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GROWTH PERFORMANCE, BIOMASS PRODUCTION AND CARBON STOCK OF 19- YEAR OLD *Fraxinus floribunda* (ASH TREE) PLANTATION IN KASHMIR VALLEY

SUMMARY

Trees are recognized as important components of carbon cycle have gained importance owing to their potential to sequester carbon. Reviving tree cover and finding low cost methods to sequester carbon is emerging as a major international policy goal. The study attempted to estimate growth, biomass production, carbon stock and carbon dioxide mitigation potential of 19 year old *Fraxinus floribunda* plantation under different diameter classes. The DBH of trees in the stand varied from 7.74 cm to 23.50 cm, height from 4.16 m to 10.40 m, basal area between 0.004 m^2 to 0.043 m^2 and volume between 0.007 m^3 to 0.135 m^3 during 2009 and 2010.The average dry stem biomass of the trees at the site varied between 4.91 kg to 90.45 kg, branch dry biomass between 1.63 kg to 29.44 kg, leaf dry biomass between 0.39 kg to7.14 kg, total above ground dry biomass between 6.93 kg to127.03 kg, root dry biomass varied from 1.73 kg to 31.77 kg and total biomass (above + below ground) varied from 8.66 kg to 158.80 kg. The stem carbon varied from 12.12 kg to 39.05 kg, branch carbon between 0.69 kg to 12.48 kg, leaf carbon between 0.14 kg to 2.62 kg, root carbon between 0.74 kg to 13.66 kg and total carbon between 3.69 kg to 67.81 kg. The stem carbon dioxide mitigation potential varied from 7.75 kg to 142.92 kg, branch from 2.52 kg to 45.67 kg, leaf from 0.51 kg to 9.58 kg, root from 2.70 kg to 49.99 kg and total carbon dioxide mitigation varied from 13.48 kg to 248.16 kg during 2009 and 2010.

Key words: Biomass, Carbon stock, Carbon dioxide mitigation, *Fraxinus floribunda*, Growth

INTRODUCTION

Trees play a vital role in mitigating the diverse effects of environmental degradation and increasing concentration of carbon dioxide in the atmosphere and also its consequences on climate change. Trees promote sequestration of carbon into soil and plant biomass. Therefore tree based land use practices could

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be viable alternatives to store atmospheric carbon dioxide due to their cost effectiveness, high potential of carbon uptake and associated environmental as well as social benefits (Singh and Lodhiyal, 2009).Such practices could render not only economic benefit through increasing supplies of fuelwood, fodder, fibre, timber, medicine and other non wood products etc, but also to some extent, provide ecosystem services by improving the hydrological balance, nutrient cycling and microclimate amelioration, conserving biodiversity and consequently maintain the habitability of a region (Swamy *et al*., 2003). Trees generate large volumes of wood residues which have potential to replace fossil fuels as an energy source, reducing greenhouse gas emissions (Richardson, 2005).Trees also provide additional non-wood forest products and benefits, from the trees planted or from other elements of the ecosystem that they help to create. Trees are used in combating desertification, absorbing carbon to offset carbon emissions, protecting soil and water, rehabilitating lands exhausted from other land uses, providing rural employment and if planned effectively, diversifying the rural landscape and maintaining biodiversity. The potential tree plantations to partially meet demand for wood and fibre for industrial uses are increasing. In several countries, a significant portion of the wood supply for industrial uses comes from plantations, rather than natural forest resources (FAO, 2001).

The biomass of forests is a useful way of providing estimates on the quantity of these components. The word biomass generally refers to a renewable resource of plant or animal origin. Forest biomass in contrast with agricultural or ocean biomass includes all renewable goods produced in the forests. The more important ones are the principal forest products derived from wood such as timber, pulpwood and fuel-wood. In addition, wood in other forms (residue from logging and sawmilling operations such as branches, tops, dead or diseased trees, saw dust, bark chips) and leaves constitute a substantial proportion of the potentially usable forest biomass (Rawat and Nautiyal, 1988).The total above ground biomass of forests is defined as biomass density when assessed, may be expressed as dry weight per unit area usually in tonnes/hectare (Brown, 1997) and is a useful way of quantifying the amount of resource available for all traditional uses. It either gives the quantity of total biomass directly or the quantity of each component (e.g. leaves, branches and bole) because their biomass tends to vary systematically with the total biomass. However, the biomass of each forest component depends on the forest type such as natural or planted forests. The quantity of biomass in a forest is the result of the difference between production through photosynthesis and consumption by respiration and harvest processes. Thus, it is a useful measure for assessing changes in forest structure. Changes in forest biomass density are brought about by natural succession. Biomass density is also a useful variable for comparing structural and functional attributes of forest ecosystems across a wide range of environmental conditions. Biomass of forests is also very relevant for issues related to global climate changes because forest can be a carbon source and sink. Therefore, the management of the forests can affect the global carbon cycle and climate change.

Approximately 50 per cent of the biomass is carbon. This represents the potential amount of carbon that can be added to the atmosphere as CO_2 when the forest is cleared (Brown, 1997). Tipper (1998) estimated that deforestation contributes about 1.8 Gigatonne carbon (GtC) per year. However, forests can also remove CO_2 from the atmosphere through photosynthesis. It is estimated that 1.1 to 1.8 GtC per year can be sequestered in 50 years through forests (Makundi *et al.*, 1998).Forests play an important role in carbon sequestration due to several reasons. The first is that the tree component fixes and stores carbon from the atmosphere via photosynthesis and they can function as active carbon for the period of many years and continue to store carbon until they are harvested or die. The second reason is that the forests provide a good surface cover which minimizes the loss of nutrients from the surface soil, improves edaphic conditions, increases biomass production, provide a protective ground cover through tree and crop cover and decrease risk of soil degradation by erosion, leaching and nutrient depletion. Such favourable trends enhance soil resilience and lead to overall improvement in soil carbon pool. Finally trees are one of the alternatives to increase forest cover which will widen the area of carbon sink. Farmers can be benefited if they raise forest plantations. These plantations shall provide tangible and intangible benefits and carbon credits generated through plantation will provide additional income to the farmers besides all other benefits of raising plantations. The *Fraxinus floribunda* commonly known as East Indian Ash belongs to family oleaceae. It is a middle sized to a large deciduous tree attains a height of about 15m and a girth of about 1.2m (Brandis, 1906). The tree is common in the eastern Himalayas (Nepal, Sikkim, Assam and Burma) and is found at an elevation between 1500-2700 m. Its growth is best on deep moist soils. The tree is planted as an ornamental and its wood is moderately hard, heavy and tough and is used for ploughs and carrying poles (Luna, 2005).In Kashmir valley it is an introduced tree species and is mostly planted in gardens and parks. Thus keeping in view the importance of the tree species an attempt was therefore made to quantify the ability of the tree species to sequester atmospheric carbon under Kashmir conditions.

MATERIAL AND METHODS

Study area

The experimental site is located between 74.89^{o} East longitude and 34.08^{o}North latitude at an altitude of about 1600 meters above mean sea level. It is roughly 15 km south east to the Srinagar city and the soil of the site is silty loam and is well drained. The climate is generally temperate with severe winter extending from December to March. The region faces a wide temperature range from a minimum of -4^{o}C in winter to a maximum of 33^{o}C in the summers. The annual precipitation of the area is about 676 mm and most of the precipitation is received in the form of snow during winter months. The present study was carried out in *Fraxinus floribunda* Plantation Block of Faculty of Forestry during the year 2009 and 2010 at Sher-e-Kashmir university of Agricultural sciences and technology of Kashmir (SKUAST-K), Shalimar. The trees were planted during March, 1990 having 19 years of age.

Demarcation and enumeration for measurements

After survey of the experimental site, a quadrate of size 10 x 10 m was laid at the area and total 24 trees in a particular quadrate were enumerated according to diameter at breast height (DBH). These trees were then classified into three diameter classes viz; 0-10 cm, 10-20 cm and 20-30 cm for measuring various parameters.

Methods of measurements

Volume and tree biomass. Tree biomass was estimated by adopting non-destructive methods for different plant parts viz; stem, branch and leaf.

Stem biomass. The diameters at breast height (DBH) of the trees falling in the plot of size 10 x 10 m were measured with diameter tape and height with Ravi's multimeter respectively. Form factor and volume was calculated by using the following formula given by Pressler (1865) and Bitlerlich (1984).

$$f = \frac{2h_1}{3h}$$

Where, f is the form factor, h_1 = height at which diameter is half of DBH and h is the total height.

The volume (V) was calculated by Pressler's formula:

V = f × h × g Where,f = form factor, h = total height (m) and g = basal area, g = πr^2 or $\pi\,(dbh/2)^2$ Where, r = radius

Specific gravity. The stem cores were taken to find out specific gravity of wood, taking into account the variation in different parts of the tree, which was used further to determine the biomass of stem using the maximum moisture method (Smith, 1954).

$$Gf = \frac{1}{\frac{M_n - M_o}{M_o} + \frac{1}{G_{so}}}$$

Where,

G_f = specific gravity based on gross volume

M_n = weight of saturated volume sample

M_o = weight of oven dried sample

G_{so} = Average density of wood substance equal to 1.53

Thus weight of stem wood = specific gravity × stem volume

or

Stem biomass = Specific gravity × stem volume

Branch biomass. The total number of branches irrespective of size was counted on each of the sample tree, then these branches were categorised on the basis of basal diameter into three groups viz; small, medium and large. Fresh weight of two sampled branches from each group was recorded separately. The following formula (Chidumaya, 1990) was used to determine the dry weight of branches:

$$B_{dwi} = B_{fwi} \Big/ 1 + M_{cdbi}$$

Where,
B_{dwi} = oven dry weight of branches
B_{fwi} = Fresh/green weight of branches
M_{cdbi}= Moisture content of branches on oven dry weight basis

Total branch biomass (fresh/dry) per sample tree will be determined as given below:

$$B_{bt} = n_1 b_{w1} + n_2 b_{w2} + n_3 b_{w3} \ldots\ldots = \sum_{i=1}^{n} n_i b_{wi}$$

Where,
B_{bt} = Branch biomass (fresh/dry) per tree
n_i = Number of branches in the ith branch group
b_{wi} = Average weight of branch of ith group
I = 1, 2, 3,............. the branch groups

Leaf biomass. Leaves from five branches of individual trees were removed. Five trees per plot were taken for observation. The leaves were weighed and oven dried separately to a constant weight at 80±5^{o}C. The average leaf biomass was then arrived at by multiplying the average biomass of the leaves per branch with the number of branches in a single tree and the number of trees in a plot (Koul and Panwar, 2008).

Total Tree biomass (Aboveground). The total tree biomass was the sum of stem, branch and leaf biomass.

Root biomass. The root biomass was determined as per the procedure given by (Dury *et al.*, 2002). The aboveground biomass was multiplied with default ratio of 0.25 for hardwood species for estimating root biomass.

Biomass carbon stock. Carbon percentage was estimated by ash content method described by Negi *et al.* (2003). In this method oven dried plant components (bark, leaves, stem wood and root) were burnt into muffle furnace at 400^{o}C. The ash content left after burning was weighed and carbon content was calculated by using the following equation:

Carbon % = 100 – (ash weight + molecular weight of O_2 (53.3) in $C_6H_{12}O_6$

The carbon (%) was then multiplied with the biomass to get biomass carbon stock.

Carbon stock = Biomass × carbon (%)

Carbon dioxide equivalent (CO_2e). The carbon dioxide equivalent was calculated as per the following equation:

Carbon dioxide equivalent = Carbon stock × 3.66

Statistical analysis. The data was statistically analyzed for the computation of standard error (Gomez and Gomez, 1989).

RESULTS AND DISCUSSION

Growth characteristics of *Fraxinus floribunda*

Among the different diameter classes, the DBH, height, basal area and volume increased with the increase in diameter class (Table 1) and the maximum DBH (23.50 cm/tree) was recorded in diameter class 20-30 cm during 2010 and minimum (7.74 cm/tree) was observed in diameter class 0-10 cm during 2009. The maximum height (10.40 m/tree) was recorded in diameter class 20-30 cm during 2010 and minimum (4.16 m/tree) was recorded in diameter class 0-10 cm, during 2009. The basal area was found to be maximum (0.043 m^2/tree) in diameter class 20-30 cm during 2010 and minimum (0.004 m^3/tree) in diameter class 0-10 cm during 2009.The stem volume was maximum (0.135 m^3/tree) under diameter class 20-30 cm during 2010 and minimum (0.007 m^3/tree) under diameter class 0-10 cm during 2009.

Biomass production of *Fraxinus floribunda*

The average dry stem biomass of *Fraxinus floribunda* increased with corresponding increase in diameter class (Table 2) and was recorded maximum (90.45 kg/tree) in diameter class 20-30 cm during 2010 and minimum (4.91 kg/tree) in diameter class 0-10 cm during 2009. The branch biomass also showed an increasing trend with the increase in diameter class and was recorded maximum (29.44 kg/tree) under diameter class 20-30 cm during 2010 and minimum (1.63 kg/tree) under diameter class 0-10 cm during 2009. The leaf biomass was recorded maximum (7.14 kg/tree) under diameter class 20-30 cm during 2010 and minimum (0.39 kg/tree) under diameter class 0-10 cm. The root biomass increases with increase in diameter class and was recorded maximum (31.77 kg/tree) under diameter class 20-30 cm during 2010 and minimum (1.73 kg/tree) under diameter class 0-10 cm during 2009.The total biomass (above + belowground) was recorded maximum (158.80 kg/tree) under diameter class 20-30 cm during 2010 and minimum (8.66 kg/tree) under diameter class 0-10 cm during 2009.The biomass productivity of *Fraxinus floribunda* (19 years old) was recorded maximum (3.62 t ha^{-1} yr^{-1}) under diameter class 20-30 cm and minimum (0.47 t ha^{-1} yr^{-1}) under diameter class 0-10 cm.

Table 1. Growth parameters of *Fraxinus floribunda* trees under different diameter classes

Diameter class (cm)	DBH (cm)			Height (m)			Basal area (m^2/tree)			Stem volume (m^3/tree)		
	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment
0-10	7.74 (±0.03)	8.31 (±0.31)	0.57 (±0.13)	4.16 (±0.23)	4.56 (±0.27)	0.40 (±0.08)	0.004 (±0.003)	0.005 (±0.004)	0.001 (±0.001)	0.007 (±0.008)	0.009 (±0.001)	0.002 (±0.001)
10-20	12.96 (±0.91)	13.46 (±1.01)	0.50 (±0.12)	6.79 (±0.42)	7.42 (±0.46)	0.63 (±0.14)	0.013 (±0.002)	0.014 (±0.023)	0.001 (±0.001)	0.039 (±0.006)	0.051 (±0.011)	0.011 (±0.009)
20-30	22.08 (±0.81)	23.50 (±1.08)	1.42 (±0.27)	9.56 (±1.36)	10.40 (±1.59)	0.84 (±0.16)	0.038 (±0.028)	0.043 (±0.004)	0.005 (±0.002)	0.106 (±0.028)	0.135 (±0.044)	0.028 (±0.036)

Table 2 Production of above and below ground biomass of *Fraxinus floribunda* trees under different diameter classes

Diameter class (cm)	Stem biomass (kg/tree)			Branch biomass (kg/tree)			Leaf biomass (kg/tree)			Total above ground biomass (kg/tree)		
	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment
0-10	4.91 (±0.54)	6.56 (±0.73)	1.65 (±0.19)	1.63 (±0.04)	2.18 (±0.24)	0.55 (±0.09)	0.39 (±0.04)	0.72 (±0.08)	0.33 (±0.05)	6.93 (±0.77)	9.46 (±1.06)	2.53 (±0.11)
10-20	26.46 (±4.54)	34.04 (±7.92)	7.58 (±1.23)	8.83 (±1.51)	11.34 (±2.64)	2.51 (±0.12)	2.20 (±0.37)	3.77 (±0.88)	1.57 (±0.16)	37.49 (±6.43)	49.15 (±11.44)	11.66 (±2.03)
20-30	71.35 (±16.54)	90.45 (±23.61)	19.10 (±2.75)	23.56 (±4.23)	29.44 (±5.84)	5.88 (±1.01)	4.29 (±0.48)	7.14 (±1.32)	2.85 (±0.13)	99.20 (±25.79)	127.03 (±32.77)	27.83 (±5.61)

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Diameter class (cm)	Root biomass (kg/tree)			Total biomass (kg/tree)			Total biomass (t ha^{-1})		Biomass productivity (t ha^{-1} yr^{-1})
	2009	2010	Increment	2009	2010	Increment	2009	2010	
0-10	1.73 (±0.19)	2.36 (±0.26)	0.63 (±0.10)	8.66 (±0.96)	11.82 (±1.33)	3.16 (±0.64)	7.79 (±1.34)	10.63 (±1.85)	0.47 (±0.06)
10-20	9.38 (±1.60)	12.28 (±2.86)	2.90 (±0.16)	46.87 (±8.04)	61.43 (±14.30)	14.56 (±2.83)	46.87 (±7.03)	61.43 (±9.06)	2.77 (±0.47)
20-30	24.80 (±4.29)	31.77 (±6.03)	6.97 (±1.23)	124.00 (±31.53)	158.80 (±39.92)	34.80 (±7.98)	62.0 (±9.27)	79.40 (±11.31)	3.62 (±0.81)

Figures in parenthesis are standard error of mean

Table 3 Production of above and below ground carbon stock of *Fraxinus floribunda* trees under different diameter classes

Diameter class (cm)	Stem carbon (kg/tree)			Branch carbon (kg/tree)			Leaf carbon (kg/tree)		
	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment
0-10	2.12 (±0.23)	2.83 (±0.31)	0.71 (±0.08)	0.69 (±0.07)	0.92 (±0.10)	0.23 (±0.04)	0.14 (±0.01)	0.26 (±0.03)	0.12 (±0.03)
10-20	11.42 (±1.96)	14.69 (±2.42)	3.27 (±0.46)	3.74 (±0.34)	4.81 (±0.47)	1.07 (±0.12)	0.80 (±0.08)	1.38 (±0.32)	0.58 (±0.06)
20-30	30.80 (±5.87)	39.05 (±8.61)	8.25 (±1.14)	9.99 (±1.16)	12.48 (±2.02)	2.49 (±0.25)	1.57 (±0.19)	2.62 (±0.29)	1.05 (±0.09)

Contd….

Diameter class (cm)	Root carbon (kg/tree)			Total carbon (kg/tree)			Total carbon (t ha^{-1})		Carbon productivity (t ha^{-1} yr^{-1})
	2009	2010	Increment	2009	2010	Increment	2009	2010	
0-10	0.74 (±0.08)	1.01 (±0.11)	0.27 (±0.05)	3.69 (±0.41)	5.02 (±0.56)	1.33 (±0.27)	3.32 (±0.51)	4.51 (±0.37)	0.20 (±0.04)
10-20	4.03 (±0.37)	5.28 (±0.61)	1.25 (±0.19)	19.99 (±3.01)	26.16 (±4.79)	6.17 (±0.79)	19.99 (±0.2.81)	26.16 (±4.33)	1.18 (±0.03)
20-30	10.66 (±1.19)	13.66 (±2.23)	3.0 (±0.37)	53.02 (±8.69)	67.81 (±10.03)	14.79 (±2.45)	26.51 (±4.90)	33.90 (±7.12)	1.54 (±0.22)

Figures in parenthesis are standard error of mean

Table 4 Carbon dioxide mitigation potential of different components of *Fraxinus floribunda* trees under different diameter classes

Diameter class (cm)	Stem CO_2e (kg/tree)			Branch CO_2e (kg/tree)			Leaf CO_2e (kg/tree)		
	2009	2010	Increment	2009	2010	Increment	2009	2010	Increment
0-10	7.75 (±0.83)	10.35 (±1.16)	2.60 (±1.30)	2.52 (±0.28)	3.36 (±0.38)	0.84 (±0.42)	0.51 (±0.06)	0.95 (±0.10)	0.44 (±0.22)
10-20	41.79 (±7.01)	53.76 (±12.31)	11.97 (±5.98)	13.68 (±2.23)	17.60 (±2.97)	3.92 (±1.96)	2.93 (±0.50)	5.05 (±0.47)	2.12 (±1.06)
20-30	112.72 (±21.46)	142.92 (±28.79)	30.20 (±15.10)	36.56 (±8.63)	45.67 (±11.32)	9.11 (±4.55)	5.74 (±0.58)	9.58 (±1.02)	3.84 (±1.92)

Contd.....

Diameter class (cm)	Root CO_2e (kg/tree)			Total CO_2e (kg/tree)			Total CO_2e (t ha^{-1})
	2009	2010	Increment	2009	2010	Increment	
0-10	2.70 (±0.30)	3.69 (±0.38)	0.99 (±0.49)	13.48 (±1.51)	18.35 (±2.05)	4.87 (±2.43)	14.31 (±2.36)
10-20	14.74 (±2.53)	19.32 (±2.83)	4.58 (±2.29)	73.14 (±12.56)	95.73 (±18.37)	22.59 (±11.29)	84.43 (±11.13)
20-30	39.01 (±9.63)	49.99 (±13.11)	10.98 (±5.49)	194.03 (±41.39)	248.16 (±53.01)	54.13 (±27.06)	110.54 (±19.92)

Figures in parenthesis are standard error of mean

(CO_2e= Carbon dioxide equivalent)

Production of carbon stock of *Fraxinus floribunda*

It is clear from the data presented in (Table 3) that stem carbon showed an increasing trend with the corresponding increase in diameter class and was recorded maximum (39.05 kg/tree) under diameter class 20-30 cm during 2010 and minimum (2.12 kg/tree) under diameter class 0-10 cm during 2009.The branch recorded maximum (12.48 kg/tree) carbon under diameter class 20-30 cm during 2010 and minimum (0.69 kg/tree) under diameter class 0-10 cm during 2009. The leaf carbon stock was registered maximum (2.62 kg/tree) under diameter class 20-30 cm during 2010 and minimum (0.14 kg/tree) under diameter class 0-10 cm during 2009. The root carbon stock shows an increasing trend with the increase in diameter class and was recorded maximum (13.66 kg/tree) under diameter class 20-30 cm during 2010 and minimum (0.74 kg/tree) under diameter class 0-10 cm during 2009. The total carbon stock of *Fraxinus floribunda* was recorded maximum (67.81 kg/tree or 33.90 t ha^{-1}) under diameter class 20-30 cm during 2010 and minimum (3.69 kg/tree or 3.32 t ha^{-1}) under diameter class 0-10 cm during 2009. The carbon productivity was registered maximum (1.54 t ha^{-1} yr^{-1}) under higher diameter class 20-30 cm and minimum (0.20 t ha^{-1} yr^{-1}) under lower diameter class 0-10 cm.

Carbon dioxide mitigation potential of different components of *Fraxinus floribunda*

Perusal of the data in (Table 4) reveals that stem CO_2 equivalent shows an increasing trend with the increase in diameter class and was recorded maximum (142.92 kg/tree) under diameter class 20-30 cm during 2010 and minimum (7.75 kg/tree) under diameter class 0-10 cm during 2009. The branch CO_2 equivalent was registered maximum (45.67 kg/tree) under diameter class 20-30 cm during 2010 and minimum (2.52 kg/tree) under diameter class 0-10 cm during 2009.The leaf CO_2 equivalent was registered maximum (9.58 kg/tree) under diameter class 20-30 cm during 2010 and minimum (0.51 kg/tree) under diameter class 0-10 cm during 2009. The root CO_2 equivalent was registered maximum (49.99 kg/tree) under diameter class 20-30 cm during 2010 and minimum (2.70 kg/tree) under diameter class 0-10 cm during 2009. The total CO_2 equivalent of *Fraxinus floribunda* was registered maximum (110.54 t ha^{-1}) under diameter class 20-30 cm and minimum (14.31 t ha^{-1}) under diameter class 0-10 cm.

DISCUSSION

The maximum DBH was recorded in diameter class 20-30 cm during 2010 and minimum was observed in diameter class 0-10 cm during 2009 (Table 1). The increase in DBH with the increase in diameter class is due to radial growth of the trees (Heryati *et al.*, 2011). The maximum height was recorded in diameter class 20-30 cm during 2010 and minimum was recorded in diameter class 0-10 cm, during 2009. The increase in height with the increase in diameter class could be due to apical growth in the buds of the trees (Heryati *et al.*, 2011). The basal area was found to be maximum in diameter class 20-30 cm during 2010 and minimum in diameter class 0-10 cm during 2009. Increase in basal area with the increase in diameter class is due to increase in diameter (Singh and Gupta, 2008). The stem volume was maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2010. Heryati *et al.* (2011) have reported in their study that volume increases with increasing diameters and heights while studying growth performance of a *Khaya ivorensis* plantation in three soil series of ultisols at Johor, Malaysia. Further our results are in agreement with the results of several workers (Montagnini *et al.*, 2003; Piotto *et al.*, 2004; Brenes and Montagnini, 2006 and Uma *et al.*, 2011) who reported in their study that with the increase in diameter and height, the volume increased proportionately.

The average stem dry biomass of *Fraxinus floribunda* increased with corresponding increase in diameter class (Table 2) and was recorded maximum in diameter class 20-30 cm during 2010 and minimum in diameter class 0-10 cm during 2009. Roy *et al.* (2006) studied biomass production in 8 year old trees of *Melia azedarach* on farm boundaries in a semi-arid region at Jhansi (U.P) and reported that the stem biomass was maximum (102.11 kg/tree) under diameter class 22 cm and minimum (23.31 kg/tree) under diameter class 18 cm. Since biomass of trees varies from species to species according to climatic conditions, because climate plays a vital role in biomass development of trees (Wright *et al.*, 2001).Several other workers also support present findings like Buvaneswaran *et al.* (2006), Redondo and Montagnini (2006) and Fonseca *et al.* (2012) who reported that with the increase in diameter class, the biomass production increases and maximum biomass allocation is towards stem. The branch biomass also showed an increasing trend with the increase in diameter class. The branch biomass depends on the average number of branches of the trees. Moreover, it increases with an increase in diameter class. These results are in agreement with those reported earlier for other tree species like Tandon *et al.* (1988), Swamy *et al.* (2003) and Chauhan *et al.* (2009) who reported that the branch biomass varies from 1.39 to 7.98 kg/tree after studying biomass in different components of agro forestry trees of 13 species (3 year old) planted at 6m × 3m spacing on a uniform site. The leaf biomass was recorded maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm. The increase in leaf biomass in higher diameter class could be attributed to more number of branches as compared to lower diameter class. Singh (2005) in a biomass study of some MPTs (12 years old) at 5 × 5m spacing in Jodhpur district of Rajasthan and reported that the leaf biomass was recorded 2.25, 1.85 and 3.0 kg/tree in *Acacia tortilis*,*Acacia Senegal* and *Prosopis juliflora* respectively. Present results also corroborates with the results of several other workers (Pal and Raturi, 1989; Roy *et al.*, 2006 and Koul and Panwar, 2008). The total above ground biomass was recorded maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009.Uma *et al.*, 2011 in a similar study reported that the total aboveground biomass was recorded (16.95 kg/tree) while working on 3 years old *Casuarina equisetifolia* in farm forestry plantation of

Tamil nadu. Further similar results were earlier reported by many other workers (Lodhiyal *et al.*, 1992; Swamy *et al.*, 2003 and Jana *et al.*, 2009). The root biomass increases with increase in diameter class. Hase and Foeister (1983) observed that trees produce larger root system that needed for uptake of soil resources, thus resulting in higher values in higher diameter class. These results are similar to the findings of Mohsin *et al.* (1999), Singh and Lodhiyal (2009) and Yadava (2010a) who reported that root biomass is more in higher diameter class as compared to lower diameter class. The biomass productivity of *Fraxinus floribunda* (19 years old) was recorded maximum under diameter class 20-30 cm and minimum under diameter class 0-10 cm. Pande (2005) while studying biomass and productivity of some disturbed tropical dry deciduous teak forests (16 years old) of Satpura plateu, Madhya Pradesh and reported that the biomass productivity at the site varied between 4.76 to 6.39 t ha^{-1} yr^{-1}. But the biomass productivity of tree species varies from place to place due to variation in climate, soil, temperature and rainfall and also on age. The present findings are also well in accordance with the findings of Brown *et al.* (1986), Rana and Singh (1990) and Heryati *et al.* (2011). The low productivity in the present study is probably caused by small leaf surface and smaller duration of photosynthetic activity as the *Fraxinus floribunda* trees recorded late leaf initiation and earliest leaf fall under Kashmir conditions (Anonymous, 2010).

It is clear from the data presented in (Table 3) that stem carbon showed an increasing trend with the corresponding increase in diameter class and was recorded maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. Terakunpisut *et al.* (2007) has reported that carbon stock is more in trees having greater diameter as compared to trees having lower diameter. Thus trees with greater diameter are the largest component of biomass and carbon stock. Our results are in well conformity with the findings of Ravindranath *et al.* (1997), Gera *et al.* (2006) and Ramachandran *et al.* (2007). The branch recorded maximum carbon under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. The branch carbon stock depends on the average number of branches on the trees. Moreover, it increases with the increase in diameter class. Our results corroborates with the findings of Chavan (2007), Matala *et al.* (2009) and Tolunay (2011). The leaf carbon stock was registered maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. The increase in leaf carbon stock from lower diameter class to higher diameter class could be due to more number of branches in higher diameter class. Singh and Lodhiyal (2009) while studying biomass and carbon allocation in different components of 8 year old *Populus deltoides* plantation in Tarai agroforestry systems in central Himalaya and reported 6.5 tha^{-1} of carbon stock in the leaves. Since the leaf carbon stock depends up on the ash content and the ash content depends on the structural tissue, less the ash content, more will be the carbon stock (Negi *et al.*,2003) The present findings are in agreement with the findings of Kumar *et al.* (2009), Yadava (2010a), Juwarkar (2011) and Fonseca *et al.* (2012). The root carbon stock shows an increasing trend with the increase in diameter class.The present findings are in line with the observations made by Koul and Panwar (2008), Brenes and Montagnini (2006), Yadava (2010b) and Juwarkar *et al.* (2011) who reported that root carbon stock is more in higher diameter class as compared to lower diameter class. The total carbon stock of *Fraxinus floribunda* was recorded maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009.Similar results have also been reported earlier by many workers (Gera *et al.*, 2006; Ramachandran *et al.*, 2007; Kumar *et al.*, 2009 and Jana *et al.*, 2009). The carbon productivity was registered maximum under higher diameter class 20-30 cm and minimum under lower diameter class 0-10 cm. Similar results were earlier reported by many other workers (Brenes and Montagnini, 2006; Kumar *et al.*, 2007 and Yadava, 2010a).

Perusal of the data in (Table 4) reveals that stem CO_2 equivalent shows an increasing trend with the increase in diameter class and was recorded maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. CO_2 mitigation potential is more in higher diameter class as compared to lower diameter class because in higher diameter class, there is higher biomass production which is directly related to CO_2 mitigation (Yadava, 2010a). The results are well in conformity with the findings of Lal and Singh (2000), Brenes and Montagnini (2006) and Rizvi *et al.* (2011). The branch CO_2 equivalent was registered maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. Higher mitigation potential of branch in higher diameter class can be due to more biomass (Yadava, 2011). Our results are well in agreement with the findings of Kursten and Burschel (1993), Wang and Fenz (1995) and Albrecht and Kandji (2003). The leaf CO_2 equivalent was registered maximum under diameter class 20-30 cm during 2010 and minimum under diameter class 0-10 cm during 2009. Higher mitigation potential of leaf in higher diameter class is attributed to more biomass production (Lal and Singh, 2000). Similar results were earlier reported by many other workers (Nowak and Crane, 2001; Gera *et al.*, 2006 and Yadava, 2011). The root CO_2 equivalent was registered maximum under diameter class 20-30 cm during 2010 and minimum (2.70 kg/tree) under diameter class 0-10 cm during 2009. Higher mitigation potential of root is attributed to more root biomass in higher diameter class (Yadava, 2011). The results are well in conformity with the findings of Wang and Fenz (1995), Kursten (2000) and Matala *et al.* (2009). The total CO_2 equivalent of *Fraxinus floribunda* was registered maximum under diameter class 20-30 cm and minimum under diameter class 0-10 cm. In higher diameter class, there is more biomass production which in turn is related to CO_2 mitigation (Yadava, 2011). Our results are well in agreement with the findings of Wang and Fenz (1995), Lal and Singh (2000) and Uma *et al.* (2011).

CONCLUSIONS

– Growth parameters like DBH, height, basal area and volume showed an increasing trend with the increase in diameter class and maximum volume was recorded under higher diameter class 20-30 cm.

– Total biomass was noticed maximum under the higher diameter class 20-30 cm but in case of individual contribution of biomass allocation of different components, maximum biomass was accumulated by stem followed by root, branch and leaf respectively.

– Total carbon stock was recorded maximum in higher diameter class 20-30 cm but in case of individual contribution stem recorded the maximum carbon stock followed by root, branch and leaf respectively.

– Carbon dioxide mitigation potential was recorded maximum under the higher diameter class 20-30 cm. Among the different components of tree species, stem recorded the maximum mitigation potential followed by root, branch and leaf respectively.

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PERFORMANSE RASTA, PROIZVODNJA BIOMASE I SKLADIŠTENJE UGLJENIKA NA 19-GODIŠNJOJ PLANTAŽI *Fraxinus floribunda* (JASEN) U DOLINI KAŠMIRA

SAŽETAK

Šume su prepoznate kao važna komponenta u kruženju ugljenika, a njihov je značaj u potencijalu da ugljenik sekvestriraju. Oživljavanje šuma i pronalaženje povoljnih metoda za sekvestriranje ugljenika predstavlja veliki međunarodni politički cilj. Ovom studijom je pokušano procijeniti rast, proizvodnju biomase, skladištenje ugljenika i potencijal za ublažavanje ugljen dioksida na 19 godina staroj plantaži *Fraxinus floribunda* kod prečnika različitih klasa. Planirani ciljani prečnik (DBH) zasada drveća varirao je od 7,74 cm do 23.50 cm, visine od 4,16 m do 10.40 m, bazalne površine od 0.004 m^2 do 0.043 m^2 i zapremine od 0.007 m^3 do 0.135 m^3 tokom 2009. i 2010. godine. Prosječna suva biomasa stabala varirala je od 4,91 kg do 90,45 kg, suva biomase grana od 1,63 kg do 29,44 kg, suva biomase lišća od 0.39 kg to7.14 kg, suve nadzemne biomase od 6,93 kg to127. 03 kg, suva biomase korjena od 1,73 kg do 31,77 kg i ukupna biomase (iznad + ispod zemlje) varirala je od 8.66 kg do 158.80 kg. Ugljenik stabla varira od 12.12 do 39.05 kg, ugljenik grana od 0,69 kg do 12.48 kg, ugljenik lišća iznosi između 0,14 kg i 2,62 kg, ugljenik korijena od 0.74 kg do 13,66 kg i ukupan iznos ugljenika iznosi između 3,69 kg i 67,81 kg. Potencijal stabla za ublažavanje ugljendioksida varira od 7,75 kg do 142.92 kg, potencijal grane od 2,52 kg do 45,67 kg, lista od 0,51 kg do 9,58 kg, korijena od 2,70 kg do 49.99 kg i ukupan potencijal za ublažavanje ugljendioksida varirao je od 13.48 kg do 248,16 kg tokom 2009 i 2010. godine.

Ključne riječi: biomasa, zalihe ugljenika, ublažavanje ugljendioksida, *Fraxinus floribunda*, rast