higher in the old trees. The potential soil carbon storage of the trees having pods´ ability was higher than non-pods trees.

In Pakistan, the Punjab province has irrigated plantations over an area of 23.55% of the forest area, which is merely 0.72% of the entire geographical area within the province (Basit *et al*., 2013). There is an imperative need to measure the exact potential role of irrigated plantations in the terms of protective and productive functions. In protective term these plantations have been providing an indispensable biomass and effectively carbon sinks to mitigate the global climate-change turbulence. In productive term all IPs have been managed keeping in front financial objectives primarily i.e. production of timber, fuel wood and other minor forest produces. A conspicuous utility of these IPs i.e. their vibrant role in environmental protection has occasionally fetched due consideration. In current time, their role has become more important due to drastic climatic catastrophes in the shape of national hazards such as devastating floods, alarming water crisis, low crop productivity, etc. Results of this study will be helpful for future planners in Pakistan, as a first authentic research study depicting the carbon stocks available in this IP.

Conclusion

Although irrigated plantations have a great commercial potential yet in current global atmospheric trends the prime value of these plantations is environmental amelioration being the only large-sized green clusters existing in central and southern Punjab. Current study established that Chichawatni compact plantation has mean carbon stocks of 68.20 Mg ha^{-1} in upper storey, 1.8 Mg ha^{-1} in under storey and 21.57 Mg ha^{-1} in soil. Potential of biomass and carbon stocks in Punjab can be enormously improved by undertaking plantation on the available 31,223 ha blank areas through scientific research and appropriate forest management activities.

Acknowledgements

This work has been conducted with the financial help of the College of Economics and Management Northeast Forestry University Harbin 150040 P.R. China. Special thanks are extended to the Secretary of Punjab Forest Department Government of Punjab, Pakistan and the Chief Conservator of Forests, Planning, Monitoring and Evaluation Lahore for the provision of relevant data of Chichawatni Irrigated Plantation.

References

Abaker, W.E., F. Berninger, G. Saiz, V. Braojos and M. Starr, 2016. Contribution of *Acacia senegal* to biomass and soil carbon in plantations of varying age in Sudan. *For. Ecol. Manage.,* 368: 71–80

Ahmad, A., S.N. Mirza and S.M. Nizami, 2014. Assessment of biomass and carbon stocks in coniferous forest of Dir Kohistan, KPK. *Pak. J. Agric. Sci*., 51: 35–350

Ahmad, A. and S.M. Nizami, 2015. Carbon stocks of different land uses in the Kumrat valley, Hindu Kush Region of Pakistan. *J. For. Res.,* 26: 57–64

Ahmad, S., A. Ahmad and N.S. Moazzam, 2014. Assessment of biomass expansion factor of *Picea smithiana* (Wall) Boiss. *Int. J. Sci. Eng. Res*., 5: 1232–1239

Ajmal, S.M.R., 2010. *Working Plan of Changa Manga Forest Division*, p: 3. Forestry, Wildlife and Fisheries Dept., Govt. of Punjab, Lahore, Pakistan

Alam, S.A., M. Starr and B.J.F. Clark, 2013. Tree biomass and soil organic carbon densities across the Sudanese woodland savannah: a regional carbon sequestration study. *J. Arid Environ.,* 89: 67–76

Awan, A.R., M.T. Siddiqui, K. Mahmood, R. A. Khan and M. Maqsood, 2015. Interactive Effect of integrated nitrogen management on wheat production in *Acacia nilotica*- and *Eucalyptus camaldulensis*-based alley cropping systems. *Int. J. Agric. Biol.*, 17: 1270–1274

Baishya, R., S.K. Barik and K. Upadhaya, 2009. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. *Trop. Ecol.,* 50: 295–304

Basit, M.A., F. Ahmad and A. Mehwish, 2013. *Book on Forest Area*. Forestry, Wildlife and Fisheries Dept., Govt. of Punjab, Lahore, Pakistan p: 5

Bonner, M.T.L., S. Schmidt and L.P. Shoo, 2013. A meta-analytical global comparison of aboveground biomass accumulation between tropical secondary forests and monoculture plantations. *For. Ecol. Manage.,* 291: 73–86

Bora, N., A.J. Nath and A.K. Das, 2013. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar district, Assam, Northeast India. *Int. J. Ecol. Environ. Sci.,* 39: 97–106

Borah, M., D. Das, J. Kalita, H.P.D. Boruah, B. Phukan and B. Neog, 2015. Tree species composition, biomass and carbon stocks in two tropical forest of Assam. *Biomass Bioener.,* 78: 25–35

Bukhari, S.S., A. Haider and M.T. Laeeq, 2012. *Landcover Atlas of Pakistan* Pakistan Forest Institute, Peshawar, Pakistan. p: 12.

Brown, S. and A.E. Lugo, 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica,* 14: 161–187

Chhabra, A., S. Palria and V.K. Dadhwal, 2002. Growing stock-based forest biomass estimate for India. *Biomass Bioener.,* 22: 187–194

Chrsquo, H.Y., O.S. Ahmed and N.M.A. Majid, 2011. Assessment of soil carbon storage in a tropical rehabilitated forest. *Int. J. Phys. Sci.,* 6: 6210–6219

Clark, D.B. and D.A. Clark, 2000. Landscape-scale variation in forest structure and biomass in a tropical rain forest. *For. Ecol. Manage.,* 137: 185–198

Coyle, D.R., M.D. Coleman and D.P. Aubrey, 2008. Above and below ground biomass accumulation, production, and distribution of sweetgum and loblolly pine grown with irrigation and fertilization. *Can. J. For. Res.,* 38: 1335–1348

Foroughbakhch, R., G. Reyes, M.A. Alvarado-Vazquez, J. Hernandez-Pinero and A. Rocha-Estrada, 2005. Use of quantitative methods to determine leaf biomass on 15 woody shrub species in northeastern Mexico. *For. Ecol. Manage*., 216: 359–366

Gasparini, P. and L.D. Cosmo, 2015. Forest carbon in Italian forests: stocks, inherent variability and predictability using NFI data. *For. Ecol. Manage.,* 337: 186–195
Goodale, C.L., M.J. Apps, R.A. Birdsey, C.B. Field, L.S. Heath, R.A. Houghton, J.C. Jenkins, G.H. Kohlmaier, W. Kurz and S. Liu, 2002. Forest carbon sinks in the Northern Hemisphere. *Ecol. Appl.,* 12: 891–899
Goswami, S., K.S. Verma and R. Kaushal, 2014. Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. *Biol. Agric. Hortic.,* 30: 88–96
Haripriya, G.S., 2000. Estimates of biomass in Indian forests. *Biomass Bioenergy,* 19: 245–258
Hero, J.M., J.G. Castley, S.A. Butler and G.W. Lollback, 2013. Biomass estimation within an Australian *Eucalyptus* forest: meso-scale spatial arrangement and the influence of sampling intensity. *For. Ecol. Manage.,* 310: 547–554
Holl, K.D. and R.A. Zahawi, 2014. Factors explaining variability in woody above-ground biomass accumulation in restored tropical forest. *For. Ecol. Manage.,* 319: 36–43
Houghton, R.A., F. Hall and S.J. Goetz, 2009. Importance of biomass in the global carbon cycle. *J. Geophys. Res.,* 114: G00E03
IPCC, 2003. Good practice guidance for land use, land use change and forestry. Institute for Global Environmental Strategies, Hayama, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf (Accessed: 18 June 2017)
Jalkanen, A., R. Makipaa, G. Stahl, A. Lehtonen and H. Petersson, 2005. Estimation of the biomass stock of trees in Sweden: comparison of biomass equations and age-dependent biomass expansion factors. *Ann. For. Sci.,* 62: 845–851
Kanowski, J. and C.P. Catterall, 2010. Carbon stocks in above-ground biomass of monoculture plantations, mixed species plantations and environmental restoration plantings in north-east Australia. *Ecol. Manage. Restor.,* 11: 119–126
Keenan, R.J., G.A. Reams, F.D.R. Achard, J.V.D. Freitas, A. Grainger and E. Lindquist, 2015. Dynamics of global forest area: results from the FAO global forest resources assessment 2015. *For. Ecol. Manage.,* 352: 9–20
Khaggah, N.H., 2014. *Draft Working Plan of Chichawatni Forest Division*, pp: 164-166. Forestry, Wildlife and Fisheries Dept., Govt. of Punjab, Lahore, Pakistan
Kinyanjui, M.J., P. Latva-Kayra, P.S. Bhuwneshwar, P. Kariuki, A. Gichu and K. Wamichwe, 2014. An inventory of the above ground biomass in the Mau forest ecosystem, Kenya. *Open J. Ecol.,* 4: 619–627
Lal, R., 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Clim. Change.,* 51: 35–72
Lal, R., 2004. Carbon sequestration in dryland ecosystems. *Environ. Manage.,* 33: 528–544
Laurance, W.F., 2007. A new initiative to use carbon trading for tropical forest conservation. *Biotropica,* 39: 20–24
Lehtonen, A., R. Makipaa, J. Heikkinen, R. Sievanena and J. Liski, 2004. Biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch according to stand age for boreal forests. *For. Ecol. Manage.,* 188: 211–224
Liu, J., S. Liu and T.R. Loveland, 2006. Temporal evolution of carbon budgets of the Appalachian forests in the US from 1972 to 2000. *For. Ecol. Manage.,* 222: 191–201
Madgwick, H.A.I., 1982. *Forest Biomass,* 1st edition. Springer Science and Business Media, Netherlands
Magalhaes, T.M. and T. Seifert, 2015. Tree component biomass expansion factors and root-to-shoot ratio of Lebombo ironwood: measurement uncertainty. *Carbon Balanc. Manage.,* 10: 9–23
Malhi, Y., P. Meir and S. Brown, 2002. Forests, carbon and global climate. *Philos. Trans. R. Soc. Lond.,* 360: 1567–1591
Marin-Spiotta, E. and S. Sharma, 2013. Carbon storage in successional and plantation forest soils: a tropical analysis. *Glob. Ecol. Biogeogr.,* 22: 105–117
Martin, P.A., A.C. Newton and J.M. Bullock, 2013. Carbon pools recover more quickly than plant biodiversity in tropical secondary forests. *Proc. R. Soc. B.,* 280: 22–36
Masera, O.R., J.F. Garza-Caligaris, M. Kanninen, T. Karjalainen, J. Liski, G.J. Nabuurs, A. Pussinen, B.H.J.D. Jong and G.M.J. Mohren, 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V. 2 approach. *Ecol. Model.,* 164: 177–199
Nath, C.D., R. Pelissier and C. Garcia, 2010. Comparative efficiency and accuracy of variable area transects versus square plots for sampling tree diversity and density. *Agrofor. Syst.,* 79: 223–236
Nizami, S.M., 2012. The inventory of the carbon stocks in sub tropical forests of Pakistan for reporting under Kyoto Protocol. *J. For. Res.,* 23: 377–384
Paquette, A. and C. Messier, 2010. The role of plantations in managing the world's forests in the Anthropocene. *Front. Ecol. Environ.,* 8: 27–34
PARC., 1994. *Handbook of Forestry*. Pakistan Agricultural Research Council, Islamabad, Pakistan. pp: 118–119
Philip, M.S., 1994. *Measuring Trees and Forests*, 2nd edition. CAB international, Wallingford, UK
Qureshi, A., R. Badola and S.A. Hussain, 2012. A review of protocols used for assessment of carbon stock in forested landscapes. *Environ. Sci. Policy,* 16: 81–89
Rabha, D., N. Borah and A.K. Das, 2014. Assessment of aboveground and soil organic carbon stocks in Dipterocarpus forests of Barak valley, Assam, Northeast India. *Int. J. Ecol. Environ. Sci.,* 40: 29–40
Ramachandran, A., S. Jayakumar, R.M. Haroon, A. Bhaskaran and D.I. Arockiasamy, 2007. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. *Curr. Sci.,* 92: 323–331
Rana, B.S., R.P. Singh and S.P. Singh, 1989. Carbon and energy dynamics of seven central Himalayan forests. *Trop. Ecol.,* 30: 253–264
Ringius, L., 2002. Soil carbon sequestration and the CDM: opportunities and challenges for Africa. *Clim. Chang.,* 54: 471–495
Roy, J., H.A. Mooney and B. Saugier, 2001. *Terrestrial Global Productivity*, 1st edition. Academic Press, USA
Rutherford, M.C., 1979. Plant-based techniques for determining available browse and browse utilization: a review. *Bot. Rev.,* 45: 203–228
Saeed, S., M.I. Ashraf, A. Ahmad and Z. Rahman, 2016. The bela forest ecosystem of district Jhelum, a potential carbon sink. *Pak. J. Bot.,* 48: 121–129
Sankaran, M., N.P. Hanan, R.J. Scholes, J. Ratnam, D.J. Augustine, B.S. Cade, J. Gignoux, S.I. Higgins, X. Le Roux and F. Ludwig, 2005. Determinants of woody cover in African savannas. *Nature,* 438: 846–849
Schmitt-Harsh, M., T.P. Evans, E. Castellanos and J.C. Randolph, 2012. Carbon stocks in coffee agroforests and mixed dry tropical forests in the western highlands of Guatemala. *Agrofor. Syst.,* 86: 141–157
Sheikh, M.I., 1993. *Trees of Pakistan*. GOP-USAID Forestry Planning and Development Project, Islamabad, Pakistan. p: 65
Singh, P. and L.S. Lodhiyal, 2009. Biomass and carbon allocation in 8-year-old poplar (*Populus deltoides*) plantation in Tarai agroforestry systems of central Himalaya, India. *N.Y. Sci. J.,* 2: 49–53
Somogyi, Z., E. Cienciala, R. Makipaa, P. Muukkonen, A. Lehtonen and P. Weiss, 2007. Indirect methods of large-scale forest biomass estimation. *Eur. J. For. Res.,* 126: 197–207
Tabacchi, G., L. Di Cosmo and P. Gasparini, 2011. Aboveground tree volume and phytomass prediction equations for forest species in Italy. *Eur. J. For. Res.,* 130: 911–934
Terakunpisut, J., N. Gajaseni and N. Ruankawe, 2007. Carbon sequestration potential in aboveground biomass of Thong Pha Phum national forest, Thailand. *Appl. Ecol. Environ. Res.,* 5: 93–102
Tolunay, D., 2011. Total carbon stocks and carbon accumulation in living tree biomass in forest ecosystems of Turkey. *Turk. J. Agric. For.,* 35: 265–279
Tomppo, E., T. Gschwantner, M. Lawrence, R.E. McRoberts, K. Gabler, K. Schadauer, C. Vidal, A. Lanz, G. Stahl and E. Cienciala, 2010. *National Forest Inventories. Pathways for Common Reporting.* European Science Foundation, Strasbourg, France
Ung, C.H., P. Bernier and X.J. Guo, 2008. Canadian national biomass equations: new parameter estimates that include British Columbia data. *Can. J. For. Res.,* 38: 1123–1132

Usuga, J.C.L., J.A.R. Toro, M.V.R. Alzate and A.D.J.L. Tapias, 2010. Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. *For. Ecol. Manage*., 260: 1906–1913
Van Camp, N., I.V. Walle, J. Mertens, S. De Neve, R. Samson, N.l. Lust, R. Lemeur, P. Boeckx, P. Lootens and D. Beheydt, 2004. Inventory-based carbon stock of Flemish forests: a comparison of European biomass expansion factors. *Ann. For. Sci.,* 61: 677–682
Vesa, L., R.E. Malimbwi, E. Tomppo, E. Zahabu, S. Maliondo, N. Chamuya, E. Nssoko, J. Otieno, G. Miceli and A.K. Kaaya, 2010. *NAFORMA Field Manual: Biophysical Survey*. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism, Dar-Es-Salaam, Tanzania
Vgen, T.G. and T. Gumbricht, 2012. *Sahel Atlas of Changing Landscapes: Tracing Ttrends and Variations in Vegetation Cover and Soil Condition*. UNEP, Nairobi, Kenya
Walle, I.V., N. Van Camp, D. Perrin, R. Lemeur, K. Verheyen, B. Van Wesemael and E. Laitat, 2005. Growing stock-based assessment of the carbon stock in the Belgian forest biomass. *Ann. For. Sci.,* 62: 853–864
Whittaker, R.H. and P.P. Feeny, 1971. Allelochemics: Chemical Interactions between Species. *Science*, 171: 757–770
Woodbury, P.B., J.E. Smith and L.S. Heath, 2007. Carbon sequestration in the US forest sector from 1990 to 2010. *For. Ecol. Manage.,* 241: 14–27
Zhang, Y., F. Gu, S. Liu, Y. Liu and C. Li, 2013. Variations of carbon stock with forest types in subalpine region of southwestern China. *For. Ecol. Manage.,* 300: 88–95

(Received 22 November 2016; Accepted 20 June 2017)