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Cultivation of *Salix*- A Potential Bio-energy Crop in the Kashmir Himalaya, India

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Abstract

Salix is considered to be a golden crop among the tree canopy and *Salix* cultivation is known to be a practicable concept to get the best possible return in yield and profit. The eventual aim of present scientific activity was to produce maximum biomass/hectare of different *Salix* species/cultivars in the Kashmir Valley for resource oriented activities. The seventeen accessions of various *Salix* species/cultivars were identified from different aggregates and cultivated under Short Rotation Coppice (SRC) method in natural as well as controlled conditions for three consecutive years. Various growth attributes of different *Salix* species/cultivars which were taken into consideration for the present study includes, the size of the leaves (length as well as breadth), number of branches per cutting, length of the branches and the number of leaves per branch.*Salix babylonica* showed the maximum (8cm, 11cm, 15cm) leaf length in first, second and third year of cultivation respectively, while minimum values for same was recorded for *Salix pycnostachya*. The number of branches per cutting also showed an increase in biomass in all the species/cultivars during the three years of cultivation. *Salix babylonica* showed the maximum length of branches in the first two years while *Salix viminalis* recorded the maximum in the last year. *Salix babylonica* depicted the highest number of leaves per branch during the three years of the experiment. During the three years of cultivation of different *Salix* species/cultivars, all the seventeen accessions showed an increase in biomass in all the attributes.

Keywords: golden crop, Short Rotation Coppice (SRC), management, short term storage, biomass, bio-energy, bio-fuels, bio-crafts.

INTRODUCTION

The genus *Salix* belonging to family Salicaceae is a large, taxonomically complex genus represented by about 450 species worldwide, however, estimates range from 330-350 to 500 [1]. *Salix* occurs mainly in the Northern Hemisphere and its center of abundance is in China, where more than 270 species grow [1]. Kashmir Himalaya is very rich for *Salix* distribution. [2] in "Flora of British India" described 29 species of *Salix* from Indian Sub-continent, [3] reported 9 species of *Salix* from Kashmir, [4] recorded 28 species of family *Salicaceae* in Kashmir Himalaya, [5] reported 15 species of *Salix* from Kashmir valley whereas [6] reported 21 species from Kashmir Himalaya.

The majority of species belonging to genus *Salix* growing in Kashmir have been introduced and raised from cuttings, common ones among them being *S. triandra* L., *S. alba* L., ssp. *coerulea* (Sm). Rech., *S. purpurea* L. and grow gregariously in swampy areas of the valley. Cricket bats are obtained from *S. alba* L. ssp. *coerulea* (Sm.) Rech. while *S.viminalis* L. is the important wicker willow [5].

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Salix is the original source of aspirin which reduces pain, fever and inflammation. It is an efficient renewable energy crop which has higher productivity and lower production costs, and hence serves as an alternative crop for the production of wood fuel. Different species of *Salix* are commonly used for phytoremediation due to their rapid growth rate, ease of propagation and contaminant uptake capability.

Willows have played dominant role in shaping the economy of the area, state or countries of the world as the species of *Salix* are being commonly used as bio-energy, bio-fuels, biomedicines, bio-crafts etc. In Kashmir, *Salix* species provide raw material for handicraft, traditionally used in wickering articles for daily use and work of art, horticulture industry, sports (cricket bat) industry, match factories, plywood and plyboard industries, fodder for sheep and cattle population and serves as source of fire wood.

Short Rotation Woody Crops (SRWC) are being developed around the world as sustainable systems that simultaneously produce a renewable feedstock for biomass and bio-products and a suite of environmental and rural development benefits [7-9].

Salix is considered a golden crop among the tree canopy and presently the concept of *Salix* cultivation is to get the best possible return in yield and profit. *Salix* is an economically important plant and its species can be cultivated/propagated very easily by cuttings. It is also economical, produces large quantities of the original plant material and allows retention of all the characteristics of that plant [10].

Since 1970, substantial efforts have been made to pursue research and trials for an improved short-rotation forest production, mainly with willows [11].Willow coppice can also be used for waste water treatment and soil reclamation [12], filter strips, stream and reservoir bank stabilization [13], phytoremediation and riparian buffer strip applications [14-17). Despite several benefits, including high treatment efficiency, increased biomass yields, improved energy and resource efficiency and cost savings, willow vegetation filters have so far been implemented to a limited degree [18-19].

Keeping in view the importance of *Salix* and its cultivation in the world, an effort was made to cultivate various *Salix* species/cultivars in this climatic zone as per the internationally established protocols. Some species of *Salix* are generally excellent bio-energy crops due to their fast growth and excellent sprouting capacity.

MATERIAL AND METHODS

The present study was carried out from the year 2004-2007. Various *Salix* species/cultivars (**Table 1**) were identified from different aggregates and cultivated under Short Rotation Coppice (SRC) method [20] in natural as well as controlled conditions for three consecutive years with slight modifications in length of cuttings and spacing between rows as well as between cuttings. The experiments for controls were carried out in polybags and pots. Preparation of soil was done by deep ploughing and was dressed with good organic manure. Phosphorous, Potassium and Nitrogen were supplied as basic fertilizers.

Propagation

- Different *Salix* species/cultivars were propagated from un-rooted cuttings.
- Cuttings measuring 24 inches were taken during their growth season (March), for planting.
- All cuts were made at an angle with the top cut above a bud and the bottom cut below a bud.
- On planting the cuttings, 4 inches were inserted into the soil and 20 inches were kept above ground.
- Spacing between the rows as well as the spacing in the row between cuttings was taken as 6 inches.
- Sufficient water was made available to the cuttings.
- Weeds were removed manually from the planting site.
- During the successive years, pruning was carried out to restrict the excessive growth.

The seventeen accessions (07 collected from Kashmir University Campus, 03 from Telbal Srinagar and 07 from various sites in Ladakh) considered in present study were grown in the Kashmir University Botanical Garden (KUBG). Plants were maintained until fully grown for three consecutive years and were observed for their morphological traits. Various growth attributes of different *Salix* species/cultivars which were taken into consideration for the present study includes, the size of the leaves (length as well as breadth), number of branches per cutting, length of the branches and the number of leaves per branch. All these attributes were analyzed regularly and the data was obtained. All the measurements were done randomly and mean was calculated and recorded.

RESULTS

Short Rotation Coppice (SRC) protocol has been found very useful for raising biomass when employed for various *Salix* species/cultivars in this climatic condition. Coppicing (pruning at the stump height of 5-10 cm) was done after one year of propagation in order to develop maximum number of shoots from the cuttings which would subsequently yield maximum biomass for harvesting. The growth during the three consecutive years showed an increase in biomass which was maximum during the third year of establishment.

To observe the viability among different species/cultivars of *Salix*, the cuttings were grown in controlled as well as in natural habitat. The maximum viability was recorded in *Salix matsudana* under controlled conditions whereas viability was maximum in *Salix viminalis* under natural conditions. Other species/cultivars also showed satisfactory results in both the conditions.

Leaf size showed marked variations during the three years of the study. During the first year, the maximum length of leaves (8 cm) was obtained in *Salix babylonica* while the minimum of 0.6 cm was recorded for *Salix fragilis* and *Salix pycnostachya.* In the second year, *Salix babylonica* was again showing maximum leaf length of 11 cm while the minimum leaf length of 0.8 cm was shown by *Salix pycnostachya.* In the last year of cultivation, the maximum length (15 cm) of leaves was recorded as in *Salix babylonica,* while as minimum length (1.1 cm) was recorded for leaves of *Salix pycnostachya.* The breadth of leaves also showed progressive increase during the three years of cultivation of these different *Salix* species/cultivars. During the first year of cultivation the maximum and minimum breadth of the leaves recorded was 7.4 cm and 0.5 cm respectively for *Salix alba* ssp. *coerulea* and *Salix viminalis.* In the second year of cultivation, a maximum leaf breadth of 9.7 cm and minimum leaf breadth of 0.9 cm was recorded for *Salix alba* ssp. *coerulea* and *Salix viminalis* (black) respectively. In the third year of cultivation, *Salix alba* ssp. *micans* and *Salix viminalis* (black) showed maximum and minimum leaf breadth of 11.9 cm and 1.1 cm respectively (Table 2, 3 and 4).

The second attribute which was taken into consideration for recording the increase in biomass of different *Salix* species/cultivars was the number of branches per cutting. In the first year of cultivation of different *Salix* species/cultivars, the highest number of 9 branches was recorded in *Salix viminalis* (red) while the lowest number of 1.6 branches was recorded in *Salix wallichiana*. In the second year, *Salix viminalis* (white) showed a maximum of 29 branches whereas *Salix daphnoides* showed a minimum of 3.3 branches. In the last year of cultivation, a maximum of 41 branches were observed in *Salix* sp. and *Salix viminalis* (white) while a minimum of 5.3 branches were recorded in *Salix wallichiana* (Table 2, 3 and 4).

The third attribute i.e. length of branches used in the present study to analyze the increase in biomass of different *Salix* species/cultivars revealed that in the first year of cultivation, 46.8 cm was the maximum length of branches recorded in *Salix babylonica*,

while as minimum length (8 cm) of branches was observed in *Salix daphnoides*. In the second year of cultivation, *Salix babylonica* showed a highest branch length of 57.6 cm whereas *Salix wallichiana* showed a lowest branch length of 9.5 cm. In the last year of cultivation, the maximum and minimum length of branches of 75 cm and 11.8 cm was recorded in *Salix viminalis* (white) and *Salix wallichiana* respectively **(Table 2, 3 and 4)**.

The forth attribute which was taken into consideration was the number of leaves per branch. In the first year of cultivation, the highest number of leaves per branch was 38.75 as seen in *Salix babylonica,* while as the lowest number of 4.6 was recorded in *Salix alba* ssp. *coerulea.* Second year of cultivation recorded a maximum of 49.6 leaves per branch in *Salix babylonica* and a minimum of 13.8 leaves per branch in *Salix wallichiana.* In the last year of cultivation, a maximum and minimum number of 57.8 and 16.4 leaves per branch were recorded in *Salix babylonica* and *Salix wallichiana* respectively **(Table 2, 3 and 4)**

Table 1: Comparative morphological features of different *Salix* species/cultivars growing in Kashmir Himalaya

Name of species/cultivars	Morphological traits		
	Bark	Leaves	Inflorescence
Sca	Smooth, dark-grey	Ovate or oblong	Catkins with sweet scented male flowers
Sae	Greyish brown	Lanceolate	Catkin
Sal_1	Greyish-redish brown	Lanceolate	Catkin
Sal_2	Olive green	Lanceolate, acuminate	Catkin, appearing with leaves
Scu	Light green	Linear, spirally twisted	Catkin
Sbab	Yellowish brown	Linear lanceolate	Catkin, appearing with leaves
Svm	Greyish brown	Linear lanceolate	Catkin, appearing before leaves
SvmW	Light green	Linear lanceolate	Catkin, appearing before leaves
SvmCk	Redish brown	Linear lanceolate	Catkin, appearing before leaves
Svmnb	Greyish black	Linear lanceolate	Catkin, appearing before leaves
SaGl	Brown or grey with shallow fissures	Broadly lanceolate and pubescent	Catkin
Sabl	Yellow	Linear	Catkin
SaCl	Grey, deeply fissured	Lanceolate	Catkin appear with leaves
SalF	Greyish brown	Ovate or oblong lanceolate	Catkins appear before leaves
SaSl	Shiny	Lanceolate	Catkin
Salbv	Greenish grey	Lanceolate, acuminate	Catkin
SaG_2l	Bluish, pubescent	Oblong or narrowly obovate	Catkins appear before leaves

Sca- *Salix caprea*; Sae- *Salix aegyptica*; Sal_1- *Salix alba*; Sal_2- *Salix* sp.; Scu- *Salix matsudana*; Sbab- *Salix babylonica*; Svm- *Salix viminalis*; SvmW- *Salix viminalis* (white); SvmCk- *Salix viminalis* (red); Svmnb- *Salix viminalis* (black); SaGl- *Salix alba coerulea* ; Sabl- *Salix alba* (Ladakh); SaCl- *Salix fragilis*; SalF- *Salix wallichiana*; SaSl- *Salix pycnostachya* ; Salbv- *Salix alba micans*; SaG_2l- *Salix daphnoides*.

Table 2: Various growth attributes of different *Salix* species/cultivars in Kashmir during 1st year of cultivation

Attributes (mean)	*Salix* species/cultivars																
	Sca	Sae	Sal_1	Sal_2	Scu	Sbab	Svm	SvmW	SvmCk	Svmnb	SaGl	Sabl	SaCl	SalF	SaSl	Salbv	SaG_2l
Leaf size (length x breadth) cm	5.5x1.4	5.0x1.0	2.5x0.9	5.0x1.5	4.1x0.7	8.0x0.7	2.0x0.5	3.0x0.9	2.5x0.85	1.5x0.6	1.9x7.4	0.8x1.7	0.6x3.2	1.2x5.6	0.6x4.4	0.8x4.6	1.1x2.6
No. of branches per cutting	3.5	6.35	2.8	3.0	4.8	3.7	6.0	7.5	9.0	5.0	3.5	4	3	1.6	2.8	4	1.7
Length of branches (cm)	24.5	20.01	27.5	24.7	39.7	46.8	16.0	11.7	10.0	13.0	21.3	9.4	15.6	8.3	12.9	11.2	8
No. of leaves per branch	20.0	17.5	20.5	20.5	22.9	38.75	16.2	15.9	12.5	16.7	4.6	14.8	23.8	12.6	15.3	15.7	12.3

Sca- *Salix caprea*; Sae- *Salix aegyptica*; Sal_1- *Salix alba*; Sal_2- *Salix* sp.; Scu- *Salix matsudana*; Sbab- *Salix babylonica*; Svm- *Salix viminalis*; SvmW- *Salix viminalis* (white); SvmCk- *Salix viminalis* (red); Svmnb- *Salix viminalis* (black); SaGl- *Salix alba coerulea* ; Sabl- *Salix alba* (Ladakh); SaCl- *Salix fragilis*; SalF- *Salix wallichiana*; SaSl- *Salix pycnostachya* ; Salbv- *Salix alba micans*; SaG_2l- *Salix daphnoides*.

Table 3: Various growth attributes of different *Salix* species/cultivars in Kashmir during 2nd year of cultivation.

Attributes (mean)	*Salix* species/cultivars																
	Sca	Sae	Sal_1	Sal_2	Scu	Sbab	Svm	SvmW	SvmCk	Svmnb	SaGl	Sabl	SaCl	SalF	SaSl	Salbv	SaG_2l
Leaf size (length x breadth) cm	7.5x3.5	6.5x3.9	7.5x1.0	9.5x2.8	5.5x1.0	11x1.3	7.1x1.25	3.5x1.5	3.0x1.1	2. 3x0.9	2.2x9.7	1.2x4.3	.9x4.6	.5x6.8	0.8x5.5	1.5x8.5	1.6x4.3
No. of branches per cutting	9.7	15.7	7.5	19.0	10.9	10.6	10.0	29.0	13.0	7.0	6	3.7	5.3	3.6	4.8	4.8	3.3
Length of branches (cm)	39.6	41.5	45.4	40.2	46.8	57.6	35.0	37.0	15.0	17.0	25.5	12.2	14.7	9.5	14.3	12.1	12
No. of leaves per branch	32.0	27.4	30.9	31.0	39.5	49.6	20.5	26.0	17.0	21.0	14.6	18.4	22.4	13.8	17.5	16.9	15.8

Sca- *Salix caprea*; Sae- *Salix aegyptica*; Sal_1- *Salix alba*; Sal_2- *Salix* sp.; Scu- *Salix matsudana*; Sbab- *Salix babylonica*; Svm- *Salix viminalis*; SvmW- *Salix viminalis* (white); SvmCk- *Salix viminalis* (red); Svmnb- *Salix viminalis* (black); SaGl- *Salix alba coerulea* ; Sabl- *Salix alba* (Ladakh); SaCl- *Salix fragilis*; SalF- *Salix wallichiana*; SaSl- *Salix pycnostachya* ; Salbv- *Salix alba micans*; SaG_2l- *Salix daphnoides*.

Table 4: Various growth attributes of different Salix species/cultivars in Kashmir during 3rd year of cultivation.

Attributes (mean)	*Salix* species/cultivars																
	Sca	Sae	Sal_1	Sal_2	Scu	Sbab	Svm	SvmW	SvmCk	Svmnb	SaGl	Sabl	SaCl	SalF	SaSl	Salbv	SaG_2l
Leaf size (length x breadth) cm	10.5x5	11x5.0	10x2.0	12x3.0	10.3x1.2	15x1.5	9.5x1.5	4.0x2.0	5.6x1.3	4.9x1.1	2.9x11.7	1.8x7.9	1.3x7.7	2.1x9.9	1.1x7.9	1.6x11.9	2.1x8.1
No. of branches per cutting	20.9	35.4	19.7	41.0	17.7	18.9	17.0	41.0	17.0	11.0	9.5	5.5	10	5.3	7.2	7.3	5.7
Length of branches (cm)	59.7	62.7	65.7	55.9	56.2	64.7	60.0	75.0	25.0	23.0	30.15	15.3	19.8	11.8	15.2	14.1	14.2
No. of leaves per branch	43.9	41.2	45.6	42.7	52.3	57.8	30.9	45.0	29.0	28.0	18.6	22.2	25.7	16.4	18.2	20.3	20.6

Sca- Salix caprea; Sae- Salix aegyptica; Sal_1- Salix alba; Sal_2- Salix sp.; Scu- Salix matsudana; Sbab- Salix babylonica; Svm- Salix viminalis; SvmW- Salix viminalis (white); SvmCk- Salix viminalis (red); Svmnb- Salix viminalis (black); SaGl- Salix alba coerulea ; Sabl- Salix alba (Ladakh); SaCl- Salix fragilis; SalF- Salix wallichiana; SaSl- Salix pycnostachya ; Salbv- Salix alba micans; SaG_2l- Salix daphnoides.

DISCUSSION

During the three years of cultivation of different *Salix* species/cultivars it is evident that, all the seventeen accessions showed an increase in biomass in all the attributes (Fig.1, 2, 3, 4 and 5). The protocol has been found very useful for raising biomass for research oriented activities like bio-fuels, bio-energy, biomedicines, bio-crafts etc. A similar type of study was also carried out by [11] using intensive short rotation coppice cultivation of *Salix* (short rotation forestry) on agricultural land for the production of biomass for energy and fiber and its integration with environmental aspects such as bio-filters, waste recycling, and utilization of sludge as a fertilizer. [21] also focused on short rotation willows as a potential renewable energy source.

In the present research, the high yield for biomass for different *Salix* species/cultivars was obtained at the closest spacing of the cuttings. The observation was the same as reported by [22] for spacing of willows grown as Short Rotation Coppice in Sweden. Close spacing and successive coppice rotation was also observed by [23] where woody biomass productivity rates averaged 5.6 Mg ha^{-1} yr^{-1}.

Salix is being propagated vegetatively. So it is prerequisite to design a protocol for their propagation. The literature revealed that there are two protocols which are internationally standardized. The oldest method of *Salix* cultivation is the Pollard Willow Cultivation which was later improved by Energie Boerdery Project Sittard (EBPS) foundation in South Holland [24]. The second method is the cultivation by Coppice method which was further developed and

improved in Sweden and the UK as the Short Rotation Coppice (SRC) method [20].

Salix can be coppiced easily as they grow quickly and are very tolerant to cutting. So they can produce a regular supply of biomass. Coppicing method involves the pruning of shoots after first winter at the stump height of 5-10 cm in order to promote a large number of vigorous shoots during the following spring.

The growth during the three consecutive years showed an increase which was maximum during the third year of establishment In a similar study by [25] it was observed that biomass for bio-energy based on willow, planted and managed at high densities and short (3-4 year) coppice harvest cycles, provide fuel for co-firing with coal and have environmentally and ecologically sustainable production and utilization systems.

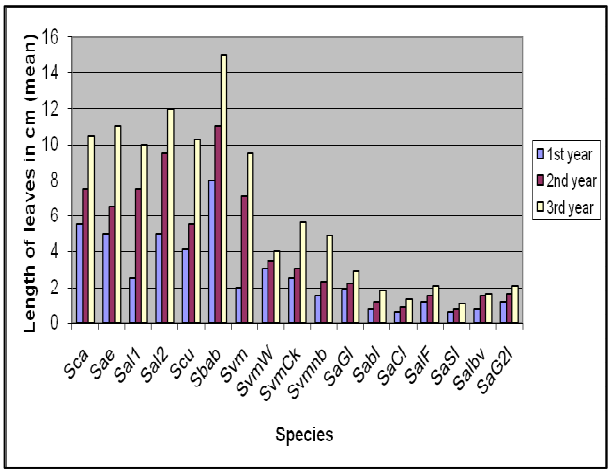

Fig.1: Histogram showing growth (length of leaves) of different *Salix* species for three consecutive years.

Sca- Salix caprea; Sae- Salix aegyptiaca; Sal_1- Salix alba; Sal_2- Salix sp.; Scu- Salix matsudana; Sbab- Salix babylonica; Svm- Salix viminalis; SvmW- Salix viminalis (white); SvmCk- Salix viminalis (red); Svmnb- Salix viminalis (black); SaGl- Salix alba ssp. coerulea ; Sabl- Salix alba (Ladakh); SaCl- Salix fragilis; SalF- Salix wallichiana; SaSl- Salix pycnostachya ; Salbv- Salix alba ssp. micans; SaG_2l- Salix daphnoides.

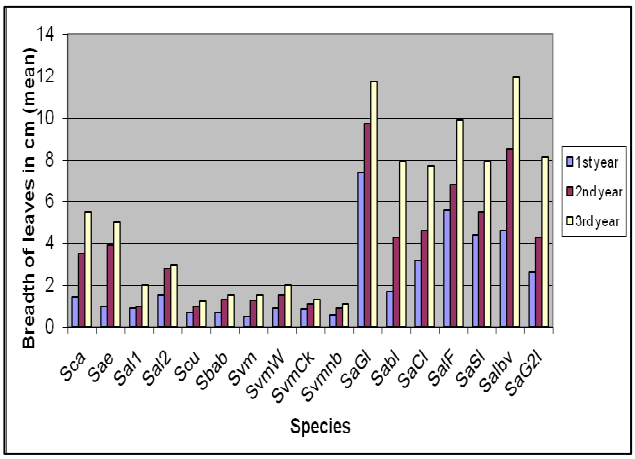

Fig.2: Histogram showing growth (breadth of leaves) of different Salix species for three consecutive years.

Sca- Salix caprea; Sae- Salix aegyptiaca; Sal_1- Salix alba; Sal_2- Salix sp.; Scu- Salix matsudana; Sbab- Salix babylonica; Svm- Salix viminalis; SvmW- Salix viminalis (white); SvmCk- Salix viminalis (red); Svmnb- Salix viminalis (black); SaGl- Salix alba ssp. coerulea ; Sabl- Salix alba (Ladakh); SaCl- Salix fragilis; SalF- Salix wallichiana; SaSl- Salix pycnostachya ; Salbv- Salix alba ssp. micans; SaG_2l- Salix daphnoides.

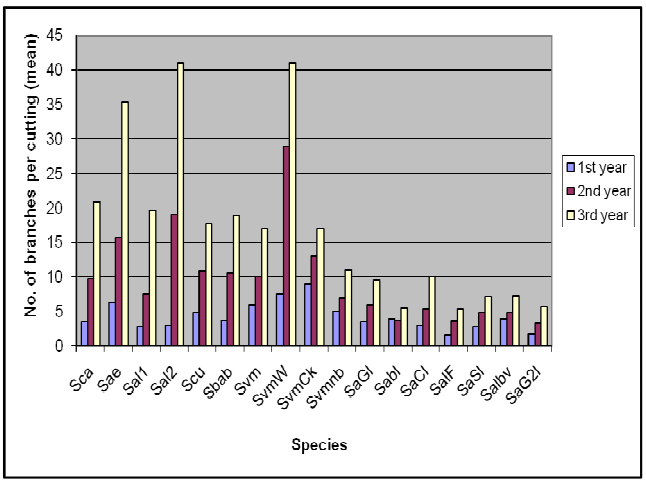

Fig.3: Histogram showing growth (no. of branches per cutting) of different Salix species for three consecutive years.

Sca- Salix caprea; Sae- Salix aegyptiaca; Sal_1- Salix alba; Sal_2- Salix sp.; Scu- Salix matsudana; Sbab- Salix babylonica; Svm- Salix viminalis; SvmW- Salix viminalis (white); SvmCk- Salix viminalis (red); Svmnb- Salix viminalis (black); SaGl- Salix alba ssp. coerulea ; Sabl- Salix alba (Ladakh); SaCl- Salix fragilis; SalF- Salix wallichiana; SaSl- Salix pycnostachya ; Salbv- Salix alba ssp. micans; SaG_2l- Salix daphnoides.

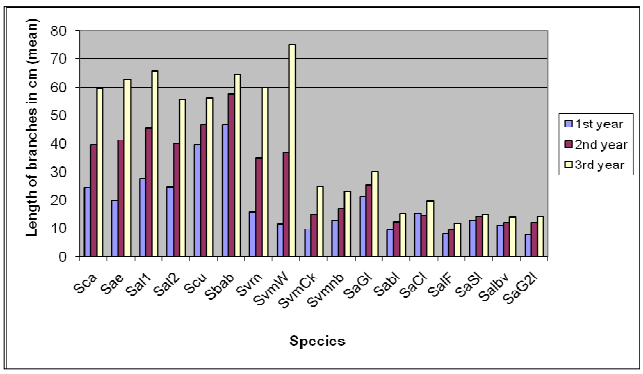

Fig.4: Histogram showing growth (length of branches) of different Salix species for three consecutive years.

Sca- *Salix caprea*; Sae- *Salix aegyptiaca*; Sal_1- *Salix alba*; Sal_2- *Salix* sp.; Scu- *Salix matsudana*; Sbab- *Salix babylonica*; Svm- *Salix viminalis*; SvmW- *Salix viminalis* (white); SvmCk- *Salix viminalis* (red); Svmnb- *Salix viminalis* (black); SaGl- *Salix alba* ssp. *coerulea* ; Sabl- *Salix alba* (Ladakh); SaCl- *Salix fragilis*; SalF- *Salix wallichiana*; SaSl- *Salix pycnostachya* ; Salbv- *Salix alba* ssp. *micans*; SaG_2l- *Salix daphnoides*.

CONCLUSION

Short Rotation Coppice (SRC) method of cultivation when employed for various *Salix* species in this climatic condition has been found very useful for raising biomass for various resource oriented activities like bioenergy, biomedicines, biofuels etc. Cultivation during the three consecutive years showed an increase in growth which was maximum during the third year of establishment. In the present study the highest yield was obtained at the closest spacing. The observation was the same as reported by Rushton [22] for spacing of willows grown as Short Rotation Coppice (SRC) in Sweden. *Salix matsudana* has highest viability under control conditions whereas *Salix viminalis* showed highest viability under natural conditions.

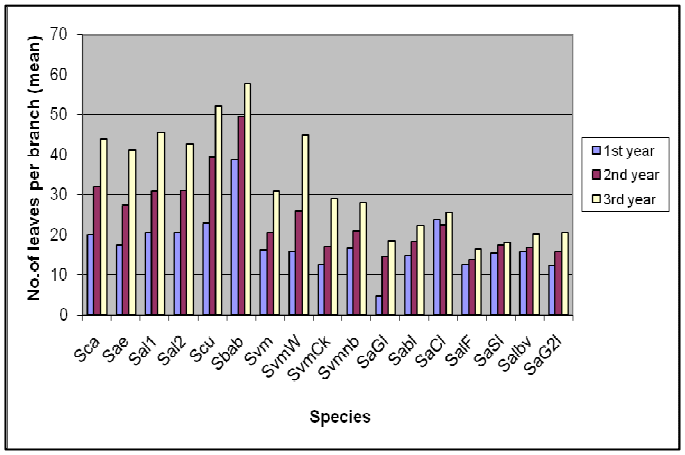

Fig.5: Histogram showing growth (no. of leaves per branch) of different *Salix* species for three consecutive years.
Sca- *Salix caprea*; Sae- *Salix aegyptiaca*; Sal_1- *Salix alba*; Sal_2- *Salix* sp.; Scu- *Salix matsudana*; Sbab- *Salix babylonica*; Svm- *Salix viminalis*; SvmW- *Salix viminalis* (white); SvmCk- *Salix viminalis* (red); Svmnb- *Salix viminalis* (black); SaGl- *Salix alba* ssp. *coerulea* ; Sabl- *Salix alba* (Ladakh); SaCl- *Salix fragilis*; SalF- *Salix wallichiana*; SaSl- *Salix pycnostachya* ; Salbv- *Salix alba* ssp. *micans*; SaG_2l- *Salix daphnoides*.

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