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BIOMASS PRODUCTION AND CARBON SEQUESTRATION POTENTIAL OF *SALIX ALBA* PLANTATIONS UNDER TEMPERATE CONDITIONS OF KASHMIR (INDIA)

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ABSTRACT

Quantifying carbon balance in plant biomass is necessary to determine the species specific greenhouse gas potential. This study is one of such attempts aimed to compare the C balances among various white willow (*Salix alba*) groves established across the four Districts (viz. Anantnag, Bandipora, Baramulla and Ganderbal of Kashmir valley. After conducting a detailed survey, two plantation blocks of white willow ranging in age from 1to 20years were selected in each of the four Districts. Five quadrates of 10 × 40 m (400 m^2) size were laid at each plantation block for sampling of trees to record the various observations. The vegetation analysis of plantation groves revealed that *Salix alba* comprised the dominant position with distinctive density of 81.90 % and IVI of 213.80. The existing stem volume, biomass production, carbon density and carbon sequestration potential of trees at all the selected locations were evaluated employing standard methods. The maximum and minimum stem volume of 739.34 and 595.09 cum ha^{-1} and respective biomass production of 532.61and 429.27 t ha^{-1} was recorded at Bandipora and Anantnag. The maximum soil carbon density of 68.07t ha^{-1} was recorded at Bandipora, followed by 67.93 t ha^{-1} at Baramulla, 66.86t ha^{-1} at Ganderbal and 66.43t ha^{-1} at Anantnag. The results of this study further visualized that; on an average, white willow (*Salix. alba*) can store up to 292.98 tons of C ha^{-1} and Sequesters around 1075.24 CO_2e tons ha^{-1} from the atmosphere. Thus enhancing carbon sequestration through commercial plantations of this species can prove to be a long term future policy option for sustained carbon storage program in Jammu and Kashmir where willows alone comprise a total population of around 37 million trees (departmental and private) with further scope for expansion as permanent marketable carbon sinks owing to the availability of about 15,082 km^2 of waste land that could be used for plantation forestry.

KEY WORDS: ***Salix alba*, Biomass production, Carbon density, Carbon sequestration**

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INTRODUCTION

The anthropogenic activities during last few decades have led to increased accumulation of carbon dioxide in the atmosphere. According to future emission scenario presented by Shukla *et al.* (2003) the CO_2 emissions shall continue to dominate national GHG emission scenario with its share reaching to 74% in 2030. The doubling of atmospheric concentration of CO_2 could raise the mean temperature of the earth's surface by 1.5 to 4.5^{o}C by the end of the year 2100 (Gera *et al.*, 2011). Thus the environmental and ecological consequences of global warming are believed to outweigh economic benefits. Under such circumstances, the quantification of carbon conservation by plantation forests will form the major objective of developing national inventories of the available carbon sinks (FAO, 2001). Willows have been successfully implicated in carbon sequestration programmes of almost all the European countries. The estimates illustrate that the carbon yield of willow biomass ranges between 4 to 7.2 t ha^{-1} yr^{-1} (Taylor and Bunn, 2008). The estimates further show that significant amounts of soil carbon (up to 24.4 t ha^{-1}) can be sequestered under these plantations (Samson *et al.,* 2001). Since willows constitute the most dominant position among the broadleaves, enhancing carbon sequestration through commercial plantation of this species can prove to be a long term future policy option for the entry of this State in clean development mechanism (CDM) to earn marketable carbon credits. The successful carbon management through willow plantation will; however, require a solid scientific information and sound accounting system to quantify the available carbon repositories. With this in mind the present study was taken up with the main objective of quantifying the standing biomass and carbon density of *Salix alba* plantations across the major willow growing Districts of Kashmir valley.

MATERIALS AND METHODS

The present investigations were carried out during the year 2010-11 & 2011-12 in the willow plantations established by Plantation Division of State Forest Department in four Districts viz., Anantnag, Bandipora, Baramulla and Ganderbal of Kashmir valley. The study sites fall in temperate region of the State. There is a considerable variation in the seasonal and climatic variables at the experimental sites. The seasons are very distinct viz., Spring (March- May), Summer (June to August), Autumn (September to November) and Winter (December to February). The climatic data comprising rainfall pattern, minimum and maximum temperature and relative humidity for the study period i.e. 2010 and 2011 was collected from the Meteorological Department of the respective Districts. Precipitation in the form of rain occurs during spring and as snowfall during the winter. While average annual rainfall received during the period of investigation varied between 1241-1290 mm, the mean annual minimum and maximum temperatures were 2.35 ºC and 23.70 ºC respectively. The average relative humidity of the study sites varied between 50.00 to 84.50 % during the year 2010 and 56.50 to 84.00 % during the year 2011. After conducting a detailed survey, two plantation blocks of willow were selected in each District. Five quadrates of 10 × 40 m (400 m^2) size were laid at each block for sampling. A holistic phytosociological status of the *Salix alba* trees was recorded to calculate the Importance Value Index (IVI) at species level (Misra, 1968). In all, five willow species were recorded at the selected plantation sites. *Salix alba* comprised the dominant position with an individualistic density of 81.90 % and IVI of 213.80 (Fig.1). *Salix fragilis, Salix wallichiana*, *Salix tetrasperma*, and *Salix viminalis* with respective IVI values of 24.10, 22.82, 21.54, and 17.74 were the co-dominant species. The estimates further envisage that the average density of *Salix alba* plantations was 1270 trees ha^{-1} across the selected locations.

Total biomass production

The white willow trees were grouped into various diameter classes and the volume of each of these classes was calculated as per procedure followed by Pressler (1865) and Bitlerlich (1984). The specific gravity of wood was determined by using the maximum moisture method prescribed by Smith (1954). Five representative sample trees in each diameter class were used to record the stem wood biomass. The total number of branches on the five representative trees were categorized (on the basis of basal diameter) into three groups viz., small, medium and large and five branches from each category were randomly removed from each sample tree and their fresh weight was determined separately. After recording the fresh weight, these samples were taken to the laboratory and oven dried at 65±5 ^{o} C for a period of 72 hours or till the weight became constant (Chapman, 1964). The leaf biomass of all the representative branches of three sample trees in each diameter class was determined just after removing them from the branch to minimize the loss of weight. The leaf samples were then placed in separate paper bags and oven dried at 65±5^{o} C for a period of 72 hours or till the weight became constant (Chapman, 1964). The root biomass was determined by Bush for Greenhouse Field Measurement Procedure (Dury *et al.,* 2002) which recommends taking the estimate of above ground biomass ha^{-1} and multiplying it with default root: shoot ratio of 0.25 for hardwood species. Finally, the total tree biomass was determined as sum of stem, branch, leaf and root biomass.

Standing carbon density

The standing carbon density (above and below ground) of *Salix alba* was determined by using tissue specific carbon content as measured by Ash Content Method prescribed by Negi, *et al*. (2003). The carbon density (tons ha^{-1} or Kg $tree^{-1}$) was then calculated as per method followed by Jianzhong, (2006). The elemental carbon removed from the atmosphere (CO_2) and the net carbon sequestration (CS ton ha $^{-1}$) was then calculated as per procedure followed by Dury *et al*., (2002).

RESULTS AND DISCUSSION

The data presented in table 1 reveals that maximum and minimum stem volume of 739.34 and 595.09 m^3 ha^{-1} was recorded at Bandipora and Anantnag respectively. The biomass production for these sites varied from 429.27 t ha^{-1} in Anantnag to 532.61 t ha^{-1} in Bandipora. The average stem volume and biomass production for all the locations was 688.38 m^3 ha^{-1} and 496.42 t ha^{-1} respectively. The perusal of data (Table 2) envisages that on an average *Salix alba* plantations stored 225 t C ha^{-1} across the four selected locations. While maximum plant carbon density of 240.71 t ha^{-1} was recorded at Bandipora, minimum carbon stock of 195.70 t ha^{-1} was exhibited by trees at Anantnag. This disparity in volume at various sites may be attributed to variation in growth, tree density and soil status at each selected site. Singh and Gupta (2008) have also advocated that volume of trees increases with increase in dbh and height. Walsh *et al* (2008) have reported that increase in growth parameters like dbh, height and basal area correspondingly increase the volume of trees. They further noted that volume of some *Eucalyptus* species ranges from 9.5 to 125 .9 m^3 ha^{-1} for various diameter classes attained until the age of 10 years. Wong *et al.* (2000) advocated that the stem volume for similar species ranges from 167 to 232 m^3 ha^{-1} (equating to an M.A.I of 8.4 - 11.6 m^3 ha^{-1} yr^{-1}) when the plantations attained an age of 20 years. The higher biomass production can also be explained on the basis of height, age and number of trees ha^{-1} that varied between the locations (Table-2). Similar results have also been reported by Dey (1996) in *Populus deltoides* and Singh and Negi (1997) in *Cinnamomum camphora.* Komiyama *et al.* (2008) revealed that the variation in aboveground biomass not only depends on species but also on ecological circumstances and geographical locations. With both these conditions being ideal for willows in Kashmir, the biomass production recorded in this study are higher as compared to those reported from elsewhere.

The data (Table-3) further reveals that maximum soil carbon density of 68.07 t ha^{-1} was recorded at Bandipora, followed by (67.93 t ha^{-1}) at Baramulla, (66.86 t ha^{-1}) at Ganderbal and (66.43 t ha^{-1}) at Anantnag. The soil microbial biomass carbon was maximum (0.427 t ha^{-1}) at Bandipora and minimum (0.376 t ha^{-1}) at Anantnag. The average value of soil microbial biomass carbon under *Salix alba* plantations for all locations was 0.402 t ha^{-1}. The data in the Table-3 also reiterates that while minimum total carbon density of 262.51 t ha^{-1} was recorded in Anantnag, the maximum total carbon density of 309.21 t ha^{-1} was observed at Bandipora. The carbon sequestration potential of *Salix alba* plantations at these two locations was 963.40 and 1134.79 CO_2e t ha^{-1} respectively. The average Carbon sequestration potential of *Salix alba* at all the four selected locations was 1075.24 CO_2e t ha^{-1}. The carbon density in tree biomass depends upon its age, dbh, structure, functional component and the intensity of management (Heriansyah *et al.,* 2007). These results are also comparable with the findings of Komiyama *et al.* (2008) and Chandra *et al.* (2011) who reported that variation in carbon stock may be related to ecology, species composition and location. The results on carbon density recorded in the present study (Table-3) correspond perfectly to the findings of Kumar *et al.* (2009), Yadava (2010) and Juwarkar *et al.* (2011) who reported that trees during initial stages of growth will sequester less carbon and gradually increase its storage with the advancement in age or increase in diameter and height growth. Similar results of increase in carbon stock with increase in tree diameter have been reported by Bhardwaj *et al.* (2001); Albrecht and Kandji (2003); Raizada *et al.* (2007); Gera *et al.* (2011); Ramachandran *et al.* (2007); Yadava (2010) and Fonseca *et al.* (2012) for various species under a range of climate and edaphic factors..

The net carbon sequestration by *Salix alba* trees presented in Table-4 envisages that the plantations of this species sequester about 29.271 t C ha^{-1} yr^{-1} across the selected locations. While maximum annual net carbon sequestration of 31.298 t ha^{-1} yr^{-1} was recorded at Bandipora, the minimum change of 25.988 t ha^{-1} yr^{-1} was recorded at Anantnag. Cubero and Rojas (1999), Subak (2000), Perez and Kanninen (2003) have reported carbon accumulation of 2.0 to 6.7 t ha^{-1} yr^{-1} for *Tectona grandis* and *Gmelina arborea.* The highest rate of carbon accumulation (7.1 t ha^{-1} yr^{-1}) was reported by Fonseca *et al.* (2012) for some tree plantations in humid tropical low lands of Costa Rica. However, these estimates have not taken into account the components such as roots, soil organic carbon, microbial biomass carbon and litter biomass carbon, which in our results have caused significant increase in net carbon sequestration. The preceding results envisage that the rate of carbon sequestration is higher during the juvenile stage as compared to more lignified stage when the rate of incremental growth falls down towards the maturity. Similar results have been recorded by many workers in different species (Wong *et al.*, 2000; Bugg *et al.,* 2002; Booth *et al.,* 2007; Walsh *et al.,* 2008; Fonseca *et al*., 2012). The results of the present study also suggest that a considerable amount of carbon allocation in *Salix alba* plantations over a 20 year rotation cycle can act as a carbon repository in this region as there are approximately 37 million willow trees (Departmental + private plantations) in Kashmir and Ladakh. This parameter along with the availability of around 15082 km^2 of waste lands for plantation forestry is a positive factor in determining the potential of tree species to mitigate and sequester carbon dioxide on long term basis. Furthermore, *Salix alba* has gained considerable importance in temperate regions of Kashmir mainly due to its fast growing habit and high industrial requirement. These factors can promote cultivation of this species for carbon markets and generate additional revenue for the State of Jammu and Kashmir.

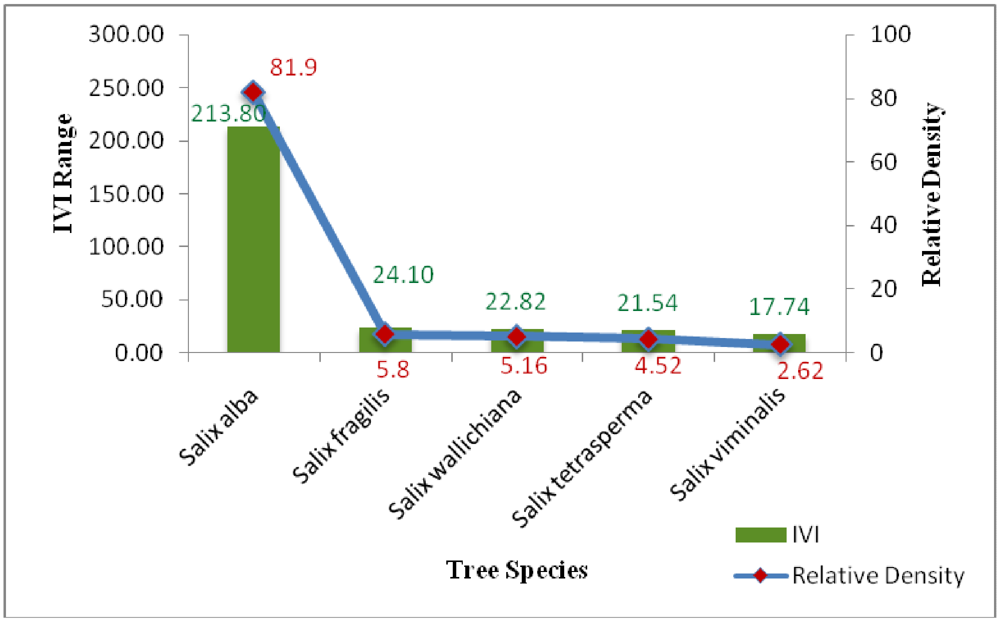

Figure 1
IVI and Relative Density of different willow species at selected experimental sites

Table 1
Stem volume and Biomass production of Salix alba plantations at various locations.

Districts	Stem volume (m^3 ha^{-1})	Total Biomass (t ha^{-1})
Anantnag	595.09	429.27
Bandipora	739.34	532.61
Baramulla	717.21	517.85
Ganderbal	701.87	505.98
Mean	**688.38**	**496.42**

Table 2
Total carbon density and CO_2 sequestration by Salix alba plantations at selected locations.

Districts	Plant Carbon Density (t ha^{-1}) (A+B)	Soil Carbon Density (t ha^{-1})	Soil Microbial Biomass Carbon (t ha^{-1})	Total Carbon Density (t ha^{-1})	Total CO_2 Sequestration Potential (CO_2e t ha^{-1})
Anantnag	195.70	66.43	0.376	262.51	963.40
Bandipora	240.71	68.07	0.427	309.21	1134.79
Baramulla	233.93	67.93	0.417	302.28	1109.36
Ganderbal	230.69	66.86	0.387	297.94	1093.43
Mean	**225.26**	**67.32**	**0.402**	**292.98**	**1075.24**
A- Above ground, B- Below ground					

Table 3
Net carbon sequestration by Salix alba plantations at selected locations.

Districts	Current annual change in shoot and root biomass carbon (t ha^{-1})	Current annual change in litter biomass carbon (t ha^{-1})	Current annual change in soil organic carbon (t ha^{-1})	Current annual change in microbial biomass carbon (t ha^{-1})	Net carbon sequestration (CS t ha^{-1})
Anantnag	19.730	1.819	4.416	0.0225	**25.988**
Bandipora	25.270	1.339	4.661	0.0278	**31.298**
Baramulla	22.540	2.315	4.562	0.0250	**29.442**
Ganderbal	24.470	1.418	4.445	0.0255	**30.359**
Mean	**23.003**	**1.723**	**4.571**	**0.0252**	**29.271**

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