INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 13, No. 6, p. 8-16, 2018
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Tree biomass and carbon estimation of *Pinus roxburghii* and *Eucalyptus camaldulensis*

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Article published December 15, 2018

Key words: Above ground biomass, Below ground biomass, Carbon stocks, REDD+.

Abstract

Forest play great role in regulation of global carbon cycles and acts as sink and source. The present study focused on the carbon stock in two carbon pools, above-ground biomass (AGB) and below ground biomass (BGB) in conifer forests and Eucalyptus plantation located in district Buner, Pakistan. The specific objectives were (1) to estimate above ground biomass (AGB) and below ground biomass (BGB), (2) to estimate carbon sequestration potential of the study area and (3) suggest measures for conservation and enhancement of carbon stock in the study area. Results the highest AGB and BGB (t/ha)for *Pinusroxburghii*was217.4and 72.5 and 44.8 respectively while the lowest tree biomass (36.8 t/ha). Regarding Eucalyptus plantation the highest and lowest for total biomass, AGB and BGB values (t/ha) were 35.6, 28.2 and 28.2 respectively. Similarly, highest total carbon stocks, AGC and BGC (t/ha) for *Pinus roxburghii* were 102.1, 81.1 and 21 respectively while regarding Eucalyptus, the highest total carbon stocks, AGC and BGC (t/ha) were estimated as 16.7, 13.2 and 3.4 respectively. Correlation between basal area (m^2) per plot and total tree biomass for both species showed strong positive relationships. Regarding *Pinus roxburghii* the R^2 value was 0.97 and for Eucalyptus the R^2 value was 0.98. This study also recommends that the different forest types of Buner forest division have the potential for REDD+ activities in future.

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Introduction

Forest play great role in regulation of global carbon cycles and can acts as sink and source (Chambers *et al.*, 2000). It is estimated that about 60 percent of terrestrial carbon storage are stored in forest ecosystems (Cerririlo and Oyonarte, 2006). Changes in forest carbon pools can be assessed by biomass of trees and forest types at various scales with sufficient accuracy (Djomo *et al.*, 2017; Ene *et al.*, 2017; Sullivan *et al.*, 2017).Such estimations and calculations are very important for carbon measurement and monitoring systems in carbon sequestration projects (sink projects) that focused long-term and sustainable storage of atmospheric carbon in different forest pools i.e above ground biomass (AGB), below ground biomass (BGB), dead wood carbon, forest floor (litter, twings) carbon and soil organic matter (Nizami *et al.,* 2009).United Nations Framework Convention on Climate Change (UNFCCC) has recognized forest role as carbon sinks under Kyoto protocol that the ability of forests to sequester carbon (Evison, 2017). In contrast large scale deforestation results in release of greenhouse gases which not only resulted in forests cover decline but also contributing towards adverse of climate change (Nizami *et al,* 2009; Avitabile *et al* 2017).

Measurement of biomass and carbon stocks require forest inventory data in which different forest attributes are measured in sampled plots (Ene *et al.*, 2017; Sullivan *et al.*, 2017). To represent all forest carbon pools, detailed and intensive measurement of all forest attributes representing particular pool through integrated destructive and non-destructive methods (Vashum and Jayakumar, 2012; Djomo *et al.*, 2017). Sample plots number, size, shape and layout should be properly decided and above ground biomass, litter, and deadwood and soil carbon data are collected while below ground biomass is determined through root shoot-ratios available in the literature (Borah *et al* 1997).

Various studies of carbon stock assessments are conducted in Pakistan, but(Nizami *et al.*, 2012) conducted inventory for the carbon stocks in subtropical forests of Pakistan; Subtropical Chirpine and Subtropical broadleaved forests. The total number of sample plots were 21 each of 0.1 ha size. The study estimated biomass of 50.93 t/ha and 40.43 t/ha and estimated carbon was 31.18 and 24.36 t C/ha for two sites (Kherimurat and Sohawa) respectively. Pakistan has a total land area of 88.87 million hectares; with forest cover spread over 4.6 million hectares with 5.23% of the total land area (Bukhari and Bajwa, 2012). The country has substantial scope for REDD+ projects in its different forest types including Coniferous forests, Dry temperate juniper and Chilghoza forests, riverine forests, Coastal forests, and plantations of different types (Nizami *et al.*, 2009). The present study focused on the tree biomass estimation of conifer forests and Eucalyptus plantation located in district Buner, Pakistan. This research study investigated carbon stock in two carbon pools, above-ground biomass (AGB) and below ground biomass (BGB).The specific objectives are (1) to estimate above ground biomass (AGB) and below ground biomass (BGB), (2) to estimate carbon sequestration potential of the study area and (3) suggest measures for conservation and enhancement of carbon stock in the study area.a total of 20 circular sample plots of 0.1 ha area was randomly laid out in the forest and all the trees inside the circle were enumerated.

Materials and methods

Study area

Buner district of Swat forest division is the study area of the current research. The district lies between 34º-10′ and 34º-43′ North latitudes and 72º-11′ and 72º-49′ East longitudes. The boundaries of District Buner joins Swabi at KasKuruna on the South, Mardan at Ambela check post on the South-West, Gadoon at famous Mahaban and Amb on the South-East and the tribal belt separates it from Hazara at Biwokandao in Tehsil Chagharzaion the East. To its North and North-West lies the District of Swat across the Karakar pass and mount Ilam, which serves as the natural boundary Swat and Buner. To the west is Malakand Agency beyond the peaks of Kohisar and Nanser.

The forest types of the area are: Dry Sub tropical broad leaved, Pure Chir pine, Dry Oak (*Quercus baloot*) and mixed forests of Chir and Kail. Dry Sub-tropical broad-leaved forest is the potential forest type of the area below 1000m elevation. Dodonea viscose is the most predominant species of the type while other species are Kao, Phulai, Khair, *Carissa spinarum*, *Pistaci aintegrama*, Ficus spp, *Celtis australis*, *Zizyphus jujuba*, *Punica granatum*, and *Adhatoda vassica*.

The Chir forests extend from about 1000 to 1500m elevation and occupy major parts of the planning area. They are Gadazai, Malik pur, Batai, Karakar, Daggar, Chamla, Nagri, Mohaban, and Malka. There are almost pure chir-pine forests with little Kail on the upper reaches. The mixed forests of chir and Kail occur from about 1500 to 3000m elevation. They are found in a small extent in the Jawar, Daggar, Chamla and Chagharzai Planning units. Eucalyptus is also planted by the local people and communities in nearly plain area for commercial purposes. The mountainous area near BabajeeCandao and other nearby areas are covered with Eucalyptus plantation. In some areas these plantations are mixed with chir forests at lower elevation or plain areas.

Selection of the forest areas

In district Buner there are both, Sub-tropical Dry Broadleaved Forest, Sub tropical Chir Forest and Mixed Forests of Chir and Kail but this research study only covered subtropical Chirpine forest and Eucalyptus plantation. The Chirpine forest includes areas of Jabbi, Shpala, Munda and Karezo while Eucalyptus plantation includes areas of Babajee Candao and Tutyanoo Kalay.

Sample plots

For this study, a total of 20 circular sample plots of 0.1 ha area was randomly laid out in the forest and all the trees inside the circle were enumerated. During forest inventory overall 20 plots were taken, out of which ten plots were taken from Chirpine forest while the rest of the ten plots were laid in Eucalyptus plantation.

Measurements in the sample plots

Diameter at breast height (DBH) and height of all trees in a sample plot were attributes for above ground biomass (AGB) determination. For the carbon inventory all the trees with a DBH of ≥ 10 cm were measured in Chir forest and DBH ≥ 8 cm in Eucalyptus plantation except that of *Dodona eaviscosa* whose basal diameter was found to be less than < 5 cm so all plants of Dodonaea were measured at the base.

The heights of trees were measured with Haga-altimeter, diameter at breast height (1.37m or 4.5 feet) with Diameter tape or Diameter caliper, radius of the circular plot with measuring tape and angles (degrees) with Sunnto compass. Odd shaped trees i.e. buttressed or forked trees were also measured keeping in mind all the necessary points.

Estimation of carbon stocks

Carbon stock was estimated through the following steps:

Basal area calculation: All trees that were enumerated in the plot were arranged properly in Excel sheets and the basal area of each tree was calculated. Tree Basal Area (TBA) is the cross-sectional area (over the bark) at breast height (1.3m above the ground) measured in meter squared. Basal area and height are the basic variables to estimate the volume and biomass of a tree. Greater the basal area greater will be the volume. To determine Tree Basal Area simply measure the diameter at breast height in cm (DBHOB) and calculate the basal area (m^2) using the following equation which is simply adapted from the simple formula for the area of a circle (area=πr^2). This equation (1) converts the diameter in cm to the basal area in meter squared.

$$TBA = \left(\frac{DBH}{200}\right)^2 \times 3.14$$ ------------ Equation 1

Where

TBA is Tree basal area in square meters DBH is the Diameter at Breast height in centimeters.

Estimation of biomass

The total biomass, above ground biomass (AGB) and below ground biomass (BGB) was calculated in kilograms for each tree in the plot and then sum of all trees dry biomass was also calculated using Allometric equations. Tree diameter and height values were used to calculate dry biomass for each tree which was necessary for carbon estimation later on. The given equation (2)was taken from Pakistan Forest Institute, Peshawar (PFI) and used for dry biomass:

$Y = 0.224 \times (DBH^2 \times Ht)^{0.9767}$-------- Equation 2

Where

Y is above ground biomass in kilograms

DBH is Diameter at Breast Height in centimeters

Ht is height in meters.

These above ground biomass (AGB) in kilograms were then converted into dry biomass in tons per hectare by scale factor of 10 because plots size was 0.1 ha. Below ground biomass (BGB) was calculated by multiplying AGB by 0.26 as IPCC guidelines (Paustian and Ravindranath, 2006). Total biomass was obtained by summation of AGB and BGB.

It is generally considered that about half of the dry biomass consists of carbon. Thus the AGB was converted to above ground carbon (AGC) stock by multiplying it with 0.47.

In the current study the carbon stock was calculated by assuming that the carbon content is 47 % of total biomass, as described by IPCC (Paustian and Ravindranath, 2006). Further, AGC was converted into BGC by multiplying it with 0.26, the ratio provided IPCC guidelines (Paustian and Ravindranath, 2006).

Results and discussion

DBH range and average

DBH range and average for each plot have been summarized in Table 1.

Table 1. DBH, Height and Basal Area of the sample plots.

Plot No	Species	Trees/ Plot	DBH Range (cm)	DBH (cm)/plot	Height Range (m)	Height (m)/plot	Basal Area (m^2)/plot
1.	*Pinus roxburghii*	15	29 to 76	44	13 to 25	18.9	2.50
2.	*Pinus roxburghii*	15	35 to 77	49.5	13 to 26	20.2	3.08
3.	*Pinus roxburghii*	18	28 to 81	45.8	15 to 25	20.2	3.24
4.	*Pinus roxburghii*	17	26 to 65	42.8	14 to 25	18.3	2.64
5.	*Pinus roxburghii*	26	29 to 54	39.3	14 to 21	18.4	3.29
6.	*Pinus roxburghii*	18	15 to 62	37	8 to 24	17.2	2.17
7.	*Pinus roxburghii*	13	15 to 68	44	8 to 25	18.2	2.30
8.	*Pinus roxburghii*	15	30 to 92	44.3	15 to 22	18.7	2.58
9.	*Pinus roxburghii*	14	13 to 74	55.4	7 to 25	20.9	3.61
10.	*Pinus roxburghii*	13	13 to 39	27	7 to 19	15	0.78
11.	Eucalyptus	30	8 to 16	10.3	9 to 16	11.1	0.26
12.	Eucalyptus	41	8 to 14	10.1	9 to 16	11.1	0.34
13.	Eucalyptus	34	8 to 18	11.9	9 to 23	12	0.40
14.	Eucalyptus	28	8 to 12	9.3	9 to 15	10.7	0.19
15.	Eucalyptus	43	8 to 24	13.8	9 to 18	12.8	0.69
16.	Eucalyptus	32	8 to 15	10.9	9 to 14	11.2	0.30
17.	Eucalyptus	30	8 to 16	12.2	9 to 14	11.9	0.36
18.	Eucalyptus	26	8 to 11	8.6	9 to 12	9.9	0.15
19.	Eucalyptus	27	8 to 16	10.2	9 to 14	11	0.23
20.	Eucalyptus	23	8 to 29	15.1	9 to 18	13.1	0.47

The DBH range was determined by the minimum and maximum DBH within the given plot. The table depicted that lowest average DBH for *Pinusroxburghii*is 27 cm in plot number 10 with 13 total trees while the highest average DBH is 55cm in plot 9 with 14trees. Regardingdiameter range and mean DBH of Eucalyptus plantations, the highest value of average DBH was 15.1 cm in plot number 20 with 23 trees and the lowest 8.6 cm average DBH was found in plot 18 with 26 trees according to Table 2.

Table 2. Tree biomass and carbon stocks estimation.

Plot No	Species	AGB (t/ha)	BGB (t/ha)	Total tree biomass (t/ha)	AGC (t/ha)	BGC (t/ha)	Total carbon stocks (t/ha)
1.	*Pinus roxburghii*	110.8	28.8	139.6	52.1	13.5	65.6
2.	*Pinus roxburghii*	148.9	38.7	187.6	70.0	18.2	88.2
3.	*Pinus roxburghii*	153.6	39.9	193.5	72.2	18.7	90.9
4.	*Pinus roxburghii*	114.6	29.8	144.5	53.9	14.0	67.9
5.	*Pinus roxburghii*	139.7	36.32	176.0	65.6	17.0	82.7
6.	*Pinus roxburghii*	94.7	24.6	119.3	44.5	11.5	56.1
7.	*Pinus roxburghii*	104.7	27.2	131.9	49.2	12.7	62.0
8.	*Pinus roxburghii*	110.2	28.6	138.9	51.8	13.4	65.2
9.	*Pinus roxburghii*	172.5	44.8	217.4	81.1	21.0	102.1
10.	*Pinus roxburghii*	29.2	7.6	36.8	13.7	3.5	17.3
11.	Eucalyptus	8.8	2.3	11.1	4.1	1.0	5.2
12.	Eucalyptus	11.3	2.9	14.3	5.3	1.3	6.7
13.	Eucalyptus	15.3	3.9	19.3	7.2	1.8	9.0
14.	Eucalyptus	6.3	1.6	7.9	2.9	0.7	3.7
15.	Eucalyptus	28.2	7.3	35.6	13.2	3.4	16.7
16.	Eucalyptus	10.4	2.7	13.1	4.9	1.2	6.1
17.	Eucalyptus	13.1	3.4	16.5	6.1	1.6	7.7
18.	Eucalyptus	4.5	1.1	5.7	2.1	0.5	2.7
19.	Eucalyptus	7.7	2.0	9.7	3.6	0.9	4.6
20.	Eucalyptus	20.1	5.2	25.4	9.4	2.4	11.9

DBH range of these plantations is from 8 to 29 cm but most of the trees have a DBH less than 16 cm because of its commercial uses. These plantations were for the commercial purposes for few years. Therefore, large diameter trees were not found in these plots.

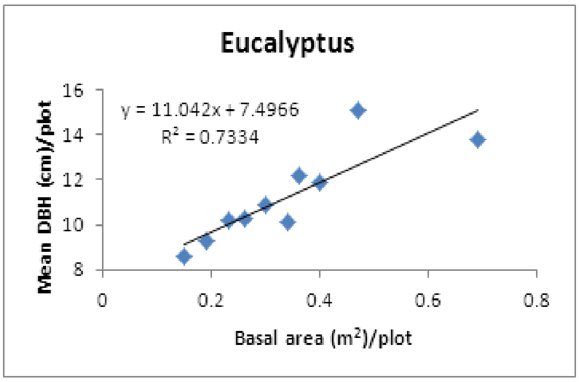

Fig. 1. Correlation between Basal areas and mean DBH (Eucalyptus).

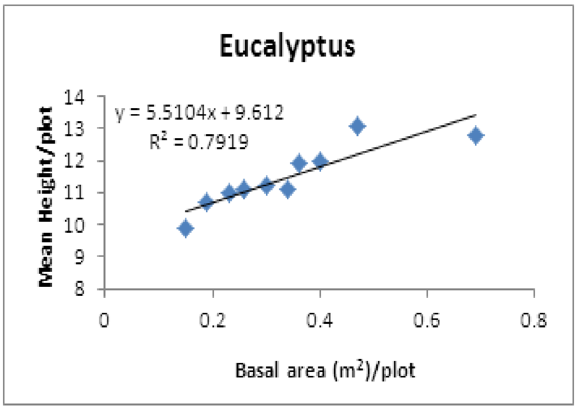

Fig. 2. Correlation between Basal area and mean Height (Eucalyptus).

These plantations were present in the lower mountainous region where *Dodonia viscosa* were also present in some regions.

Height range and average

Pinus roxburghii species where different attributes such as number of trees per plot, height range and average height have been discussed in Table 1. As given in Table 1shows that the lowest average height is 15m of plot number 10 with 13 trees and the range height of this plot varies from 7 to 19m, while the highest average height is 20.9 of plot number 09 where total number of trees is 14 and height range of 07 to 25 m. Regarding Eucalyptus, height range and average height, Table 2 depicted that most of plots have similar height ranges and average height per plot because all trees fall within minimum diameter range and have little age difference. Eucalyptus plantations have attained more height few years.

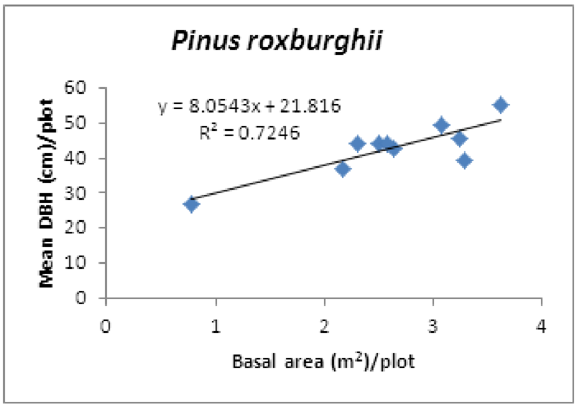

Fig. 3. Correlation between Basal area and mean DBH (Chirpine).

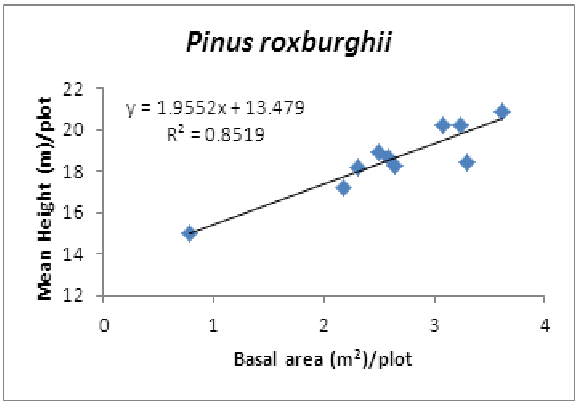

Fig. 4. Correlation between Basal area and mean Height (Chirpine).

The normal range of height which the Eucalyptus attains in four to six years is 12 to 16m.

The maximum height range for Eucalyptus plantation was from 9 to 23m in plot number 13. Also the average height (m) per plot is given against each plot where the highest average height is 13.1m while the lowest average height is 9.9m.

Basal area

Basal area shows that how much area the given tree is occupied in the plot which is represented in $m^2$and the basal areas of sample plots are presented in Table 1.

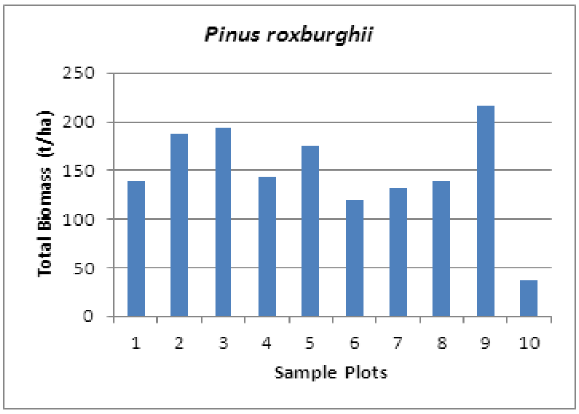

Fig. 5. Total Tree Biomass (t/ha of Chirpine).

The highest total basal area is 3.61 m^2 for plot number 9 with 14 trees total number of trees for *Pinus roxburghii*. While the lowest total basal area is 0.78 m^2 for plot number 10 with total 13 trees. For eucalyptus the highest and lowest values are 0.69 and 0.15 with 43 and 26 trees respectively.

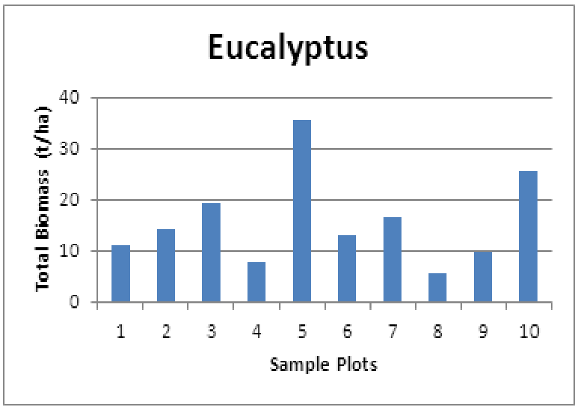

Fig. 6. Total tree biomass (t/ha) of Eucalyptus.

Strong correlation was found between basal area and mean DBH and mean height for both species. Regarding Eucalyptus, Fig. 1 shows R^2 value of 0.73

between mean DBH and mean basal area while mean height versus basal area, R^2 value (0.79) was observed in Fig. 2. Similarly, R^2 values for *Pinus roxburghii* were 0.72 and 0.85 for mean DBH and mean Height in Figure 3 and 4 respectively.

Tree biomass and carbon stocks

Estimated tree biomass (t/ha) and carbon stocks (t/ha) are summarized in Table 2. The highest biomass (t/ha)for *Pinusroxburghii*was217.4 with AGB and BGB of 172.5 and 44.8 respectively while the lowest tree biomass (36.8 t/ha) among the sampled plots was found in plot number 10. Regarding Eucalyptus plantation the highest and lowest for total biomass, AGB and BGB values (t/ha) were 35.6, 28.2 and 28.2 respectively.

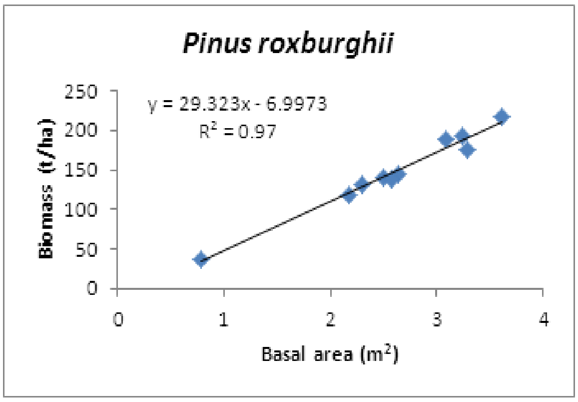

Fig. 7. Correlation between Biomass and Basal area (Chirpine).

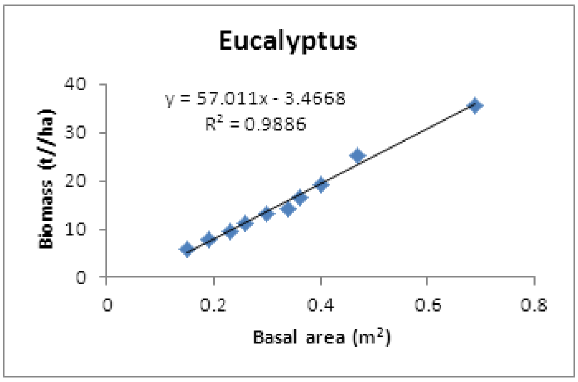

Fig. 8. Correlation between Biomass and Basal area (Eucalyptus).

Similarly, highest total carbon stocks, AGC and BGC (t/ha) for *Pinus roxburghii* were 102.1, 81.1 and 21 respectively while regarding Eucalyptus, the highest total carbon stocks, AGC and BGC (t/ha) were estimated as 16.7, 13.2 and 3.4 respectively. Figure 5 and 6 shows total tree biomass (t/ha) and total carbons (t/ha) for *Pinus roxburghii* and Eucalyptus in sample plots respectively. Correlation between basal area (m^2) per plot and total tree biomass for both species showed strong positive relationships. Regarding *Pinus roxburghii* the R^2 value was 0.97 and for Eucalyptus the R^2 value was 0.98 as depicted in Figure 7 and 8 respectively.

Conclusion

DBH of Chirpine ranged from 13 to 92cm with the highest average DBH of 55.4cm, while the DBH of Eucalyptus ranged from 8 to 29cm with the highest average DBH of 15.1cm. The study also shows that the total dry Biomass of Chirpine plots was 1485.5t/ha, while the total dry biomass of Eucalyptus plantation was 158.6 t/ha and overall total dry biomass for both chir and eucalyptus plantation was 1644.1 t/ha.

The total carbon stock of Chirpine forest and Eucalyptus plantation was 698 t/ha and 74.3 t/ha respectively with the total carbon stock of both the plantation was 772.3 t/ha. This value further explain that the Chir forest storage more carbon as compare to the eucalyptus plantation and the main reason is that the local people use eucalyptus for the local purposes which is a fast growing specie and cut it down at the age of 4 to 5 years.

The study revealed that the total crown percentage of both the Chirpine forest and Eucalyptus plantation was 66.66% sparse while 33.33% was dense. This was probably due to the fact that these forests are under severe pressures which are frequently cut by the local people for their domestic uses.

Thus by raising and protecting these forests, a large amount of carbon can be sequestered and a lots of carbon credits can be earned through carbon trading under REDD+ (Reducing Emissions from Deforestation and Forest Degradation) and voluntary carbon markets (VCM).

In addition to carbon credits, other benefits can also be achieved by establishing more broad leaved and *Pinus* species in these forests of Buner including biodiversity conservation, soil rehabilitation, fuel wood, timber and recreation.

Furthermore the study could be also helpful in management of forest to increase carbon sequestration. Some recommendations of the study are the following.

This study of forest carbon is just based on the Chir forest and Eucalyptus plantation of one region of District Buner, such estimations in other parts of the District Buner are recommended.

This study of carbon stock estimation recommend multi-purpose activities encompassing eco-tourism, sustainable forest management (SFM) and biodiversity conservation along with carbon management.

It also suggests that as the villages in District Buner are under-developed and literacy rate is also low, indicating the fact that most of the people of district Buner are unaware of social forestry. Due to which the deforestation is increasing day by day.

This study also recommends that the different forest types of Buner forest division have the potential for REDD+ activities. If the REDD+ projects and forest management under REDD+ are implemented in the study area it will have a positive impacts on the forest, local communities and other stockholders.

This study also recommends the complete control over the indiscriminate and illicit cutting of trees, especially the young ones and employing range management principles to avoid grazing and browsing of regenerations in Chirpine and other mixed forest of District Buner. Thus keeping the existence carbon stock and leaving room for further carbon capture and sequestration.

This study also suggests that the irrigated plantations should be raised in this area in district Buner so as to generate more and more carbon credits. The accuracy of carbon stock estimates can be enhanced by using locally developed allometric equations and BEFs. So it is recommended to develop these equations on local levels.

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