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ESTIMATION OF WOOD VOLUME, CARBON STOCK AND ROTATION AGE IN SUBTROPICAL PINE FORESTS OF MALAKAND, KHYBER PAKHTUNKHWA

BILAL AHMAD[1*], ANWAR ALI[2], FAZLI RABBI[1], NAVEED ALAM[1], MAMMO SIRAJ[3], KALEEM MEHMOOD[1], MAMOONA WALI MUHAMMAD[2] AND SAMI ULLAH[4,5]

[1]*Institute of Agriculture Sciences and Forestry, University of Swat, Swat, 19130, Pakistan*
[2]*Pakistan Forest Institute, Peshawar 25130, Pakistan*
[3]*Department of Biology, Ambo University, Ambo, Ethiopia*
[4]*Department of Forestry, Faculty of Life Science, Shaheed Benazir Bhutto University Sheringal, Dir Upper, Pakistan*
[5]*GIS and Space Application in Geosciences (G-SAGL) Lab, National Center of GIS and Space Application (NCGSA), Institute of Space Technology, Islamabad 44000, Pakistan*
[*]*Corresponding author's email: bilalforester89@yahoo.com*

Abstract

This study was conducted in subtropical pine forests of Malakand, situated at an elevation of 762 to 1165 m asl (34˚34´ North-latitude & 71º54´ East-longitudes) in Khyber Pakhtunkhwa. The study was aimed at estimating wood volume and carbon stock in the target area and determining a proper rotation age for Sub-tropical pine (*Pinus roxburghii*) forests. Using a simple random sampling technique, a total of 20 sample plots (with plot size of 50m×50m) were laid out in the forest area. Data was recorded for tree Diameter at breast Height (DBH), tree height, radial increment in the last 10 years, tree density and tree age for each age class. The results indicated that the tree DBH and height shows a logistic type of relation with stand age, i.e., first increase slowly then at faster rate and later-on the tree growths decline or level-off at higher ages. The average stand basal area and stand volume were 11.8 m^2/ha and 85.04 m^3/ha respectively. Tree density was 117 trees/ha, above and below ground tree biomass were 54.05 and 14.05 t/ha respectively. The aboveground carbon and belowground carbon were estimated as 27.02 and 7.03 t/ha respectively and the total tree carbon stock was determined as 34.05 t/ha. The proper economic rotation age for Sub-tropical pine forests was suggested as 90 years to get relatively maximum wood production. The study concluded that Sub-tropical pine forests have high potential for wood production and carbon sequestration if managed properly.

Key words: Growing stock, Rotation age, Wood volume, Carbon stock, *Pinus roxburghii*.

Introduction

The ecologists have been searching different ways for mitigating global warming and climate change through reducing emission of Green House Gases (GHG). Amongst all ecosystems, a special attention is given to forest ecosystem which play an important role in sequestering the atmospheric carbon-dioxide (CO_2) in the form of biomass carbon (Balboa-Murias *et al.*, 2006; Bonan, 2008; Deng *et al.*, 2011). Forests have the ability to store 20 to 50 times more carbon stock than barren lands (Houghton *et al.*, 1995), due to their woody nature (Sharma *et al.*, 2011; Danquah *et al.*, 2012). When tree grow, they capture carbon dioxide from the atmosphere through photosynthesis and store this carbon in the form of biomass and soil organic matter in the forest ecosystem (Kumar *et al.*, 2013). Forest trees can store large amounts of carbon, up to hundreds of tons ha^{-1} in their lifespan (Eggleston *et al.*, 2006).

Forests are the natural packing factory of carbon and the assessment of carbon stock present in the biomass of forest tree is a crucial step to determine the contribution of forest conservation in the global carbon cycle (Gairola *et al.*, 2011). The amount of carbon stored in the plant biomass worldwide exceeds than the atmospheric CO_2, in which about 90% of carbon stock is stored in forest trees biomass (Körner, 2006). Forests not only store a large quantity of carbon in biomass and soil but also sequester carbon from the atmosphere during their growth (Saeed *et al.*, 2016). It is, therefore, essential to conserve this carbon and increase the capacity of forests to sequester more carbon from the atmosphere. (Ajtay, 1979)

Recognizing the role of forests in climate change mitigation, United Nation Framework Convention on Climate Change (UNFCCC) has devised a mechanism called REDD+ which means Reducing Emissions from Deforestation and Forest Degradation and the plus sign indicates conservation, sustainable management of forests, and enhancement of forest carbon stocks (Scheyvens & Setyarso, 2010). REDD+ is aimed at providing financial incentives to those developing countries who reduce their deforestation and forest degradation rates and increase forest areas for climate change mitigation. Besides, voluntary carbon market is also functioning in different parts of the world, which allows polluting industries to offset their emissions by investing in forest conservation. Carbon trading under REDD+ and voluntary carbon market necessitates the accurate measurement and monitoring of carbon stocks in the forests (Nguon, 2019).

Despite the significant role of forests in climate change mitigation, forests are still the main source of timber in many countries and hence forest management is primarily focused on maximum wood production (Ahmad *et al.*, 2018). One of the most important questions in the management of a forest is the proper rotation age at which a forest crops should be harvested (Płotkowski *et al.*, 2016). There are two main approaches for estimating rotation age, the first one is physical rotation age or silvicultural rotation age, which is based on the capability of forest trees to continue satisfactory growth and reproductive function at a given site. The second approach for rotation age is economic rotation age or management rotation age, which is based on the culmination growth of mean annual increment (MAI) or some time periodic MAI (Spears, 2015). Proper rotation age of the forest tree in given site is dependent upon maximum sustainable yield (Reed, 1986). Many criteria have been developed for selecting the best harvesting age of the forest crop, such as the growth rate for maximum volume production and carbon sequestration (Asante *et al.*, 2011; Płotkowski *et al.*, 2016).

Pakistan is a forest deficient country with only 5.01% of its total area is under forest cover (Gumartini, 2009). The bulk of these forests are located in the North Western Mountainous areas of the country (Anon., 2009). These forests are facing severe problems of deforestation and degradation (Anon., 2010). Sub-tropical pine forests are very important for the economic development and providing many ecosystem services (Sheikh *et al.*, 2012). Research studies are required to explore new avenues for sustainable management of these forest resources. In this context, the present study was conducted in a relatively more protected subtropical pine forests of Malakand which had been subjected to severe degradation in the past. The main objectives of the study are to estimate wood volume and biomass carbon stocks and determine growth rate and rotation for the Sub-tropical pine forests of the study area.

Material and Methods

Study area: The study area situated at Malakand Top Forest, District Malakand, Khyber Pakhtunkhwa, Pakistan, is geographically located at 34˚ 34´ North latitude and 71◦ 54´ East longitudes as shown in the (Fig. 1). The flora mainly includes *Pinus roxburghii* (Chir pine), *Dodonea viscosa* (Sanatha), and at lower elevations *Olea ferruginia* (Wild Olive). The main wildlife species are Jackal (*Canis aurcus*), fox (*Vulpes vulpes*), Monkey (*Macaca molitta*), wolf (*Canis lupus*) etc. the soil of the forest is sandy–loam with gravel layers or loam. The weather condition is moderate i.e., summer is pleasant while harsh and cold winter is experienced in the area. Average annual rainfall varies from 750 mm to 1000 mm. Temperature ranges from 5-30°C. *Pinus roxburghii* grows well in temperature range from 5-40°C at elevation between 500 to 2500m (Sheikh, 1993).

Data collection and analysis: Random sampling techniques were used for data collection in the field. A Total of 20 sample plots were laid out for data collection in the study area. The sample plots had square shape with 50 m x 50 m dimensions. In each sample plots all trees with diameter ≥12 cm at breast height (DBH, 1.3 m aboveground) were enumerated for diameter, total height, age and increment. Diameter was measured using diameter tape and tree height was determined with the help of Haga Altimeter. Tree age and increment were determined by extracting cores with the help of increment borer and counting the annual growth rings and ten years increment in cm. Stand basal area was calculated from diameter of all trees in the plot and extrapolated into per hectare basis. The volumes of Chir pine were calculated from collected data using Philip's formula (Philip, 1994) given below:

$$\text{Volume} = \pi D^2/4 \times Ht \times FF \quad (1)$$

where D is diameter at breast height, Ht is total tree height and FF is form factor. FF was taken from the Volume Table of Chir Pine prepared by Pakistan Forest Institute (Malik, 1970).

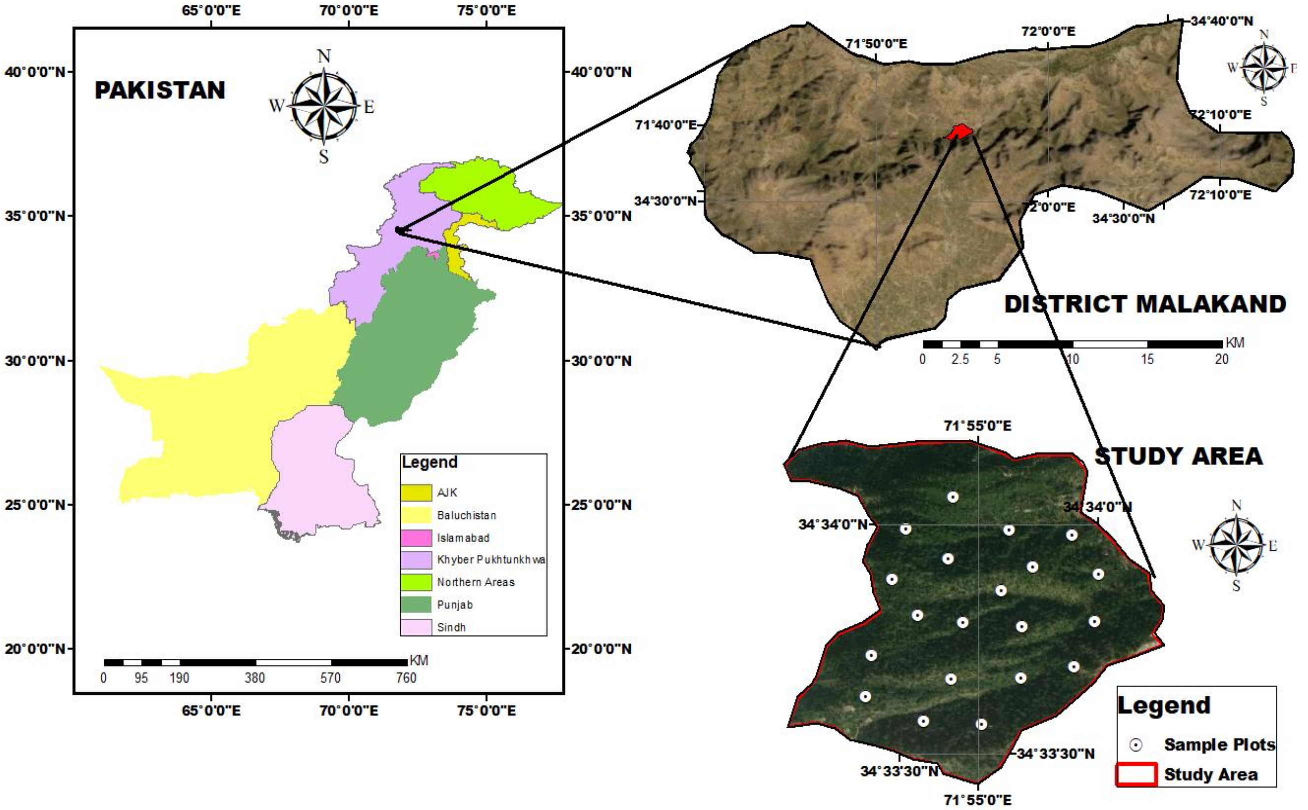

Fig. 1. Map of study area Malakand top Sub-tropical pine forest.

Carbon stock in the above ground tree biomass was estimated by two methods i.e., volumetric method and allometric method. In the former method the stem volume is converted into biomass using basic wood density and Biomass Expansion Factor and the later method involves the application of allometric equations for direct estimation of aboveground tree biomass (AGTM) from tree DBH and height data.

$$AGTB = V \times WD \times BEF \quad (2)$$

where, D is basic wood density i.e., 478 Kg/m^3 for Chir pine (Ali *et al*., 2020a), BEF is biomass expansion factor which is 1.33 for Chir pine (Ali *et al*., 2020a).

The following allometric equation was used for estimation of aboveground tree biomass of Chir pine (Ali *et al*., 2020b).

$$AGTB = 0.0224(D^2H)^{0.9767} \quad (3)$$

For below ground tree biomass (BGTB) estimation root-shoot ratio was applied which is 0.26 for *Pinus roxburghii* (Cairns *et al.*, 1997). Total tree biomass was converted to total tree carbon stock by using conversion factor of 0.50 % (Eggleston *et al.*, 2006).

Results and Discussion

Tree growth and wood production: The present study found that diameter, height, basal area and volume of individual trees increase with tree age (Fig. 2). The analysis shows that the tree DBH (cm, Fig. 2a) and height (m, Fig. 2b) increase slowly in the initial stage (upto the age of 40 years) then grow faster (upto the age of 115 years) and thereafter growth becomes slower and finally decline, exhibiting a logistic type of curve. Similar growth pattern has been reported by Luo & Liao (2008). On the other hand, the tree basal area (m^2, Fig. 2c) and volume (m^3, Fig. 2d) initially increase slowly (upto the age of 55 years) and then continuously increase at faster rate with age (upto the age of 115 years) and thereafter increase with slow growth rate (Ahmad *et al.*, 2018). The higher regression values (R^2 values, given in the Fig. 2) of tree growth and wood production with tree age shows that these variables are always controlled by tree age, as reported by other studies (Nizami, 2012; Dimri *et al.*, 2014).

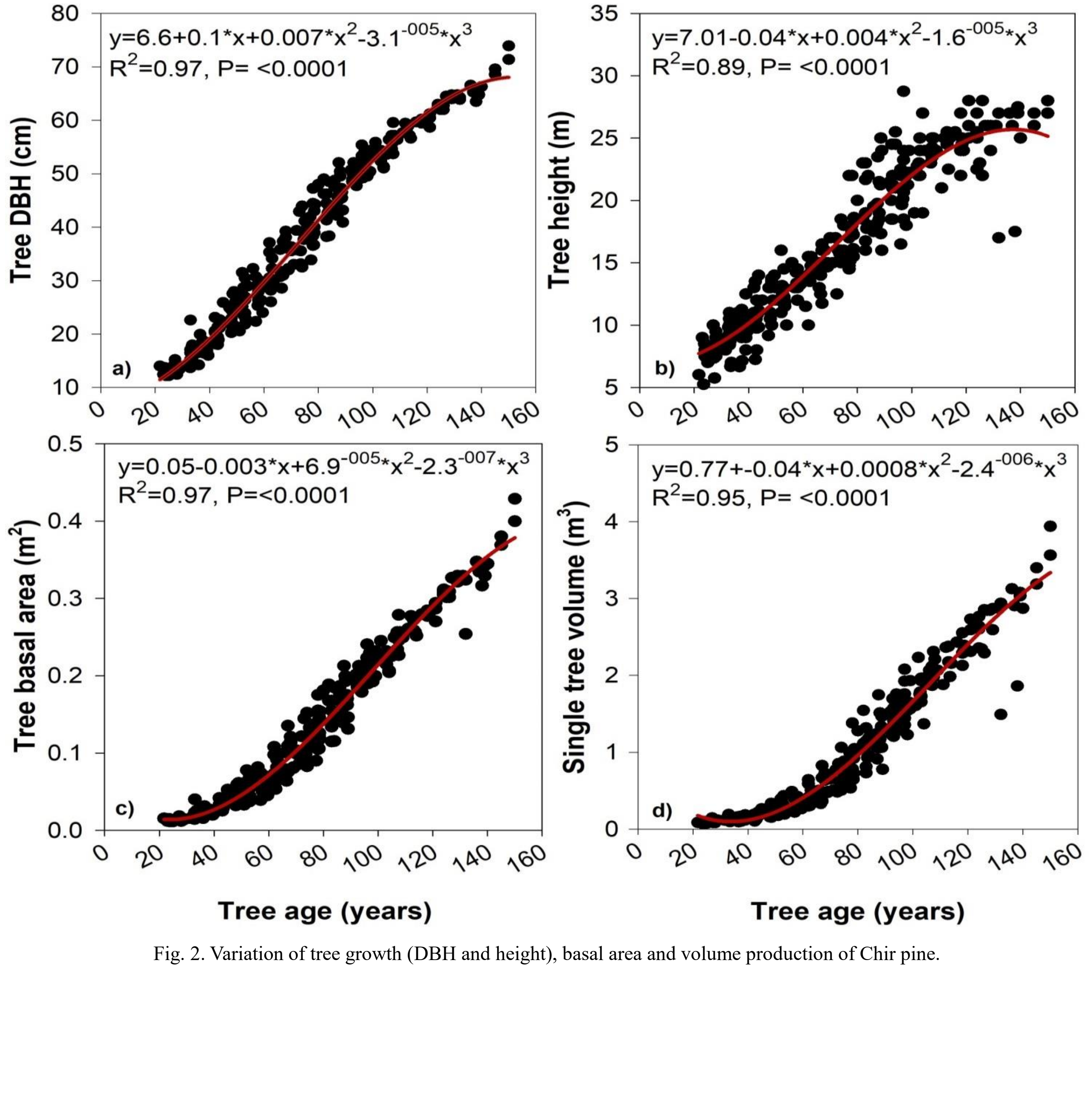

Fig. 2. Variation of tree growth (DBH and height), basal area and volume production of Chir pine.

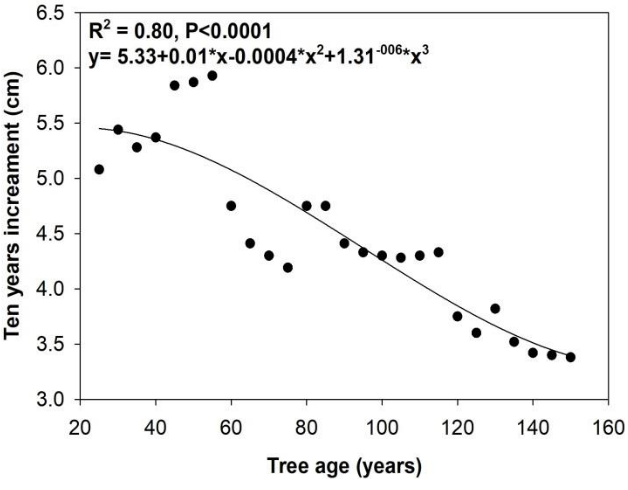

Fig. 3. Variation of ten years increment with stand age of Sub-tropical pine forest.

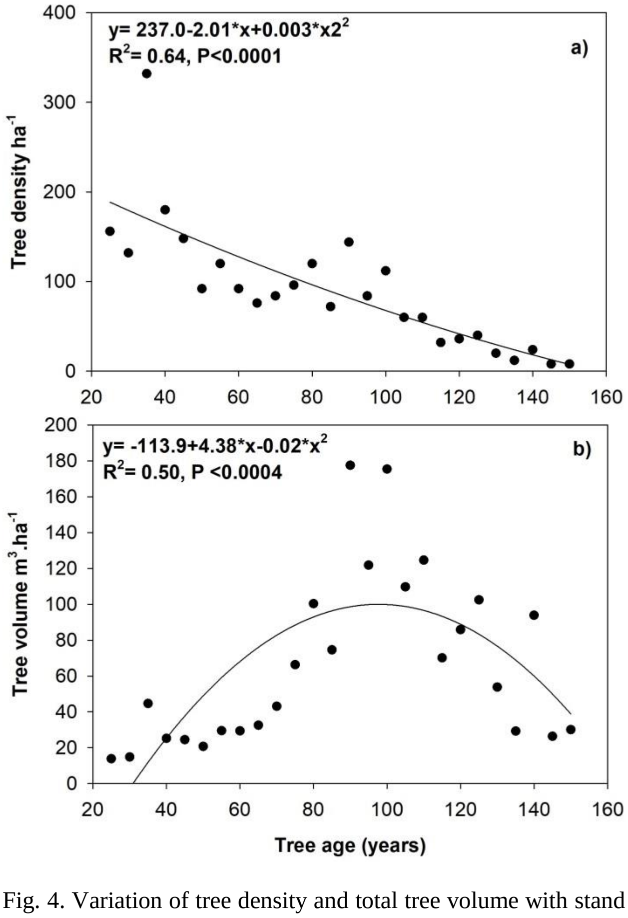

Fig. 4. Variation of tree density and total tree volume with stand ages of Sub-tropical pine forest.

Tree increment and proper rotation age: The current annual increments (CAI) of the sample tree were determined by measuring stem radial increment (cm) for the recent decade (ten years) which was plotted against tree age (Fig. 3). The data points trend showed that the tree increment increases upto 55 years then started declining upto 90 years age and became flattened upto 115 years age, thereafter the CAI significantly declined. A similar decreasing trend of tree increment along with age had also been reported by Dangal & Das (2015). Thus, 90 years was found to be the age which gave comparatively maximum wood production then at higher ages and suggested to be used as a proper economic rotation age and 115 years as a silvicultural rotation age for Chir pine as suggested by other studies (Anon., 2004; Kala, 2004; Poznanski, 2005; Bis, 2009).

Estimation of wood volume and carbon stock: Estimates of wood volume of the sample plots are given in the (Table 1). The wood volume ranged between 19.20 and 172.20 m^3/ha with average of 85.04 m^3/ha. The stand density ranged from 36 to 236 stems per ha with average of 117 trees per ha. It was found from the data of height and age of dominant and co-dominant trees that the site quality of the area is IIB as per the Yield Table of Chir pine (Cheema & Hussain, 1992). Normal forest of this site quality has density of 347 trees/ha and growing stock of 184 m^3/ha. Thus, it is clear that the forests of the study area are very degraded and are currently, less than 50% of their capacity.

Total tree biomass ranged between 15.38 and 137.94 t/ha with average of 68.10 t/ha as similarly reported by Haripriya (2000) for Sub-tropical pine forest of India. Aboveground mean biomass was estimated as 54.05 t/ha by volumetric method whereas by allometric method yielded as 51.34 t/ha. Thus, there is no significant difference between the estimates produced by the two methods. On the other hand, belowground biomass was found as 14.05 t/ha. Similarly aboveground carbon stock varied between 6.10 and 54.74 t/ha with average of 27.02 t/ha. These results are comparable with the findings of Ali et al. (2020b) who found similar results of above-ground carbon stock in subtropical forests of Khyber Pakhtunkhwa as 24.77 t/ha, and Sharma *et al.* (2010) for Sub-tropical pine forests of Siwalik.

Variation of wood volume and carbon stock with tree age: The tree density of Chir pine was maximum at lower ages and declining with the increase of tree age. The relationship between tree density and tree age was analyzed by regression analysis (Fig. 4a), an inverse relationship was found between tree density and tree age with R^2 value 0.64. Similar result was reported by Kc & Stainback (2012) for decreasing tree density with increasing stand age. The average tree density was 117 trees/ha. The single tree volume increases with increasing tree age (Fig. 2c), while the stand volume increase upto a certain age limit then levels off and thereafter starts declining (Ahmad *et al.*, 2018). Our study results show that the variation of stand volume increased with tree age upto 90 years, due to tree increment then level-off upto 115 years and thereafter decreased (Fig. 4b), due to decrease in tree density with tree age (Fig. 4a). Similar results reported by Ahmad *et al.* (2018) for stand timber volume with stand age.

Tree biomass rapidly increases with increasing tree age like tree volume as reported by Ahmad *et al.* (2019). The trend for tree carbon stock was similar to that of tree biomass, because tree carbon stock is directly related to tree biomass, i.e., the higher the biomass the higher will be the carbon. Our study results showed that tree carbon stock first increased with tree age upto 90 years, due to tree increment and density, then level-off and thereafter decreases as shows in (Fig. 5). Similar findings have been reported by Chauhan (2004) that the tree carbon stock increases with increasing tree age upto certain threshold and then level-off or decreases gradually.

Table 1. Variation of tree biomass (above and below ground biomass) in sample plots

Plot No.	No. of trees/ha	Vol per ha (m^3)	AGM t/ha (volumetric method)	BGM (t/ha)	Total M (t/ha)	AGC (t/ha)	BGC (t/ha)	Total C (t/ha)	AGM t/ha (allometric method)
1.	64	25.76	16.38	4.26	20.63	8.19	2.13	10.32	16.37
2.	180	19.2	12.21	3.17	15.38	6.10	1.59	7.69	7.45
3.	52	49.12	31.23	8.12	39.35	15.61	4.06	19.67	30.40
4.	132	90.04	57.24	14.88	72.12	28.62	7.44	36.06	54.39
5.	112	69.96	44.48	11.56	56.04	22.24	5.78	28.02	41.16
6.	120	89.48	56.89	14.79	71.68	28.44	7.40	35.84	52.95
7.	176	111.32	70.77	18.40	89.17	35.39	9.20	44.59	64.20
8.	144	59.2	37.64	9.79	47.42	18.82	4.89	23.71	34.17
9.	168	172.2	109.47	28.46	137.94	54.74	14.23	68.97	106.39
10.	148	142.44	90.55	23.54	114.10	45.28	11.77	57.05	87.26
11.	236	148.32	94.29	24.52	118.81	47.15	12.26	59.40	89.38
12.	132	127.8	81.25	21.12	102.37	40.62	10.56	51.19	78.28
13.	128	124.16	78.93	20.52	99.46	39.47	10.26	49.73	76.59
14.	60	42.68	27.13	7.05	34.19	13.57	3.53	17.09	25.73
15.	36	22.92	14.57	3.79	18.36	7.29	1.89	9.18	13.71
16.	136	112.96	71.81	18.67	90.48	35.91	9.34	45.24	68.93
17.	72	59.4	37.76	9.82	47.58	18.88	4.91	23.79	35.89
18.	76	62.84	39.95	10.39	50.34	19.97	5.19	25.17	38.29
19.	96	85.04	54.06	14.06	68.12	27.03	7.03	34.06	51.93
20.	80	85.44	54.32	14.12	68.44	27.16	7.06	34.22	53.26
Average	117.4	85.04	54.05	14.05	68.10	27.02	7.03	34.05	51.34
Minimum	36	19.2	12.21	3.17	15.38	6.10	1.59	7.69	7.45
Maximum	236	172.2	109.47	28.46	137.94	54.74	14.23	68.97	106.39

*Vol = Volume, AGM = Above ground biomass, BGB = Belowground biomass, M = Total biomass, C = Carbon

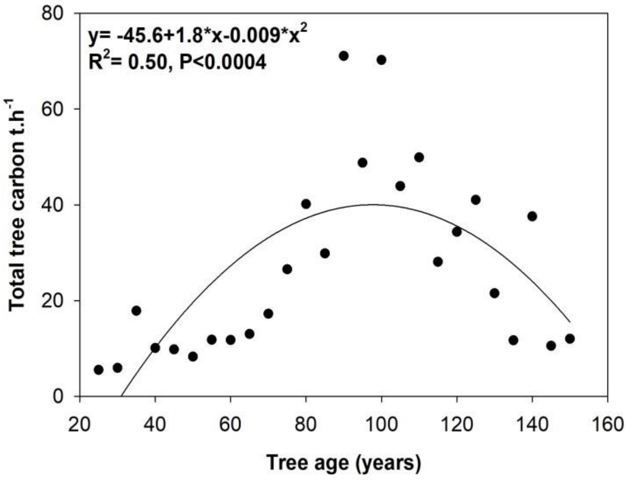

Fig. 5. Variation of total tree carbon stock with stand ages of Sub-tropical pine forest.

Conclusions

This study was conducted in subtropical pine forests of Malakand which have been subjected to severe degradation in the past. The average stand density and stand volume were found as 117 trees per ha and 85.04 m^3/ha respectively. Average tree carbon stock was estimated as 34.05 t/ha. Though the carbon stock is lower than the normal value for well-stocked pine forests in such ecological zones, still these forests have great potential for carbon sequestration and climate change mitigation. Our study analysis showed similar results for suggesting 90 years as economic rotation age and 115 years as a silviculture rotation age for Chir pine, and was found appropriate in terms of comparatively maximum volume production then other ages. There are certain limitations in the study which include small sample size and exclusion of non-biomass carbon pools. Despite these limitations, the findings of the study can be used for preparation REDD+ strategies and management plans for subtropical pine forests of Pakistan.

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