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Genotype x environment interaction and growth stability of exotic tree willow (*Salix* spp.) clones

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Abstract

Eighteen selected clones of *Salix* were taken to study genotype x environment interaction. Significant differences were observed for genotype, environments and genotype x environment interaction except non-significant genotype x environment interaction for plant height increments. Stability analysis revealed that the most of the genotypes were responsive to environmental changes. The *Salix* clones exhibited maximum growth in 2007 and 2010 growth years. Based on phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) the clones J-799, SI-63-007 and NZ-1002 for volume index and SI-63-007 for diameter at breast height were found most adaptive to overall environments. Suitable clones for poor environment was J-194, while for average environments were V-99, NZ-1040 and NZ-1179, respectively for diameter at breast height. Clones suitable for rich environment are PN7-31 for diameter at breast height and NZ-1140 and 131/25 for volume index. The clones identified for different agro ecological regions must be chosen by considering stability of the clones towards that environment.

Key words: Willow, stability, genotype x environment interaction, volume index

Introduction

Willows are fast growing, multipurpose and ecofriendly species cultivated for a variety of end uses *viz*., baskets, cricket bats, hurdles, furniture, plywood, paper and pulp and rope making etc [1, 2]. The genus *Salix* has wide geographic adaptation and fast growth with a significant economic value. It comprises of about 350-500 species worldwide distributed over wide ecological and climatic zones ranging from North America to China, excluding Australasia [3, 4] The arborescent willow species are able to grow on various types of soil. Thus these are most suitable for the biological control of soil erosion, siltation, nutrient recycling, phytoremediation, carbon sequestration and filtering of sewage polluted water.

In India, there are about 31 indigenous and 4 exotic species of willows but majority of them are not suitable for industrial uses. Arborescent species of willow like *Salix alba*, *S. humboltiana*, *S. excelsa*, *S. acmophylla*, *S. daphnoides*, *S. fragilis*, *S. nigra*, *S. matsudana*, *S. amygdaloides*, *S. jessoensis* and *S. tetrasperma* and their inter and intra specific hybrids/ clones [5] are able to grow by vegetative propagation on a large variety of edaphic, ecological and hydrological conditions and are better adapted in monoculture as well as in agroforestry systems under short rotation forestry. Most of the arborescent species of *Salix* are confined to hilly region of the country except *S. tetrasperma* and *S. babylonica* which are occurring right from tropical to temperate regions of India. There is a need for a systematic research work to be carried out on screening of genetic resource of indigenous species, import of various clones/species/ hybrids/strains, etc., clonal testing, hybridization and development of new clones matching to different sites with regard to specific enduses.

In tree improvement, the genotype x environment interaction is an important consideration, as both its magnitude and its pattern have profound implications for breeding, testing and seed deployment. Genotype by environment interaction may be due to

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heterogeneity of variance measured at each of the sites affecting ranking of genotypes in various environments [6]. Clones give a more sensitive means of determining genotype x environment interactions than either seed sources or families because non-additive gene effects might contribute. The improvement programme is enriched by giving importance not only to growth and yield but also to assess the stability of the clones for these traits in different environments. When assessing the profitability of a plantation, the choice of material is greatly facilitated if the grower possesses information regarding the stability of the clones. Although both of these aspects are commonly combined in the sphere of agriculture, it is unusual in studies concerning forest crops [7]. An assessment of stability (or adaptability) and genotype x environment interaction is fundamental to the development of a sound movement of planting material.

Keeping in view the ever increasing demand of willow wood for multifarious uses particularly for sports good manufacturing entrepreneurs, household timber, constituted wood etc., selected promising exotic clones developed by various research organizations throughout the world, were procured and introduced at university campus followed nursery screening for three times [8]. A field trial of 18 superior clones was raised in the university field to identify clones stable for variable environmental conditions. Considering different years as a different locations and yearly increment of traits as effect of variable environmental conditions in these years, stability of clones can be worked out to identify clones stable for variable environmental conditions.

Materials and methods

Eighteen exotic clones collected from four different countries (Table 1) including mostly hybrids and species having commercial importance like suitability for paper and pulp industry, lumber industry, cricket bat industry, plywood and overall high biomass productivity were selected for the study. The one year growth entire transplants of different clones were planted at 3m x 3m spacing in randomized block design with three replications. The experimental plantation was raised at Naganji field area of the Department of Tree Improvement and genetic Resources, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP). The field site is located at an elevation of 1200 m above mean sea level in the north-west of Himalaya and lies between 30°51'N latitude and 76°11'E longitude having well drained, sandy loam soil with pH of 7.20. The area experiences a wide range of temperature with a minimum of –0.5°C in winters to a

Table 1. Description of *Salix* clones grown in the field trial

S.No.	Clone	Genotype	Source Country (Plant material procured)
1.	J-799	*S. matsudana* x *S. alba*	UK
2.	PN-731	*S. nigra*	New Zealand
3.	V-99	*Salix* x *rubens*	Croatia
4.	NZ-1179	*S. matsudana* x *S. alba*	UK
5.	SE-63-016	*S. jessoensis*	Italy
6.	NZ-1040	*S. matsudana* x *S. alba*	New Zealand
7.	*S. alba* (Kashmiri willow)	*S. alba* cv. *caerulea*	UK
8.	NZ-1002	*S. matsudana* x *S. alba*	New Zealand
9.	PN-722	*S. matsudana*	New Zealand
10.	NZ-1140	*S. matsudana* x *S. alba*	UK
11.	SI-64-017	*S. alba*	Italy
12.	131/25	*S. babylonica* x *S. alba*	UK
13.	J-194	*S. matsudana* x *S.arbutifolia* x *S. matsudana*	UK
14.	PN-721	*S. matsudana* x *S. alba*	New Zealand
15.	SI-63-007	*S. alba*	Italy
16.	J-795	*S. matsudana* x *S. alba*	UK
17.	NZ-1130	*S. matsudana* x *S. alba*	New Zealand
18.	SE-69-002	*S. matsudana*	Italy

maximum of 33.3°C during May and June as the hottest months where January and February are the coldest months of the year. The annual rainfall ranges between 858-1361 mm with maximum downpour during the monsoon season (July-September).

The observations on different parameters relating to growth (diameter at breast height and height) were recorded on three trees of each clones/species in the last week of December of every year. Plant height was measured in meter with measuring scale in initial years and with the Abeney level in later years, while diameter at breast height was measured at a height of 1.37 m with caliper to the nearest centi meter. Volume index was calculated by multiplying the square of diameter with height as its relative index as also used in *Populus* [9] and *Salix* species [10]. A number of statistical procedures are available for analyzing the information gathered from the trials established in different environments. The most widely used method for identifying high yielding and stable genotypes, is the linear regression approach. Eberhart and Russell used this approach along with deviation from the regression line (S^2di) as another stability parameter. In general, the regression models partition the overall response pattern into yield performance and stability. Five growth periods in different years were considered as different environments. The genotype-environment interaction and stability parameters were estimated as per the model of Eberhart and Russell [11].

Results and discussion

The results of the combined analysis of variance as per Eberhart and Russell's model are presented in Table 2. The mean squares for genotypes and year/environments for all the traits under study were highly significant ($p < 0.01$) for all traits except genotypes mean square for plant height and diameter at breast height increments of clones, where it varied significantly ($p < 0.05$). This suggesting the existence of considerable variation among clones as well as environments/years. Differences among the clones may be due to variation in their genetic makeup in willows. Environmental index (Ij) directly reflects the poor or rich environment/years in terms of negative and positive index, respectively. In the present findings (Table 3) 1st and 4th year performance based on 2007 and 2010 growth years showed better diameter at breast height and volume index increments as compared to others. The majority of genotypes were able to exploit these environments in comparison to others. This trend of variability is related to the meteorological data

Table 2. Pooled ANOVA mean squares for growth increment in 6 year *Salix* clones

	d.f.	Height (m)	Dia. at breast height (cm)	Volume index (m^3)
Genotypes(g)	17	1.34*	1.40*	5.8E-05**
Environments/ years(e)	4	39.64**	12.10**	0.00025**
g x e	68	0.83NS	1.03*	2.7E-05**
e + g x e	72	215.0**	118.0**	0.00283**
e (linear)	1	158.5**	48.2**	0.00102**
g x e (linear)	17	1.18NS	2.09**	8.7E-05**
Pooled deviation	72	0.673**	0.64*	6.2E-06NS
J-799	3	1.13**	0.17	9.7E-07
PN-731	3	0.42**	3.69**	5.8E-06
V-99	3	1.75**	0.17	5.9E-07
NZ-1179	3	0.47**	0.1	6.6E-08
SE-63-016	3	0.12**	0.16	1.4E-07
NZ-1040	3	0.11**	0.41	1E-06
S. alba (Kashmiri willow)	3	0.98**	0.16	5E-07
NZ-1002	3	0.15**	0.24	2.3E-06
PN-722	3	0.38**	0.38	5.5E-07
NZ-1140	3	0.44**	0.77	5.5E-06
SI-64-017	3	0.42**	0.97	4.5E-07
131/25	3	1.64**	0.17	1.1E-05
J-194	3	0.93**	0.27	7.6E-07
PN-721	3	0.74**	0.55	1.6E-06
SI-63-007	3	0.27**	0.54	2.6E-06
J-795	3	1.01**	0.64	8.1E-07
NZ-1130	3	1.05**	1.7**	7.7E-05
SE-69-002	3	0.10**	0.46	9.7E-07
Pooled error	102	0.008	0.37	0.00031

NS = Non significant, ** = Significant at 1% level of probability

specially rainfall depicting higher diameter increments in years having higher rainfall (Fig. 1). Temperature and availability of water are two major factors for growth and yield of plants influenced monthly girth increments in rubber [12]. The performance of a genotype mainly depends on environmental interaction. Estimation of phenotypic stability, which involves regression analysis has proved to be valuable technique for assessing the response of various genotypes under changing environmental conditions. An evaluation of genotypes environment interactions gives an idea of the buffering capacity of the population under study; the low magnitude of genotype environment

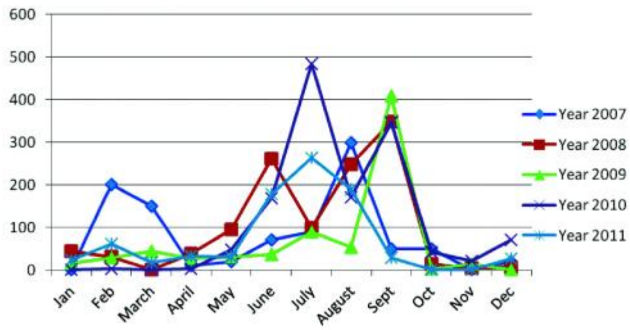

Fig. 1. Monthly rainfall (mm) in the growth years

interactions indicates consistent performance of a population over variable environment.

The genotype-environment interaction (Table 2) when tested against pooled error was found significant for diameter at breast height and volume index increments, indicating that these traits were highly influenced by the change in environments leading to existence of analysis for estimating stability parameters. While plant height increments showed non-significant genotype-environment interaction obviously indicates the presence of substantial variation in the mean increment performance (g_i) of all the 18 clones over environment (years) and in the environmental means (e_j) over test clones. On the basis of mean increments clones J799, NZ1140 and 131/25 are better for both diameter at breast height and volume index, clones 131/25, SI-63-007 and J194 for diameter at breast height only. Clone SE-63-016 recorded poor increments for all the traits studied, PN-722 for plant height and diameter at breast height and clone SE-69-002 for diameter at breast height and volume index showed poor performance in the increments of these traits. Significant interaction for percentage dry matter of Cocoa, while patch budded on different aged rootstock was earlier reported [13]. The effects of clone, site and their interaction on height and diameter

Table 3. Growth of *Salix* clones for diameter at breast height and volume index increment

S.No.	Clones	Diameter at breast height (cm) Year					Volume index (m^3) Year				
		I	II	III	IV	V	I	II	III	IV	V
1	J-799	4.9	1.55	2.44	3.42	3.43	0.01744	0.00158	0.00271	0.0039	0.00255
2	PN-731	7.11	0.79	0.98	2.16	1.68	0.02452	2.9E-05	0.00022	0.0011	0.00025
3	V-99	2.68	0.6	1.72	2.93	2.13	0.00201	7.5E-05	0.00127	0.002	0.00029
4	NZ-1179	2.8	0.34	1.98	2.55	1.73	0.00431	7.0E-06	0.00124	0.0013	0.001
5	SE-63-016	1.54	2.34	1.36	1.26	2.05	0.00105	0.00096	0.00035	0.0004	0.00091
6	NZ-1040	2.59	0.47	2.48	3.24	2.55	0.00329	7.2E-06	0.00145	0.0028	0.00061
7	*S. alba**	2.32	0.4	1.72	2.59	2.12	0.00315	5.0E-06	0.00069	0.002	0.00133
8	NZ-1002	4.92	0.23	1.77	2.74	2.6	0.0184	3.8E-06	0.00055	0.0022	0.001
9	PN-722	2.9	0.85	0.78	1.44	1.23	0.00703	0.00014	2.2E-05	0.0004	0.00015
10	NZ-1140	5.9	0.31	1.91	2.55	2.72	0.02613	2.6E-06	0.00122	0.0017	0.00234
11	SI-64-017	2.14	0.4	2.39	2.14	3.53	0.00368	3.1E-06	0.0014	0.0017	0.00189
12	131/25	5.93	0.4	3.2	3.58	3.27	0.03782	3.5E-06	0.00133	0.0039	0.00354
13	J-194	2.37	3.43	3.6	2.57	3.6	0.00552	0.00037	0.00108	0.003	0.00165
14	PN-721	2.6	1.97	1.34	3.2	1.88	0.00412	0.00041	8.9E-05	0.0031	0.00098
15	SI-63-007	3.96	1.35	3.71	3.24	2.22	0.01101	4.6E-05	0.00548	0.0031	0.00093
16	J-795	1.94	1.18	2.1	2.75	3.32	0.00255	2.1E-05	0.00163	0.0025	0.00098
17	NZ-1130	1.04	1.48	3.98	2.46	1.95	0.00052	0.00013	0.01787	0.0021	0.00058
18	SE-69-002	1.49	0.74	2.12	2.38	2.38	0.00108	0.00018	0.00078	0.0014	0.00052
	Mean (ç$_j$)	3.28	1.05	2.2	2.62	2.47	0.0118	0.00965	0.00022	0.00219	0.0021
	Environmental index (Ij)	0.96	-1.3	-0.1	0.3	0.14	0.0082	0.00657	-0.0029	-0.00089	-0.0009

*Kashmiri willow

increment were found significant in elm clones resistant to Dutch elm disease [14]. Earlier Little genotype × environment interaction was observed across sites at the parental, family, and clonal levels for height, height increment and crown width of loblolly pine [15]. Provenance x location and family within provenance x location interaction were found highly significant in *Pinus tecunumanii* in three year growth [16]. The significant genotypic, environmental and genotype environment interaction was reported in rubber clones by different authors [17-19]. Significant site x clone interactions were obtained for height and basal diameter and diameter at breast height in poplar [20, 21].

Significant environment (linear) for all characters states unit changes in environmental index for each unit change in the environmental condition. Genotype x environment (linear) interaction is significant – implying differential growth of clones in different years for increase in diameter at breast height and volume index not for plant height. The linear component of clone x year interaction was found significant in *Hevea* [22]. Pooled deviation is significant for plant height only, suggesting that different clones fluctuating from their respective path of response to different years.

The stability parameters of 18 genotypes for diameter at breast height and volume index increments have been given in the Table 4. According to Eberhart and Russell [11] a stable genotype is one which shows (i) a high mean yield (ii) a regression co-efficient equal to unity (bi=1), and (iii) a mean square deviation from regression equal to zero (S^2di). The linear regression (bi) is treated as a measure of response of a particular genotype, whereas deviation from the regression line (S^2di) is considered as a measure of stability. Accordingly, the genotypes with least or non-significant deviation are regarded as most stable and *vice-versa.*

Table 4. Stability parameters of *Salix* clones for diameter at breast height and volume index increments

S.No.	Clones	Diameter at breast height (m)				Volume Index(m^3)			
		Mean (gi)	Phenotypic index (Pi)	Regression coefficient (bi)	Deviation from regression (S^2di)	Mean (gi)	Phenotypic index (Pi)	Regression coefficient (bi)	Deviation from regression (S^2di)
1	J-799	3.15	0.824	1.47	-0.2	0.0056	0.0026	1.75	-0.000313
2	PN-731	2.55	0.222	2.46	3.32	0.0052	0.0021	2.82	-0.000311
3	V-99	2.01	-0.31	1.03	-0.2	0.0011	-0.002	0.17**	-0.000314
4	NZ-1179	1.88	-0.44	1.13	-0.27	0.0016	-0.0015	0.43**	-0.000314
5	SE-63-016	1.71	-0.61	-0.37**	-0.21	0.0007	-0.0024	0.03**	-0.000314
6	NZ-1040	2.27	-0.06	1.09	0.04	0.0016	-0.0014	0.29**	-0.000313
7	*S. alba*[@]	1.83	-0.49	0.96	-0.21	0.0014	-0.0016	0.28**	-0.000314
8	NZ-1002	2.45	0.128	2.01	-0.13	0.0044	0.0014	2.06	-0.000313
9	PN-722	1.44	-0.88	0.82	0.01	0.0015	-0.0015	0.8	-0.000314
10	NZ-1140	2.68	0.354	2.31	0.4	0.0063	0.0032	2.91	-0.00029
11	SI-64-017	2.12	-0.21	0.89	0.6	0.0017	-0.0013	0.31**	-0.000314
12	131/25	3.28	0.953	2.36	-0.2	0.0093	0.0062	4.19	-0.000307
13	J-194	3.11	0.79	-0.47**	-0.1	0.0023	-0.0008	0.5*	-0.000313
14	PN-721	2.2	-0.12	0.39	0.18	0.0017	-0.0013	0.37*	-0.000313
15	SI-63-007	2.9	0.571	1.08	0.17	0.0041	0.001	1.11	-0.000312
16	J-795	2.26	-0.07	0.52	0.27	0.0015	-0.0015	0.2**	-0.000314
17	NZ-1130	2.18	-0.14	-0.14	1.33	0.0042	0.0012	-0.28	-0.000247
18	SE-69-002	1.82	-0.5	0.47	0.09	0.0008	-0.0023	0.06**	-0.000314
	Mean	2.32				0.0031			

* = Significant different from unity at 5% level of probability; ** = Significant different from unity at 1% level of probability
[@]Kashmiri willow

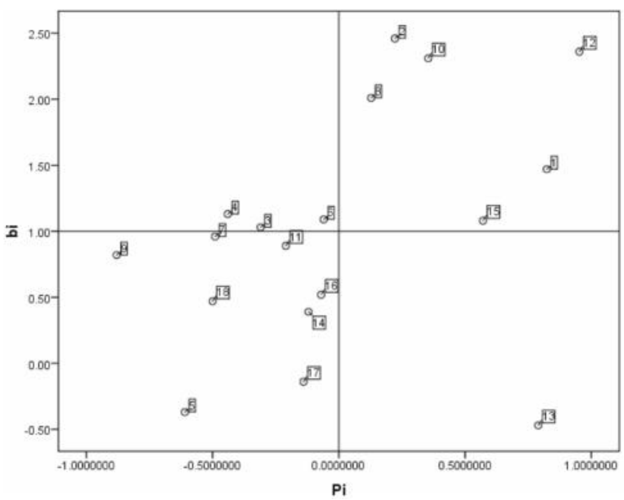

Fig. 2. Adaptive specification of diameter at breast height increments of *Salix* clones

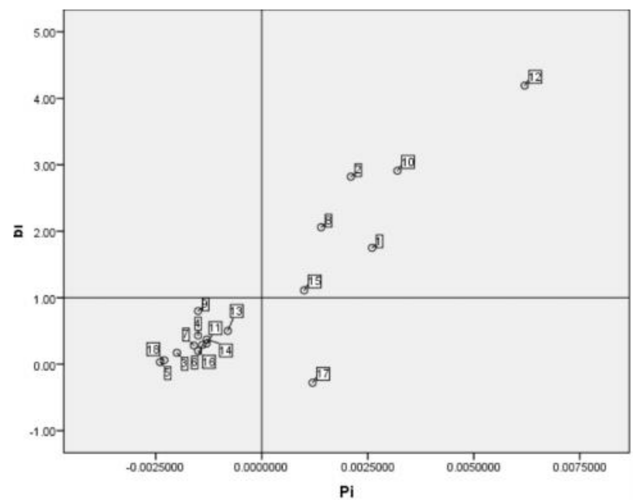

Fig. 3. Adaptive specification of diameter at volume index increments of *Salix* clones

Stability parameters were identified as a genotypic mean expressed as phenotypic index (Pi), regression value (predictable linear response) and deviation from linearity (unpredictable non-linear response) after Eberhart and Russell [11] and used by Sharma and Dabholkar [23, 24]. The stability values obtained in the present study are depicted in Figs. 2 and 3. The most stable clones having Pi>0, bi=1 and S^2di = 0. Clones J799, SI-63-007 and NZ 1002 for volume index and SI-63-007 for diameter at breast height were found most adaptive to overall environments. The clones V-99, NZ1040 and NZ1179 for diameter at breast height increment may satisfy the stability conditions but being low yielder (Pi<0) it remains questionable. Hence these clones are suitable for average environmental conditions. Clones J194 had Pi >0 with low deviation from linearity (S^2di) but regression coefficient less than unity for diameter at breast height, therefore suitable for poor environmental conditions and least sensitive to environmental conditions. In favourable environment the performance of such clones may fail to respond even moderately. Clones PN 731 for diameter at breast height and clones NZ1140 and 131/25 for volume index showed the regression coefficient >1 and Pi >0 with high deviation from linearity (S^2di). Hence these clones are suitable for rich environmental conditions with respect to these traits. Under the poor environments may not perform better.

Regression coefficient and deviation from regression parameters were also used by for assessing temporal stability for girth [17, 25] and tree dryness [18] in *Hevea brasiliensis* (rubber). Regression coefficient was measure of "response" or "environmental sensitivity" of a genotype rather than as a direct measure of stability in 17 years old Norway spruce [26]. Stability parameters including Ebarhart and Russells model for 12-year volume were investigated in seven *Populus davidiana* (Korean aspen) clonal trials in South Korea, where, a number of poplar clones were selected based on stability analysis [27]. Based on the size of regression coefficients and regression analysis, poplar clones was divided in terms of phenotypic stability and productivity, into three groups: a) phenotypically stable clones of medium productivity and a tendency to adapt to all environments; b) moderately stable clones, of moderate productivity which manifest a tendency to adapt to all environments and c) phenotypically very instable clones of high production capacity, with specific adaptation to optimal sites [28]. Stability of aspen hybrid clones in growth was assessed by plotting regression coefficient and deviation mean square against the clonal means [20]. Earlier, five stability parameters *viz*., environmental variance, Shukla's stability variance, regression of latex yield of clones on environmental index, variance due to regression and variance due to deviation from regression applied in latex [22] supports the author's finding among willow cones Since, clonal stability is genetic in nature the stable clones should be preferred for further studies on these traits.

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