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Line × tester analysis for growth and biomass characteristics of *Populus deltoides* Bartr.

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Abstract
Line × tester analysis was carried out in *Populus deltioides* to determine the genetic interaction in the expression of various quantitative characters related to productivity. Combining ability revealed that the estimates of SCA variance (σ^2SCA) were more than the GCA variance (σ^2GCA) for all the characters studied. Later the gene action study revealed that dominance variance was observed more than the additive variance for all the parameters studied. The proportional contribution of testers were higher than individual contribution of lines or line × tester interaction except for plant height, collar diameter, number of leaves/plant, root length and fresh root weight where the contribution of interactions was more. The Line L-62/84 and tester L-17/92 was found to be good general combiners and thus appeared to be worthy of exploiting in *Populus deltioides* improvement through breeding and recurrent selection followed by cloning for developing commercial superior clones. On the basis of mean performance and significant desirable SCA effects, the combinations L-62/84 X S_7C_1 was found to be the most promising family for growth and biomass characters and is recommended for within family selection followed by heterotic breeding.

Keywords: Line, tester, combining ability, gene action, *Populus deltioides*

Introduction
Poplars belong to the genus *Populus*, which is one of the oldest contemporary genera, belongs to family Salicaceae, with total of 35 identified species (FAO, 1979; Dickman and Stuart, 1984 and Khosla and Khurana, 1982) [9, 8, 11] occurs throughout the forests of temperate and cold regions of Northern hemisphere Silberhorn (1996) [18]. The genus *Populus* includes morphologically diverse species which are deciduous, relatively short-lived, and fast-growing tree Slavov and Zhelev (2010) [19]. In family Salicaceae only two major species are employed widely in plantation, both within and outside their natural ranges are *Populus deltoides* and *Populus nigra* Silberhorn (1996) [18]. *Populus deltoides* clones were introduced in India in 1952 to increase the availability of raw material for plywood industries in the country Rizvi *et al.* (2008) [15].
Populus deltoides is one of the most popular tree species in the agroforestry system in irrigated plains of Western Uttar Pradesh, Uttarakhand, Punjab and Haryana. Its wood is in demand for pulp and paper, plywood, matchwood, packing cases and light constructional timber all over the world Rizvi *et al.* (2008) [15]. These attributes make *Populus deltoides* ideally suitable for supporting rural livelihoods and contributing to sustainable development particularly in developing countries and countries with economies in transition.
Selecting parents on the basis of performance, adaption and genetic variability does not lead necessarily to useful results. This is because of the differential ability of the parents, which depends upon the complex interactions among the genes and cannot be judged by the performance alone Allard (1960) [1]. The parents, which perform well in the cross combinations are of great importance in the breeding program. The information about combining ability and relative magnitude of genetic variance with respect to traits of economic importance is essential for exploitation of the existing gene action in the population. Line × Tester analysis is, therefore, of great value to plant breeders as an attempt to select parents to be used in hybrid production and also for those whose primary objective is to transfer specific character as it assists them in identifying desirable parents for producing potential segregating populations for selection.

Materials and Methods
The flowering branches from four females (G-48, S_1, S_7C_8, and L-62/84) and four males (S_7C_{11}, L-124/86, L-17/92 and S_7C_1) trees of different clones were obtained from State Forest

Department, Haldwani and Shyampur, Haridwar Forest Division in month of January 2013 and February 2013, respectively. These materials were utilized for the different studies and crosses among male and female were made in 2013 in the germplasm block of Naganji nursery, Department of Tree Improvement and Genetic Resources, College of Forestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni- Solan, (H.P.). The study site is located at an elevation of 1200 m above mean sea level in north-west of Himalaya and lies between 30˚ 51' N latitude and 76˚ 11' E longitude. These clones were screened repeatedly in the nursery followed by field testing. The selected superior clones (Table 1) were involved in control crossing using Line×Tester (4×4 factorial) with 8 parents in 2013-2014. The seedlings were raised and the clonal cuttings of five outperforming individuals per parents were raised in RBD (Randomized Block Design) and were evaluated for growth and biomass characters in 2014-2015. Observations were recorded for plant height (cm), collar diameter (mm), intermodal length (cm), number of leaves per plant, leaf area (cm^2), root length (cm), fresh shoot weight (g), fresh root weight (g), dry shoot weight (g), dry root weight (g), total fresh weight (g) and total dry weight (g). The mean values of five clones per replication for F_1 generations of 12 crosses along with 8 parents for each trait were subjected to statistical analysis using the model suggested by Singh and Chaudhary (2001) [22]. For experimental design, sixteen F_1 hybrids were needed for Line × Tester (4×4 factorial) mating design using 4 males and 4 females out of 11 male and 13 female selected initially but only twelve F_1 hybrids survived. An attempt has been made to understand the genetic system controlling inheritance of yield, its components and the combining ability analysis from a Line × Tester mating design.

Results and Discussion

Highly significant variances were observed among parents and crosses for all the observed traits demonstrating the presence of wider genetic difference among the parents and crosses (Table 2 to 5). Variations with respect to hybrid *Populus deltoides* performance have earlier been reported (Dhir and Mohn, 1976 [7], Ceulemans *et al*., 1992 [5], Wu and Stettler, 1997 [26], Singh, 2002 [20], Ozel *et al.*, 2010 [14], Vaario *et al*., 2011 [24] and Singh *et al*., 2013 [21]).

Mean values listed in table 2 and 3 revealed that the overall performance of following hybrids: S_1 X L-17/92 for plant height (261.21 cm), collar diameter (16.97mm), number of leaves per plant (45.55), root length (39.50cm), total fresh weight (512.85g), total dry weight (300.21g); S_1 X $S_7C_{11,}$ for plant height (266.12cm), collar diameter (17.45mm), number of leaves per plant (50.41), root length (42.39cm), shoot fresh weight (323.89g), root fresh weight (138.30g), total fresh weight (462.19g), total dry weight (299.00g); L-62/84 X S_7C_1 for plant height (286.03cm), collar diameter (18.52mm), number of leaves per plant (41.17), root length (41.06cm), shoot fresh weight (324.99g), shoot dry weight (216.84g), root fresh weight (161.64g), total fresh weight (486.64g), total dry weight (305.57g); S_1XL-124/86 for plant height (228.25cm), collar diameter (15.14mm), number of leaves per plant (36.63), root length (42.23cm), shoot dry weight (151.20g), root fresh weight (145.84g), total fresh weight (381.15g), total dry weight (236.56g) and G-48 X S_7C_{11} for plant height (210.45cm), collar diameter (14.55mm), number of leaves per plant (41.66), root length (40.08cm), shoot fresh weight (181.03g), total fresh weight (264.05g), total dry weight (189.61g) were found outstanding for most of the growth and biomass traits. For number intermodal length G-48XL-17/92 (4.58) performance was promising with maximum mean values as desired for the clean bole production.

In quantitative genetics, genotypic value of an individual is determined by various types of gene actions such as additive, dominance and their interactions. Additive and dominance genetic variances are important to breeders, suggesting how far a particular trait is amenable to selection in segregating generations or is useful for hybrid development. The estimates of specific combining ability variance (σ2 SCA) were more than the general combining ability variance (σ2 GCA) for all the character studied (Table 4). Similarly, the dominance variance was observed more than the additive variance for all the parameters. Li and Wu (1997) [13] during joint analysis of combining ability and genetic components revealed that heterosis in F_1 was due to the over dominance interaction between two alleles, one from *P. tremuloides* and other from *P. tremula* at the same loci. Similarly Bailian *et al.* (1998) [2] reported that broad sense heritabilities were found to be 2-6 times higher than narrow sense heritabilities for growth and shoot components indicating the important role of dominance or over dominance in aspen growth.

The proportional contribution of lines ranged from 6.63% (dry shoot weight) to 50.85% (fresh root weight) whereas for testers it ranged from 13.75% (fresh root weight) to 56.71% (total dry weight) (Table 4 and 5). However, the proportional contribution of line × tester interaction ranged from 26.76% (fresh shoot weight) to 56.15% (plant height) indicating the importance of combination of specific parents. The proportional contribution of testers was higher than individual contribution of lines or line×tester interaction except for plant height, collar diameter, number of leaves/plant, root length and fresh root weight where interactions contribution was more.

GCA and SCA effects

Line L-62/84 exhibited the highest positive GCA effects (Table 6 and 7) for most of the traits and proved to be the best combiner for most of the growth and biomass traits. Among the testers L-17/92 expressed highest GCA effects and excelled the characters associated with leaf area, fresh shoot weight, dry shoot weight, total fresh weight and total dry weight. Different parents expressing high magnitude of GCA with respect to growth, physiological and wood traits have been reported by different workers on poplar (Stettler *et al.* 1996; Kadam 2002, Cameron *et al.* 2008 and Vijayan *et al.* 2008) [23, 10, 4, 25], willows Chaudhary (2011) [6] and other tree species (Saresh, 2013 and Zhao *et al.* 2014) [17, 27]. Our results are also in agreement with Sachsre and Mohrdick (1980) [16] whom reported variable wood properties in black poplar clones. Thus, for recurrent selection based on GCA effects, parents L-62/84 and L-17/92 appears more appropriate in crossing programme directed towards clonal improvement in *Populus deltoides*.

The specific combining ability effect (Table 8 and 9) clearly revealed that it would not be possible to isolate crosses where all attributes are in the most desirable combinations. Significant positive SCA effects were observed for G-48 X L-17/92 (Leaf area); S_7C_8 X S_7C_{11} (Leaf area); L-62/84 X S_7C_1 (root length, fresh root weight, dry root weight and total fresh weight) and G-48 X L-124/86 (dry root weight).

On the basis of mean performance and overall significant desirable SCA effects L-62/84 X $S_7C_1$was found to be the best cross combination. Thus, majority of the cross combinations

exhibiting desirable SCA effects, had at least one of the parents as good or average combiner. Majority of the cross combinations exhibiting desirable SCA effects had at least one of the parents as good or average combiner. However, it is not necessary that parents having higher estimating of general combining ability effects would always give higher estimated of specific combining ability effects. Usually the highest estimated of specific combining ability effects were obtained from crosses involving diverse parents. Sometimes specific interaction effects, most likely complementary of poor x poor cross indicated that a high magnitude of non-additive component was responsible for confirming the highest rank to the pertinent cross combination. However, the present cause is strongly supported by the findings of Bisoffi (1993) [3], Li and Wu (1996) [12], Kadam (2002) [10], Choudhary (2011) [6] and Saresh (2013) [17].

Conclusion

On the basis of Line × Tester analysis it is hereby concluded, that Line L-62/84 and tester L-17/92 were found to be good general combiners and thus appeared to be worthy of exploiting in *Populus deltoides* improvement through breeding and recurrent selection followed by cloning for developing commercial superior clones. On the basis of mean performance of hybrid clones and significant desirable SCA effects L-62/84 X S_7C_1 was found to be the most promising families for growth and biomass characters and are recommended for within family selections followed by heterotic breeding.

Table 1: List of clones involved in control crossing

S. No	Clones	Sex	Source country/Originally developed
1.	G-48	Female	Australia
2.	S_1	Female	India (Shyampur, Haridwar Forest Division)
3.	S_7C_8	Female	USA
4.	L-62/84	Female	India (Lalkuan Selection)
5.	S_7C_{11}	Male	USA
6.	L-124/86	Male	India (Lalkuan Selection)
7.	L-17/92	Male	India (Lalkuan Selection)
8.	S_7C_1	Male	USA

Table 2: Mean table for morphological traits in *Populus deltoides*

S. No	Crosses	Plant height (cm)	Collar diameter (mm)	Internodal length (cm)	Number of leaves/plant	Leaf area (cm^2)	Root length (cm)
1	G-48 X S_7C_{11}	210.45	14.55	3.42	41.66	109.11	40.08
2	G-48 X L-124/86	272.52	18.58	4.12	47.00	122.33	39.49
3	G-48 X L-17/92	316.11	21.22	4.58	41.44	199.80	36.20
4	G-48 X S_7C_1	265.98	17.36	4.07	48.65	128.93	33.59
5	S_1 X S_7C_{11}	266.12	17.45	4.05	50.41	119.40	42.39
6	S_1 X L-124/86	228.25	15.14	3.79	36.63	187.89	42.23
7	S_1 X L-17/92	261.21	16.97	4.11	45.55	231.50	39.50
8	S_7C_8X S_7C_{11}	241.56	15.29	3.71	39.78	137.71	39.45
9	S_7C_8 X L-17/92	222.77	16.07	3.75	40.55	146.35	34.45
10	L-62/84 X L-124/86	217.23	13.68	4.47	29.66	176.04	31.13
11	L-62/84 X L-17/92	280.00	18.32	4.43	35.58	159.35	34.25
12	L-62/84 X S_7C_1	286.03	18.52	4.01	41.17	211.99	41.06
	Mean	255.69	16.93	4.05	41.51	160.87	37.82
Controls							
1	G-48	224.62	15.32	4.11	33.11	195.91	36.50
2	6P	195.18	14.01	4.20	27.83	98.65	31.79
	Mean	209.90	14.67	4.16	30.47	147.28	34.15
	CD control v/s crosses	29.61	1.89	NS	5.81	NS	2.40
	CD between crosses	54.83	3.51	0.56	10.77	44.22	3.63
	CD between control	NS	NS	NS	NS	44.22	3.63

Table 3: Mean table for morphological traits in *Populus deltoides*

S. No	Crosses	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Total fresh weight (g)	Total dry weight (g)
1	G-48 X S_7C_{11}	181.03	148.85	95.96	59.15	264.05	189.61
2	G-48 X L-124/86	213.94	171.25	112.04	63.67	311.85	207.92
3	G-48 X L-17/92	326.75	237.51	117.50	77.87	444.25	308.86
4	G-48 X S_7C_1	234.03	191.45	99.49	58.54	335.35	251.16
5	S_1X S_7C_{11}	323.89	226.75	138.30	78.92	462.19	299.00
6	S_1X L-124/86	235.31	151.20	145.84	71.741	381.15	236.56
7	S_1X L-17/92	338.12	198.10	174.73	102.10	512.85	300.21
8	S_7C_8X S_7C_{11}	287.51	202.88	115.97	67.83	403.49	272.21
9	S_7C_8 X L-17/92	308.38	208.50	119.83	77.03	395.75	290.90
10	L-62/84 X L-124/86	154.16	130.39	88.92	47.52	239.84	148.89
11	L-62/84 X L-17/92	291.92	194.64	133.50	78.31	425.43	272.25
12	L-62/84 X S_7C_1	324.99	216.84	161.64	93.43	486.64	305.57
	Mean	268.34	189.87	125.31	73.01	388.57	256.93
Controls							
1	G-48	221.69	150.07	105.90	53.21	321.61	213.64
2	6P	122.63	107.50	75.17	61.75	170.98	167.50
	Mean	172.16	128.79	90.53	57.48	246.29	190.57
	CD control v/s crosses	56.20	34.51	15.59	9.68	67.19	43.84
	CD between crosses	84.96	52.17	23.57	14.63	101.59	66.29
	CD between control	NS	NS	23.57	NS	101.59	NS

Table 4: Estimation of variance components for morphological characters in *Populus deltoides*

S. No	Variance components	Plant height (cm)	Collar diameter (mm)	Internodal length (cm)	No. of leaves/plant	Leaf area (cm^2)	Root length (cm)
1	Variances of GCA (δ^2g)	-18.38	-0.04	0.002	0.80	32.30	0.14
2	Variances of SCA (δ^2s)	662.60	2.96	0.07	21.00	1388.41	11.64
3	Additive variance (D)	-73.55	-0.19	0.009	3.23	129.21	0.56
4	Dominance variance (H)	2650.42	11.86	0.31	84.00	5553.64	46.57
5	Contribution of lines	14.98	15.63	32.09	46.05	27.61	36.94
6	Contribution of testers	28.86	32.38	33.95	22.44	38.85	23.63
7	Interactions (Line x Tester)	56.15	51.97	33.94	31.50	33.53	39.41

Table 5: Estimation of variance components for morphological characters in *Populus deltoides*

S. No	Variance components	Fresh shoot weight (g)	Dry shoot weight (g)	Fresh root weight (g)	Dry root weight (g)	Total fresh weight (g)	Total dry weight (g)
1	Variances of GCA (δ^2g)	122.75	12.02	11.73	3.74	150.01	78.46
2	Variances of SCA (δ^2s)	2656.51	613.31	597.42	193.17	5623.41	1910.00
3	Additive variance (D)	491.02	48.08	46.93	14.97	600.04	313.84
4	Dominance variance (H)	10626.04	2453.27	2389.68	772.70	22493.66	7640.01
5	Contribution of lines	19.62	6.63	50.85	25.61	27.29	15.30
6	Contribution of testers	53.61	54.45	13.75	38.59	39.27	56.71
7	Interactions (Line x Tester)	26.76	38.91	35.38	35.78	33.42	27.97

Table 6: General combining ability effects of different parents for morphological characters in *Populus deltoides*

Parents	General combining ability effects					
Females	**Plant height (cm)**	**Collar diameter (mm)**	**Internodal length (cm)**	**No. of leaves/plant**	**Leaf area (cm^2)**	**Root length (cm)**
G-48	10.57	0.99	0.006	3.18	-20.82*	-0.47
S_1	-3.82	-0.41	-0.05	2.68	18.73*	2.36*
S_7C_8	-23.52*	-1.24*	-0.31*	-1.34	-18.83*	-0.57
L-62/84	5.40	-0.08	0.26*	-6.03*	21.59*	-1.55*
Males						
S_7C_{11}	-16.30	-1.16	-0.31*	2.44	-38.79*	2.82*
L-124/86	-16.35	-1.12	0.08	-3.74	1.22	-0.20
L-17/92	14.33	1.21	0.17	-0.72	23.38*	-1.71*
S_7C_1	20.32*	1.00	-0.001	3.40	9.59	-0.49
SE	9.43	0.60	0.09	1.85	7.60	0.62
CD	26.87	1.71	0.25	5.27	21.66	1.76

*Significant at 5% level of significance

Table 7: General combining ability effects of different parents for morphological characters in *Populus deltoides*

Parents	General combining ability effects					
Females	**Fresh shoot weight (g)**	**Dry shoot weight(g)**	**Fresh root weight (g)**	**Dry root weight (g)**	**Total fresh weight (g)**	**Total dry weight (g)**
G-48	-29.39	-2.59	-19.06*	-8.20*	-49.69*	-17.53
S_1	20.51	1.43	18.43*	7.49*	42.32*	14.44
S_7C_8	19.74	10.55	-4.94	-0.38	7.36	16.41
L-62/84	-7.54	-6.16	1.80	0.05	-3.06	-9.79
Males						
S_7C_{11}	-4.19	2.96	-8.56*	-4.37	-11.99	-3.32
L-124/86	-67.20*	-38.91*	-9.70*	10.81*	-77.61*	-59.13*
L-17/92	47.95*	19.82*	11.07*	-12.03*	55.99*	36.12*
S_7C_1	11.17	14.28	5.20	2.97	22.42	21.43
SE	14.61	8.97	4.05	2.51	17.47	11.40
CD	41.63	25.56	11.54	0.05	49.78	32.49

*Significant at 5 per cent level of significance

Table 8: Specific combining ability effects among different crosses for morphological characters in *Populus deltoides*

S. No	Specific combining ability effects						
	Crosses	**Plant height (cm)**	**Collar diameter (mm)**	**Internodal length (cm)**	**Number of leaves/plant**	**Leaf area (cm^2)**	**Root length (cm)**
1	G-48 X S_7C_{11}	-39.50*	-2.21	-0.31	-5.46	7.86	-0.08
2	G-48 X L-124/86	22.60	1.78	-0.01	6.05	-18.93	2.34
3	G-48 X L-17/92	35.50	2.07	0.36	-2.51	36.37*	0.58
4	G-48 X S_7C_1	-20.60	-1.57	0.02	0.55	-20.70	-2.17
5	S_1 X S_7C_{11}	30.57	2.09	0.38	3.77	-21.40	-1.80
6	S_1XL-124/86	-7.25	-0.25	-0.27	-3.82	7.07	1.05
7	S_1X L-17/92	-4.98	-0.76	-0.04	2.07	28.52	-0.15
8	S_7C_8 X S_7C_{11}	25.70	0.77	0.29	-2.82	34.47*	-0.32

9	S_7C_8 X L-17/92	-23.72	-0.82	-0.15	1.11	-19.06	-0.77
10	L-62/84 X L-124/86	-27.50	-2.02	0.08	-2.06	-7.63	-4.14*****
11	L-62/84 X L-17/92	4.57	0.26	-0.04	0.83	-46.49*****	0.48
12	L-62/84 X S_7C_1	4.62	0.66	-0.29	2.29	19.93	6.07*****
	SE	18.86	1.20	0.19	3.70	15.21	1.25
	CD	38.77	2.45	0.40	7.61	31.26	2.57

*Significant at 5 per cent level of significance

Table 9: Specific combining ability effects among different crosses for morphological characters in *Populus deltoides*

Specific combining ability effects							
S. No	**Crosses**	**Fresh shoot weight (g)**	**Dry shoot weight (g)**	**Fresh root weight (g)**	**Dry root weight (g)**	**Total fresh weight (g)**	**Total dry weigh (g)**
1	G-48 X S_7C_{11}	-53.71	-41.38*****	-1.71	-1.28	-62.83	-46.45
2	G-48 X L-124/86	42.20	22.89	15.50	10.89*****	50.59	27.67
3	G-48 X L-17/92	39.85	30.42	0.17	2.24	49.37	33.34
4	G-48 X S_7C_1	-10.72	-6.72	-8.00	-6.16	-17.29	-6.44
5	S_1 X S_7C_{11}	28.97	31.76	-6.09	-0.95	22.12	23.73
6	S_1XL-124/86	3.40	-1.90	2.59	-0.48	6.70	17.10
7	S_1X L-17/92	-8.94	-13.73	10.69	7.03	4.78	-14.50
8	S_7C_8 X S_7C_{11}	-6.24	-5.76	6.63	-0.22	15.86	-6.01
9	S_7C_8 X L-17/92	-37.52	-17.01	-9.14	-6.22	-59.86	-26.78
10	L-62/84 X L-124/86	-35.66	-11.31	-29.39*	-13.53*****	-66.50	-34.21
11	L-62/84 X L-17/92	-13.05	-5.80	-5.59	-5.59	-14.53	-6.11
12	L-62/84 X S_7C_1	56.79	21.93	28.36*****	17.36*****	80.24*	41.89
	SE	29.22	17.94	8.11	5.03	34.94	22.80
	CD	60.88	36.89	16.67	10.34	71.83	46.87

*Significant at 5 per cent level of significance

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