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Studies on the physical characteristics, properties and productivity potential of exotic and indigenous bamboos in rainfed subtropical environment

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Abstract
Age and maturity status of bamboo culm determines the strength of bamboos. The older bamboo culms and lower part of it has better strength than the younger and outer culms. From the studies carried out it is also quite evident that the productivity of the bamboo based agroforestry systems in western Himalayas can be increased many times if the exotic bamboos are introduced in the system. *Bambusa bambos* could be the best option with highest volume per ha. Similarly, the *Dendrocalamus asper* could be very good for fodder purposes with better palatability and small thick bamboo sticks for small use. Among local bamboos *Bambusa nutans* and *Dendrocalamus hamiltonii* could be better option. *Bambusa tulda* and *Bambusa balcooa* can be other best options for introduction in the farm with higher culm number per culm and biomass after *Bambusa bambos*.

Keywords: Bamboo, Lumen volume, culm volume

Introduction
Physical characteristics and properties affect the prospects of bamboo types as agroforestry crop in subtropical environment. Bamboo play a important role in the rural economy of the developing world of Asia. India is such a country where bamboo has played big role in the livelihood and social living. Bamboo is the fastest growing perennial grass on earth and is best source of wood, fuel and carbon sequestration in shortest possible time period. All aspects in Sivliculture, propagation, processing, properties and utilization of bamboo found growing wild in the forest has been studied but studies on cultivated bamboo in agroforestry systems as crop has not been under taken. Information on the properties such as morphology, characteristics, physical, mechanical, etc., at different ages in agroforestry is very limited. Studies carried out by Razak, (1998) [7]; Abdul-Latif (1992) [1]; Abdul-Latif and Mohd Tamizi, (1992) [2] and Liese, (1985) [4]. Studies on the morphological and anatomical characteristics of managed natural bamboo stands have proved that the physical properties and characteristics of bamboo culms have significant effects on their durability and strength. Information generated on these properties and characteristics can be used to determine the possible proper bamboo utilization. Depending on species, bamboo upon maturity (3-4 years after cultivation) is said to possess the best properties for various utilization purposes. There are around 60–90 genera of these species are available in different sizes and forms. Nature has given bamboo special structural design (Samsul *et al.*,2018) [9]. Exotic bamboos *viz*. *Bambusa tulda*, *Bambusa bambos*, *Bambusa balcooa* and *Dendrocalamus asper* and three indigenous bamboos *viz*. *Dendrocalamus hamiltonii*, *Bambusa nutans* and *Dendrocalamus strictus* were planted under agroforestry systems to study their performance in year 2010. Three age-groups *viz*. 3,5 and 8 years-old culms and division of bamboo clump into three circles of these bamboos planted in Agri-silviculture system were used in this study. They were chosen to represent the young and the mature culms. The physical characteristics and properties such as the culms height, numbers of internodes per culms, internode length, internode diameter, culms wall thickness, girth, moisture content and basic density are considered to be important factors in determining the suitability of bamboo for various application and chemical treatment. Basic density is important because it reflects the amount of cell wall material per unit volume of culms and relates directly to strength properties. This study highlights on the physical characteristics and properties of bamboo types *viz*. *Bambusa tulda*, *Bambusa bambos*, *Bambusa balcooa* and

Dendrocalamus asper and *three indigenous bamboos viz. Dendrocalamus hamiltonii, Bambusa nutans* and *Dendrocalamus strictus* culms under agroforestry systems.

Materials and Methods

The study was carried out in Low hill subtropical rainfed conditions i.e. Agroforestry experimental field of Regional Horticultural Research and Training Station Jachh (32º 28// N latitude and 75º 85// E longitude and elevation; 440 m msl) of Dr YS Parmar University of Horticulture and Forestry, Nauni-Solan, Himachal Pradesh. Climatically, the site lies in the sub-tropical belt but is slightly skewed towards the harsh summer, heavy rained monsoon and sever winters. The area experiences a wide range of temperature fluctuations with a minimum of – 2.0ºc in December and January in winter to a maximum of 44˚C in May and June as the hottest months. Winters are accompanied by a fair amount of frost which kills large amount of regeneration in the area but snowfall is witnessed rarely. The area receives maximum downpour during the monsoon season (July and August) Bamboo types were cut at 30 cm above ground level. These culms were taken from the randomly selected culms at different age. The bamboo was harvested immediately after monsoon. Three culms of each age were cut and investigated. These culms were subdivided in to three parts bottom, middle and top of one third of whole length of culm. Paraffin wax was applied to the cut surfaces of each portion to reduce sap evaporation. Measurements for some basic physical characteristics and properties were done on site where the culms were taken. The culms height, internode length, internode diameter, culms wall thickness and girth were measured from the cut base to the tip. The method used in the physical study was based on Razak *et al*. (2007) [8], Sulthoni (1989) and ASTM (1974). Sample blocks representing the 3 age-group (3,5 and 8 years), 3 height portions (bottom, middle and top) and 3 replicates, consisting of six bamboo types were used. All sample blocks were cut from fresh culms were 10 x 10 mm x 10 mm culms wall thickness. They were weighed and dried in an oven at 105±2 °C for 48 h until a constant weight was attained. Sample for basic density studies were obtained from the middle portion of each internode at the bottom, middle and top culms portions. Each sample blocks were cut to the size of 5 cm length starting from node to upward. Three replicates were used in the study. The sample blocks were oven dried for 48 h at 105±2°C until a constant weight were attained. The sample blocks were then weighed to give the oven dried weight. The bamboo clump was also divided in to three circles by bisecting the clump from centre as given below (Fig-1). This was done to depict the growth behavior of different culms with respect to time as bamboo every year new culms come up on the outer side and enlarge the circle. Bamboo culm volume was calculated by using quarter girth formula and the volume per clump was multiplied with the number of clump per ha to arrive at the volume produced by each bamboo species under Jachh conditions.

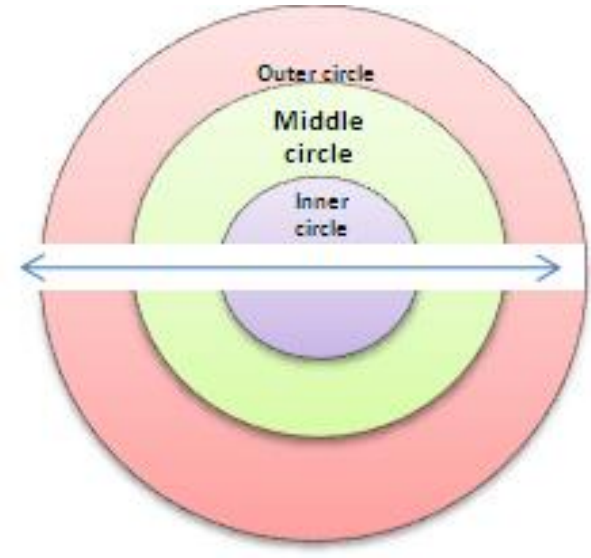

Fig1: Clump divided in to three circle representing the culms of different age in each clump

Results

The fiber direction and hollowness of bamboo makes it as strong as the heavy material with same strength. This unique property of it has made bamboo a world class product with both in cultivation and utilization. (Samsul *et al*., 2018) [9]. The result on physical characteristics of the seven types of bamboos *viz*. *Bambusa tulda, Dendrocalamus asper, Bambusa balcooa, Dendrocalamus strictus, Dendrocalamus hamiltonii, Bambusa nutans* and *Bambusa bambose* planted under the Agri-silviculture system showed changes in the culm height, culm wall thickness, Lumen volume, Number of internodes per culm, internodal length, girth, number of branches per node, fresh weight, lumen diameter, dry weight and Moisture contents with respect to the age but no regular tend was noted. Culm height of 17.90±0.360m was found in Bambusa tulda in inner circle when the whole clump was divided in to the equal circles assuming the centre as base. Whereas, the middle circle culm of *Bambusa nutans* showed the highest culm length of 11.26±0.64 m. Culm height of outer circle showed the maximum culm height of 16.50±0.50 in of *Bambusa balcoa*. Culm height of 17.90±0.360m was found in Bambusa tulda in inner circle when the whole clump was divided in to the equal circles assuming the centre as base. Whereas, the middle circle culm of *Bambusa nutans* showed the highest culm length of 11.26±0.64 m. Culm height of outer circle showed the maximum culm height of 16.50±0.50 in of *Bambusa balcoa.* The maximum number of internodes per culm were recorded 53.66±2.08, 52.33±6.35 and 55.67±1.52, respectively in *Bambusa balcooa* in all the three circles of all the bamboo types. The maximum internodal length of 40.22±5.95 cm and 31.78±6.49, respectively was found in *Bambusa tulda* in inner circle and outer circle. Whereas, the middle circle culm of *Dendrocalamus asper* showed the highest culm length of

29.88±5.96 cm. The maximum Internodal diameter per culm were recorded 5.82±2.64 mm. 7.00±1.11mm and 6.58±2.12, respectively in *Bambusa balcoa* in all the three circles of all the bamboo types. The maximum culm wall thickness was recorded 20.11±8.44 mm. 18.27±6.38 mm and 19.50±9.24 mm, respectively in *Dendrocalamus hamiltonii* in inner, middle and outer circle among all the bamboo types. The maximum girth per culm was recorded 21.89± 8.32 cm, 22.0±3.50 cm and 20.66±6.67 in *Dendrocalamus hamiltonii* in inner, middle and outer circle, respectively among all the bamboo types. The maximum Number of branches per node recorded the maximum value of 7.77±4.73, 10.22±4.99 and 10.77±2.22 respectively in *Bambusa nutans* in inner, middle and outer circle in comparison to all other bamboos types evaluated. Perusal of the table-1 reveals that the maximum fresh and dry weight of bamboo blocks was recorded in *Bambusa balcoa* in all the circle of culm than the other bamboo types. The maximum moisture percent in bamboo culm were recorded to be 53.94±19.35%,65.76±6.62% and 51.42±5.88%, respectively in *Dendrocalamus asper* in all the three circles of in comparison to the other bamboos (table-1). Perusal of data in table -1 reveals that the maximum wood density of bamboo culm were recorded to be 0.00373±0.002(kg/m^3), 0.00424±0.001(kg/m^3) and 0.002811±0.002 (kg/m^3), respectively in *Bambusa tulda* in all the three circles of in comparison to the other bamboos.

Perusal of data in the table-2 reveals that the internodal length, internodal diameter, girth decreased with height of the culm in all the bamboos. The lumen space and lumen space volume in the culm increased with the height of the culm whereas, the culm wall thickness decreases with the height of the culm. Bottom region of the culm bears few to no branch in all the bamboos across age group whereas, the number of branches increased with the height of the culm and age of the bamboo. The wood density increased with the age of the bamboo culm. It also increased from base to the middle region and decreased thereafter. There was no trend of change in moisture contents with age however, it increased with the height of the culm(table-2)

Perusal of fig-1 reveals that culm volume of *Bambusa bambos* was highest and the Dendrocalamus strictus was lowest. *Dendrocalamus hamiltonii* recorded the maximum number of culms per clump (Fig-2) however, *Bambusa nutans recorded the lowest number of culms per clump*. Wood volume per clump was maximum of *Bambusa bambose* whereas lowest was recorded in case of *Dendrocalamus asper*. Perusal in the fig-4 reveals that the *Bambusa bambos* recorded the maximum volume per ha and the lowest volume per ha was of *Dendrocalamus strictus. So* when we analyze the figures in detail we find that the *Bambusa bambose* a bamboo of North-east India has performed better than the local bamboos such as *Dendrocalamus strictus* and *Dendrocalamus hamiltonii*. The physical characteristics of exotic bamboos were found to be higher lower than the local bamboos under subtropical rainfed agroforestry system. The physical characteristics of *exotic and local bamboo types* showed variation depending on the age and height along the culms. The culms generally taper from the middle portion towards the top with a decrease in diameter, girth and culms wall thickness. The lumen space diameter and volume was low in the two local bamboos *viz* Dendrocalamus hamiltonii and Dendrocalamus strictus and in one exotic bamboo i.e. *Bambusa tulda*. Low luman space may make the bamboo suitable for supporting purpose and also good for pulp making. whereas hollow bamboos could be used for construction pupose. Similar observations were made by Razak *et al*. (2007) [8] in the study of the *G. scortechinii*. With age increment, mature tissue starts to develop and continue to change in density, strength properties (Razak *et al*. 2007) [8]. Abdul-Latif (1992) [1] in their study on morphological and anatomical characteristics of managed natural bamboo stands *G. scortechinii found that* In the young culms, the tissues of the outer zone are early maturing resulting in the minimal increment of cell wall thickness with further ageing. This study conducted by Abdul-Latif and Mohd Tamizi (1992) [2] and Razak *et al*. (2007) [8], that in green condition the moisture content is influenced by age, height and position in the culms wall thickness. Easy splitting and cracking due to high initial moisture content (Ng 1980) and the uncertain age of the harvested bamboos are some of the problems faced. The bamboo potential as an industrial raw material is linked to its agronomical and technological characteristics (Okumura *et al*. 2011) [6].

Table 1: Wood physical characteristics of indigenous and exotic bamboos planted in agro-forestry systems in subtropical region of western Himalayas

Characters	Age of clump	*Bambusa tulda*	*Dendrocalamus asper*	*Bambusa balcooa*	*Dendrocalamus strictus*	*Bambusa bambose*	*Dendrocalamus hamiltonii*	*Bambusa nutans*
		Mean±Std Deviation	Mean±Std. Deviation	Mean±Std. Deviation	Mean±Std. Deviation	Mean±Std. Deviation	Mean±Std. Deviation	Mean±Std. Deviation
Culm height (m)	Inner circle	17.90±0.360	8.27±0.56	13.46±0.896	9.30±0.60	13.33±1.52	8.67±0.56	10.20±1.06
	Middle circle	10.500±0.50	6.067±0.67	11.0±1.00	8.13±.208	11.17±1.04	7.23±0.20	11.26±0.64
	Out circle	12.16±0.763	6.47±0.50	16.50±0.50	6.63±.404	14.66±1.15	8.63±0.55	8.20±1.67
Number of internodes per culm	Inner circle	46.00±3.60	28.00±01.00	53.66±2.08	40.33±2.51	42.00±3.00	32.00±1.00	34.33±2.51
	Middle circle	47.33±4.16	25.33±03.78	52.33±6.35	38.00±1.00	47.00 ± 2.00	31.33±2.30	40.00±2.0
	Out circle	49.00±2.64	23.00±04.35	55.67±1.52	28.00±1.00	45.00 ±3.00	41.00±1.00	32.33±1.52
Internodal length (cm)	Inner circle	40.22±5.95	28.77±6.07	26.55±4.60	25.78±6.96	28.55 ± 3.97	24.67±6.70	33.66±3.12
	Middle circle	28.11±9.00	29.88±5.96	25.33±3.64	24.78±3.59	25.22 ± 4.11	19.67±1.80	26.44±7.29
	Out circle	31.78±6.49	31.77±6.92	26.33±4.71	22.56±3.50	29.11 ± 4.64	18.443.04	25.27±7.71
Internodal diameter	Inner circle	3.35±0.61	2.83±1.15	5.82±2.64	3.18±1.28	4.42 ±1.59	4.27±0.929	5.81±.45
	Middle	3.24±0.96	3.64±0.87	7.00±1.11	3.18±1.10	3.32 ±1.22	3.53±1.08	5.19±1.16

(cm)	circle							
	Out circle	4.67±1.41	3.50±0.23	6.58±2.12	3.078±1.00	6.47 ± 2.65	3.46±1.68	5.04±.63
Culm wall thickness (mm)	Inner circle	7.55±2.55	8.25±4.17	11.22±5.85	11.56±6.89	11.37±5.43	20.11±8.44	7.92±3.22
	Middle circle	6.03±3.26	10.01±4.54	11.70±5.55	13.44±7.38	11.50±2.46	18.27±6.38	7.50±2.912
	Out circle	10.58±6.38	9.54±3.75	12.15±7.39	11.36±6.34	8.79±4.74	19.50±9.24	8.11± 4.075
Girth (cm)	Inner circle	10.51±2.01	8.89±3.62	18.55±8.56	9.89±4.04	14.11±5.30	13.33±2.91	16.21±3.99
	Middle circle	10.23±2.99	11.44±2.75	22.0±3.50	10.00±3.46	10.44±3.84	11.11±3.40	15.11±4.16
	Out circle	14.67±4.42	10.44±2.45	20.66±6.67	9.67±3.16	19.89±8.32	10.88±5.27	13.77±2.18
Lumen diameter (mm)	Inner circle	5.67±1.81	25.40±4.97	42.87 ±3.94	9.44±7.10	2.79±0.46	5.33±4.04	37.96±6.16
	Middle circle	3.81±1.28	37.56±8.05	43.44±6.63	10.00±7.90	1.56±0.14	1.54±2.36	37.28±7.739
	Out circle	6.88±4.98	38.61±5.91	45.10±5.67	9.61±7.22	3.75±1.25	2.04±1.88	27.23±5.88
Number of branches per node	Inner circle	5.67±1.81	5.44±1.74	3.66±3.84	4.67±1.73	3.22±2.04	5.44±1.74	7.77±4.73
	Middle circle	3.78±1.30	4.67±2.18	4.22±3.66	5.11±1.76	5.33±2.50	6.44±2.69	10.22±4.99
	Out circle	6.89±4.99	5.78±1.96	3.93±3.97	4.78±1.56	6.44±6.30	6.78±3.23	10.77±2.22
Fresh weight(gm)	Inner circle	47.67±12.50	48.22±31.28	105.44±63.41	58.00±39.08	84.22±49.42	93.67±55.59	76.22±39.69
	Middle circle	30.22±20.24	59.89±31.61	99.33±51.90	58.22±39.62	65.56±25.21	71.00±37.62	69.33±33.50
	Out circle	105.44±61.9	43.00±24.36	120.89±81.48	56.11±32.21	87.44±51.75	92.55±65.93	74.00 ± 34.13
Dry Weight (gm)	Inner circle	25.33 ±8.93	24.11±9.80	89.55±51.13	22.22±12.94	48.89±29.01	37.11±17.47	35.55±17.95
	Middle circle	14.78 ±8.99	22.77±13.04	67.33±34.53	26.22±12.85	35.11±13.62	33.00±14.67	44.88±22.80
	Out circle	35.56±23.038	21.44±13.33	98.11±62.04	24.55 ±13.09	38.67±20.37	44.00 ±27.85	53.66±28.35
Moisture contents (%)	Inner circle	47.76 ± 7.60	53.94±19.35	14.401±8.49	66.03±19.56	43.48±7.14	42.86 ±8.5	52.52±6.91
	Middle circle	44.18 ± 19.04	65.76±6.62	30.51±7.97	49.99±13.3015	46.026±76.75	40.00 ±8.07	35.64±8.53
	Out circle	62.17 ± 13.41	51.42±5.88	18.15±7.47	54.84±4.42	66.56±25.25	28.57 ±9.23	27.73±13.52
Density (kg/m^3)	Inner circle	0.00373±0.002	0.00054±0.00011	0.000918±0.0000981	0.000059±0.00023	0.002422±0.0015	0.000300 ±0.000113	0.00105±0.000363
	Middle circle	0.00424±0.001	0.0004738±0.00023617	0.000645±0.000082	0.00061±. 0.00026	0.00142±.00017	0.000500 ±0.00035	0.001422±0.000546
	Out circle	0.002811±0.002	0.0003578±0.0000831	0.000836±0.000102	0.00067±0. 00019	0.00240±0.00066	0.000400 ±0.00012	0.00273±.00237

Table 2: Mean characteristics of different types of bamboos planted under agroforestry systems in subtropical region of Himachal Pradesh.

		Bambusa bambos			***Bambusa tulda***			***Bambusa nutans***			***Bambusa balcooa***			***Dendrocalamus hamiltonii***			***Dendrocalamus asper***			***Dendrocalamus strictus***		
Age of Bamboo Culm Character	***Culm part***	***3^{nd} yrs After Planting***	***5^{th} years After planting***	***8^{th} yrs After Planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***	***3^{nd} yrs After Planting***	***5^{th} years after planting***	***8^{th} years after planting***
Internodal Length(cm)	Bottom	32.33	23.33	30.67	38.33	22.67	37.33	35.00	32.00	22.83	25	25.33	27	18.33	19	18.33	23	23	25.33	26.67	20.67	21.33
	Middle	28.67	28.00	32.33	43.33	37.33	30.67	35.00	29.33	33.33	27.67	28.33	28.33	29.33	19.67	17.67	36	33.33	35	32.67	28	26.67
	Top	24.67	24.33	24.33	39.00	24.33	27.33	31.00	18.00	19.67	23	26	23.67	26.33	20.33	19.33	27.33	33.33	35	18	25.67	19.67
Inter-nodal Diameter (cm)	Bottom	5.84	4.67	9.45	4.02	4.03	5.84	6.16	5.63	4.94	7.43	7.75	8.17	5.2	4.78	5.41	4.14	4.56	3.82	4.46	4.35	4.14
	Middle	4.99	3.29	7.54	3.11	3.61	5.20	5.77	5.73	4.72	7.86	7.64	7.64	4.25	3.5	3.4	2.55	3.61	3.82	3.4	3.18	3.18
	Top	2.44	2.02	3.93	2.92	2.07	2.97	3.56	3.08	3.50	2.44	5.63	3.93	3.29	2.34	1.59	1.8	2.76	2.34	1.59	2.02	1.91
Girth (Cm)	Bottom	19.00	14.67	29.67	12.83	12.67	18.33	19.33	17.67	15.50	23.33	24.33	25.67	16.33	15	17	13	14.33	12	14	13.67	13
	Middle	15.67	10.33	23.67	9.77	11.33	16.33	18.13	18.00	14.83	24.67	24	24	13.33	11	10.67	8	11.33	12	10.67	10	10
	Top	7.67	6.33	12.33	9.13	6.70	9.33	11.17	9.67	11.00	7.67	17.67	12.33	10.33	7.33	5	5.67	8.67	7.33	5	6.33	6
Lumen Diameter (mm)	Bottom	2.34	1.60	2.08	4.33	2.67	3.00	34.34	34.34	30.09	39.25	34.71	40.62	0	0	0	20.2	32.26	34.67	0	0	0
	Middle	2.65	1.39	4.65	5.33	3.33	4.33	46.07	47.22	19.58	47.64	47.28	52.56	7.45	0	3.79	30.47	48.18	46.43	13.67	13.33	14.5

	Top	3.38	1.70	4.53	7.33	5.33	13.33	33.48	30.28	32.04	41.73	48.35	42.12	8.58	4.72	2.28	29.32	32.13	34.74	14.67	16.67	14.33
Culm Wall Thickness (mm)	Bottom	10.32	14.44	14.83	10.67	10.10	18.67	12.01	11.20	13.45	18.53	18.72	21.4	32.54	23.13	31.18	13.45	11.22	12.09	20.67	23	19.6
	Middle	18.06	11.27	7.25	6.33	5.00	8.57	6.51	6.52	6.12	9.8	10.17	10.17	19.31	20.79	17.06	6.82	6.61	6.12	7.67	8.67	8.16
	Top	5.75	8.82	4.30	5.67	3.00	4.50	5.25	4.80	4.77	5.33	6.24	4.89	10.89	8.54	10.37	11.63	11.56	12.8	6	8.67	6.33
Number Of Branches Per Node	Bottom	1.00	3.00	3.00	4.33	2.67	3.00	1.67	3.67	8.00	4.33	2.67	3	4	4.33	4.67	3.67	3	4.33	3.33	3.33	3
	Middle	3.33	5.00	2.00	5.33	3.33	4.33	9.67	13.00	12.33	5.33	3.33	4.33	6	6	5.67	5.67	4	5	4.67	5	5.33
	Top	5.33	8.00	14.33	7.33	5.33	13.33	12.00	14.00	12.00	7.33	5.33	13.33	6.33	9	10	7	7	8	6	7	6
Fresh Weight (gm)	Bottom	146.00	86.33	145.00	59.67	55.33	167.00	127.00	106.00	107.33	184.33	161.33	218.33	160.67	111.67	175.33	88.33	99.67	72.33	105.67	108	95
	Middle	72.33	77.00	85.00	46.67	24.00	122.00	63.33	73.00	76.00	92	93	112	86.33	75.67	74.33	37.33	51.67	40	52.33	48.33	52
	Top	34.33	33.33	32.33	36.67	11.33	27.33	38.33	29.00	38.67	39	43.67	32.33	34	25.67	28	19	28.33	16.67	16	18.33	21.33
Lumen Space Volume (mm^3)	Bottom	215.60	100.48	169.42	745.75	287.83	353.25	46317.90	46313.20	35566.90	60490.2	47341.3	64790.9	0	0	0	16019.4	40865	47180.4	0	0	0
	Middle	275.67	75.68	850.02	1151.33	444.83	798.08	83357.90	87628.00	15051.80	89178.3	87768.1	108433	2182.45	121	645.43	36465.7	93875.8	84651.9	7339.75	5436.13	8271.94
	Top	448.57	113.50	804.30	2224.17	1125.17	7038.83	44018.70	35979.60	40366.20	68396.2	91785.1	69650	2890.23	875.88	208.26	40563.8	33757.5	47373.8	10911.5	8451.83	8072.42
Density M/Volume (gm/mm^3)	Bottom	0.00041	0.00140	0.001600	0.001500	0.002700	0.000800	0.000700	0.000800	0.000900	0.000900	0.000710	0.00083	0.0004	0.0006	0.0005	0.00051	0.00055	0.00043	0.00056	0.00052	0.00068
	Middle	0.00008	0.00170	0.002700	0.005500	0.004600	0.005100	0.001100	0.002000	0.005300	0.000970	0.000630	0.00091	0.0004	0.0005	0.0007	0.00058	0.00027	0.00037	0.00051	0.00064	0.00056
	Top	0.00023	0.00130	0.00280	0.00420	0.00540	0.00250	0.00130	0.00140	0.00210	0.00083	0.00063	0.00077	0.0006	0.001	0.0007	0.00055	0.00065	0.00027	0.00037	0.00044	0.00051
Dry Weight(Gm	Bottom	84.33	49.67	63.00	36.00	25.00	64.33	58.33	66.33	77.33	150.33	110.67	170	57	48	78	35.67	38	38	37.33	42.33	40.33
	Middle	44.00	37.00	36.33	22.67	10.67	28.67	29.00	50.67	57.33	85.67	57.67	90	36	36	39.5	22.33	14.67	18.67	21	23	23
	Top	18.33	18.67	16.67	17.33	8.67	13.67	19.33	17.67	26.33	35	33.67	27.67	18.33	15	14.33	14.33	15.67	7.67	8.33	13.33	10.33
Moisture contents	Bottom	42.24	42.45	86.81	51.38	55.32	76.61	53.99	37.42	29.28	18.34	31.48	22.13	64.67	57.03	55.35	77.54	61.96	47.3	90.53	60.78	57.39
	Middle	38.63	50.94	57.15	52.81	23.48	48.43	54.06	30.51	22.30	6.79	37.27	17.91	58.3	52.02	46.63	40.16	71.82	53.27	59.95	52.38	55.66
	Top	46.25	43.87	43.89	47.95	44.19	82.55	49.53	38.99	31.61	18.07	22.79	14.43	46.1	41.54	46.52	23.02	63.51	53.7	47.62	36.72	51.52
Humidity contents	Bottom	73.39	73.93	131.25	65.65	140.07	160.33	117.89	66.32	54.45	22.75	46	28.45	184.38	129.54	174.82	373.44	249.97	107.23	1003.03	475.18	132.42
	Middle	66.47	110.15	138.48	106.01	133.81	353.83	117.89	66.32	54.45	3.82	60.99	15.51	140.25	112.53	87.39	71.29	263.59	114.07	153.62	111.34	127.27
	Top	90.31	78.85	100.35	111.92	31.02	97.95	99.21	64.38	46.91	23.4	29.95	16.89	85.89	71.11	97.61	73.92	174.85	121.16	92.13	64.97	106.97

Fig 2: Lumen variation in different types of bamboos planted in silvi-pastoral system

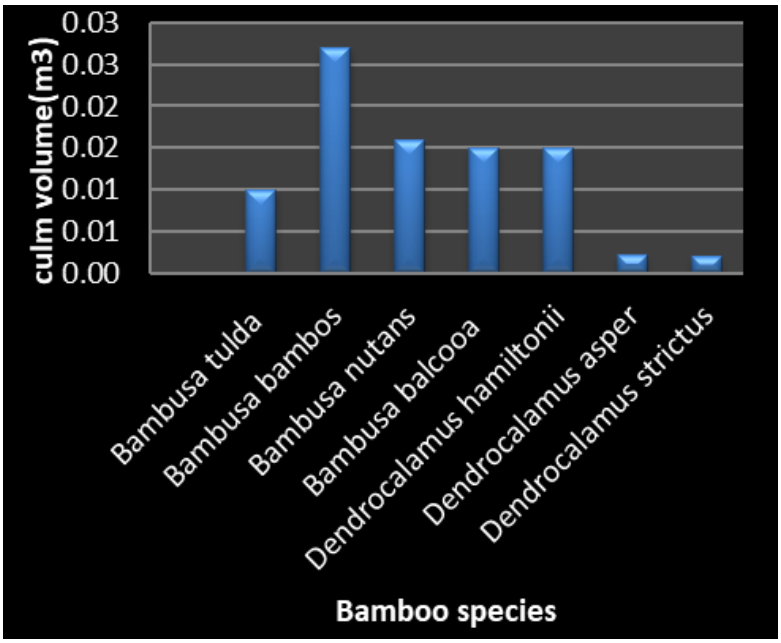

Fig 3: Culm volume (m3) of Bamboo types planted under agrofrestry system

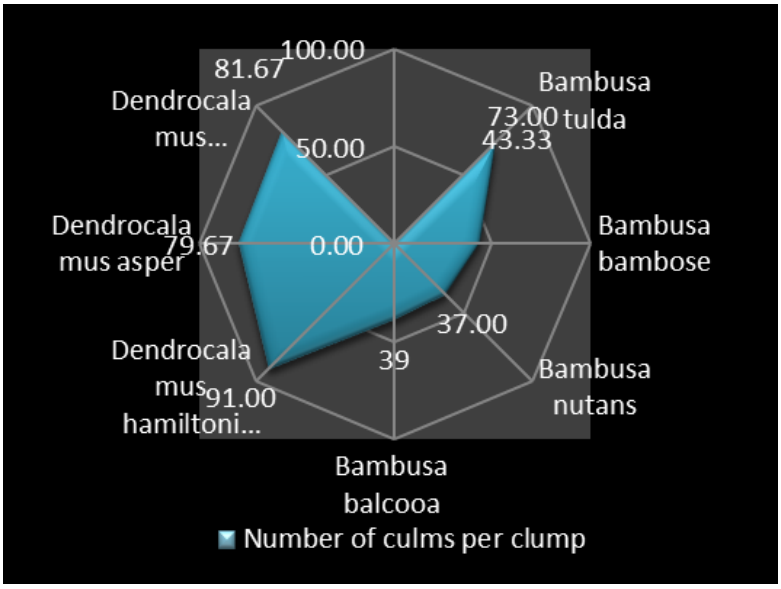

Fig 4: Number of culms per clump of bamboo types planted under agrofrestry system

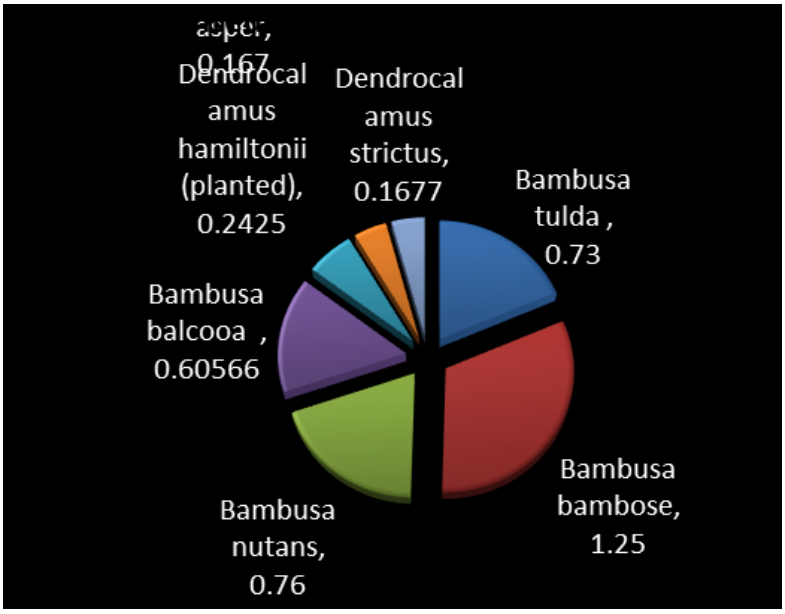

Fig 5: Volume per clump (m3) of bamboo types

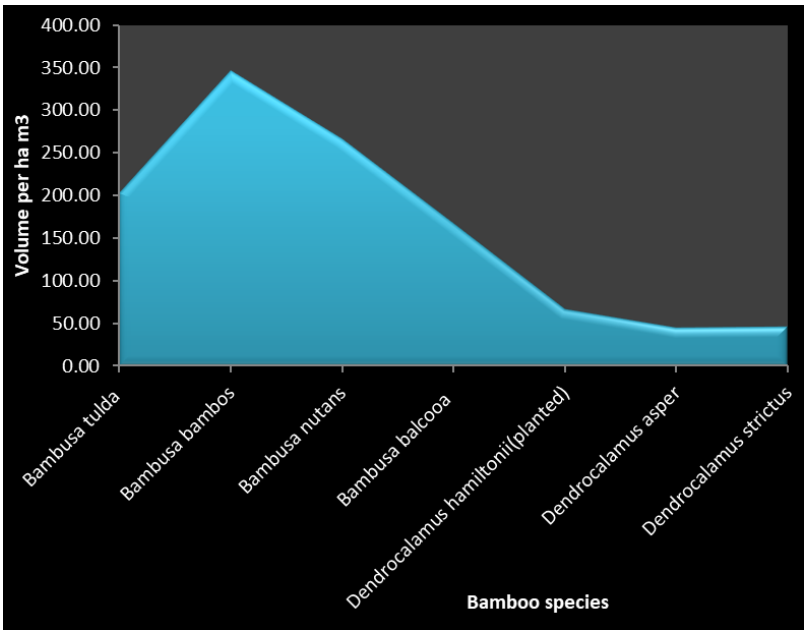

Fig 6: Volume per Hactare (m3) of bamboo types planted under agrofrestry system

Conclusion

Age and maturity status of bamboo culm determines the strength of bamboos. The older bamboo culms and lower part of it has better strength than the younger and outer culms. From the studies carried out it is also quite evident that the productivity of the bamboo based agroforestry systems in western Himalayas can be increased many times if the exotic bamboos are introduced in the system. *Bambusa bambos* could be the best option with highest volume per ha. Similarly, the *Dendrocalamus asper* could be very good for fodder purposes with better palatability and small thick bamboo sticks for small use. Among local bamboos *Bambusa nutans* and *Dendrocalamus hamiltonii* could be better option. *Bambusa tulda* and *Bambusa balcooa* can be other best options for introduction in the farm with higher culm number per culm and biomass after *Bambusa bambos.*

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