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Genetic analysis of poplar (*Populus deltoides* Bartr.) clones for early generation selection

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Abstract

The study aimed to select the best clones from a field trial of 69 newly developed clones and two check clones of *Populus deltoides* after 3 years of field performances. Growth traits were assessed for three growing seasons. Significant differences were detected among clones for plant height, stem diameter, estimated trunk volume and sylleptic branch number. Plant height, stem diameter and trunk volume had low to moderate (0.21 to 0.41) broad sense heritability (h^2) values. Sylleptic branch number showed high genetic advance (77.53%) despite moderate h^2. In nursery trial, the h^2 estimates were moderate to high h^2 (0.61 to 0.69) for growth traits. It is possible to apply selection on the basis of principal component analysis (PCA) accounting for a large part of the total variance in the observed growth relying on trunk volume followed by stem diameter, plant height and sylleptic branch number. The promising clones *viz*. FRI-AM-53, -70, -51, -6 and -45 outperformed the control clone G-48. Stem diameter showed high (0.97) genetic correlation with trunk volume and proved to be a reliable criterion for selecting for trunk volume. The set of 25 most promising clones based on PCA1 ranking will be effective for selection of clones at the age of three years.

Key words: *Populus deltoides,* genetic variability, early selection, heritability, age-age correlation, principal component analysis

Introduction

The genus *Populus* belongs to the family *Salicaceae* and is characterized by dioecious nature. It is widely distributed over the northern hemisphere and is planted in many parts of the world. *Populus deltoides* has become an important exotic species in many plantation programmes in North-West India as it propagates easily, grows fast and provides high economic returns. It is widely grown in the areas lying in the Indo-Gangetic plains north of 28°N latitude. Poplars have been extensively studied in short rotation woody biomass production systems as they produce wood for multiple uses such as plywood, pulp, matchwood, veneer, light furniture, packing cases, pencils, sport goods and environmental benefits [1]. Straight stem, thin crown, deciduous nature and short rotation are some of the good characteristics that make them suitable for agroforestry models. The productivity of a managed poplar plantation under Punjab conditions has been estimated to be 46.92 m^3/ha/yr [2]. The entire poplar culture, either in agroforestry or monoblock plantations, is dependent on a very limited genetic base which exposes it to damage by various pests [3]. Approximately 90% of poplars being planted are *P. deltoides* clones G-48, G-3 and S_7C_{15} [4, 5]. The efforts for selecting new clones and their field testing must continue under long-term genetic improvement plan [4]. Information on genetic variation and its exploitation is essential in improvement of a tree species. The magnitude of genetic gain through clonal selection depends on variation and inheritance of desired traits. Proper clonal selection practices must be utilized given the genetic variability within the genus *Populus* [6]. Due to long gestation period of forest tree crops and the extended period of maturity, breeders are constantly searching for ways to reduce the number of years required for a generation of selection so as to increase the genetic gain per unit time. One approach

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in this direction is to identify the juvenile traits that would be strongly associated with superior adult performance. The genetic potential of a generic individual is determined by the genes that reside in chromosomes. The phenotype of the individual can be visualized and measured in the field. It is influenced by the genetic makeup of the tree and conditioned by the environment in which the tree is growing. The clonal selection is a stepwise process of evaluation and it starts with a large number of genetically different progenies and ends up with a few clones with commercial utility and viability [7]. In this context, the aims of the study were: (i) estimation of genetic parameters for growth traits under field conditions, and (ii) early selection of promising set of clones. These results would serve to make early selection of manageable set of clones among a large numbers of clones.

Materials and methods

The seed of *P. deltoides* was collected from 100 plus trees (or superior individual trees) covering ten states of USA during 1997. The open-pollinated progenies were raised in a polyhouse followed by nursery testing and cloning of superior individuals at FRI, Dehradun during 1997-1999. The clonal material was subjected to repeated nursery testing during 1999-2001.

In March 2002, 69 best clones from 10 provenances with 2 check clones (Table 1) were planted on an experimental field site under agroforestry model in district Hoshiarpur (Punjab), India at 31^{o} 95'N latitude, 75^{o} 63'E longitude and 260 m altitude. The clonal trial was laid out in a randomized block design with three replications and 2 plants of each clone per replication were planted at a spacing of 5m x 4m along with two border rows. Before undertaking field trial, the same set of clones with one check clone was planted in nursery in February 2001, following similar experimental design with three replication at one site in Brandis Road Nursery, Forest Research Institute, Dehradun, India at 30^{o}20'N latitude, 77^{o}52'E longitude and 640 m altitude.

The nursery experimental plot was integrated with uniform cuttings of 22 cm length (20 cuttings/ replication/clone) at a spacing of 80 cm x 60 cm along with two border rows. After year one, the alternate rows of entire transplants were uprooted for field trial plantation.

Data collection

The data were recorded for each plant at ages 1 (2002), 2 (2003) and 3 (2004) years in field and only third year data for nursery trial (2003) was incorporated in the present study. The following traits were observed for field: first year plant height (HT1) in metre, stem diameter at breast height (DBH1) in centimeter, and D^2H-estimated trunk volume (D^2H1) in cubic metre as a derived variable that gives a good estimate of stem

Table 1. Source of clonal material and parental origins

No. of families	No. of clones	Clone name (suffix for FRI-AM-)	Location in the USA	County
1	5	4, 66-69	Tombigbee River, Columbus, Mississippi	Lowndes
2	8	6, 7, 9, 10, 77, 78, 81, 82,	Tombigbee River, Fulton, Mississippi	Itawamba
2	20	12-15, 17-19, 21-23, 27, 30-34, 87, 89, 105, 115	Roanoke River, Rich Square, North Carolina	Northampton
2	3	35, 37,95	Ashley/Edisto River, Summerville, South Carolina	Dorchester
1	11	40, 41, 44-46, 48-53	Saluda River, Silverstreet, South Carolina	Newberry
1	5	57-60, 64	Tombigbee River, Tupelo, Mississippi	Lee
1	6	70-74, 76	Tombigbee River, McIntosh, Alabama	Washington
3	6	91-93, 96, 109, 110	Tennessee River, Paris, Tennessee	Benton
1	4	97, 98, 100, 101	Clinch/Tenn. River, Oak Ridge, Tennessee	Roane
1	1	111	Apalachicola River, Quincy, Florida	Gadsen
2	2		C_1 (G-48), C_2 (UDH-47-7) [check clones]	
15 families	71 clones		10 locations	10 provenances

volume [4]. Similarly data for second and third year height (HT2, HT3), diameter (DBH2, DBH3) and trunk volume (D^2H2, D^2H3) respectively were recorded. Sylleptic branch number (SYLL2) was recorded during second year. Nursery characters for the third year namely plant height (nHt3) in metre, diameter at breast height (nDbh3) in millimetre and estimated trunk volume (nD^2h3) in cubic metre were also used for comparison.

Data analysis

Analysis of variance were conducted to detect difference among test clones of 15 families and Pearson's correlation coefficients were estimated between data of age 1, 2 and 3 years for plant height, stem diameter and trunk volume [8]. Genetic variance components, broad-sense heritabilities (h^2) and standard error (S.E.) for each character were obtained [9]. The genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) [10], expected genetic advance (GA) at 5 percent selection intensity and genetic gain (GG) [11], were computed. Genotypic and phenotypic correlation coefficients were worked out using variance and covariance components [12]. Principal component analysis (PCA) was carried with the statistical software S-Plus 2000 Professional [13]. The mean observations of traits of each region were standardized prior to analysis to avoid the effect due to difference in scale [14]. Based on the eigen values of the 'scree plot' in PCA, the first principal component (PCA1) was retained to focus on the most important variable in component.

Results and discussion

Significant differences were found among the clones for morphological growth traits (12 months after planting) *viz.,* plant height, stem diameter, number of sylleptic branches and estimated trunk volume pertaining to 71 clones (Table 2). The perusal of data revealed significant differences at age one, two and three for variance components, heritability estimates and genetic advance for the traits investigated. The extent of variability measured by GCV and PCV indicated lower magnitude GCV than PCV in all traits showing that the characteristics were more influenced by environmental factors than by genetic effects. Similar findings were reported in *Eucalyptus camaldulensis* [15] and *P. deltoides* [16].

Heritability estimates for plant height increased from 0.23 (year one) to 0.41 (year three) in field trial and were quite high (0.69) in nursery trial in year 3. Generally, heritability estimates for height increase with age in *P. deltoides* [17] and *Eucalyptus globulus* [18]. Heritability estimates in *Picea glauca* are generally high in nursery and drop in the field tests [19]. On basis of studies on *Pinus ponderosa* and *Picea glauca,* it has been opined that transplanting to field would be expected to result in an initial drop, heritability estimate would be expected to increase during early years of

Table 2. Mean, range, estimated genetic variance and genetic advance for field performance

Parameters/ variances	HT1	DBH1	D^2H1	HT2	DBH2	D^2H2	SYLL2	HT3	DBH3	D^2H3
Mean ± s.e.	5.14 ± 0.46	4.72 ± 0.54	0.012 ±0.004	8.96 ± 0.69	11.06 ± 1.06	0.114 ±0.027	2.92 ± 1.57	13.24 ± 0.55	14.08 ± 1.26	0.268 ±0.051
Range	4.29-6.46	3.29-6.15	0.005-0.025	6.68-10.83	7.32-14.16	0.036-0.199	0.50-8.07	11.85-14.53	11.98-16.68	0.171-0.378
F-cal	1.90**	2.84**	2.50**	2.27**	2.77**	2.52**	3.28**	3.11**	1.81**	2.14**
C.D. (5%)	0.91	1.06	0.0074	1.36	2.10	0.0542	3.10	1.90	2.49	0.100
C.V. (%)	10.94	13.95	37.46	9.43	11.76	29.38	78.74	5.09	10.97	23.14
G.C.V. (%)	6.02	10.94	26.55	6.14	9.05	20.91	68.64	4.27	5.73	14.28
P.C.V. (%)	12.49	17.73	45.91	11.26	14.84	36.06	104.46	6.64	12.38	27.19
h^2 ± s.e.	0.23 ±0.078	0.38 ±0.075	0.33 ±0.077	0.30 ±0.077	0.37 ±0.076	0.34 ±0.077	0.43 ±0.073	0.41 ±0.074	0.21 ±0.077	0.28 ±0.078
G.A.	0.31	0.66	0.0039	0.62	1.26	0.0285	2.26	0.75	0.77	0.0413
G.G. (%)	5.98	13.90	31.64	6.90	11.37	24.98	77.53	5.65	5.46	15.45

** - significant at $p < 0.01$, * - significant at $p < 0.05$; HT, DBH, D^2H and SYLL indicate plant height, stem diameter, trunk volume and number of sylleptic branches in field trial. Suffixes 1, 2 and 3 denote the age (in years) of measurement the test [20, 21]. In a field trial, heritability estimates of *Pinus taeda* for height increased from 0.03 to 0.29 between age 1 and 15 years [22]. Heritability estimates for stem diameter varied from 0.21 (DBH3) to 0.38 (DBH1) in field trial (Table 2) as against high heritability (0.63) exhibited in nursery in third year (Table 3). Heritability estimates for plant height were higher than those for stem diameter in both nursery and field locations. In *P. deltoides* clones, higher heritabilities for plant height (0.66) have earlier been found as compared to tree diameter (0.58) [23] and similar trend was reported in three-year-old *Albizia lebbek* [24], *Pinus taeda* [25] and *Pinus griffithii* [26]. Taking heritability range of 0-0.33, 0.34-0.66 and 0.67-1 as low, moderate and high respectively, the plant height and stem diameter in field trial showed low to moderate heritability values with satisfactory genetic advance. Heritability of height was remarkably consistent during the three years study period.

Genetic advance is of practical interest, it is determined by the magnitude of genetic variability and extent of inheritance of quantitative traits. Genetic advance provides needful information for formulating suitable selection procedure and could be a reliable basis for use in further improvement programme. High heritability coupled with high genetic advance for number of sylleptic branches indicated that this character was controlled by additive gene action and good response is expected through selection [27]. Broad-sense heritability values for height in trembling aspen have been reported as 0.52 [28] and 0.69 [29], and for diameter these values ranged from 0.14 [28] to 0.45 [29]. The heritability estimates for estimated trunk volume ranged from 0.28 to 0.34 for the three-year field trial and 0.61 for nursery in year 3. The D^2H-estimated trunk volume is an approximation for stem volume, an important tree character of commercial importance, and allows focusing on this relationship for a potential trait to mark the outstanding clones [30]. These results are in accordance with many other studies on forest species like *P. deltoides* [31, 32], *Pinus radiata* [33] and *Populus* species [34, 35].

High estimate of heritability was observed for number of sylleptic branches (0.43) with high degree of genetic advance. Genetic control of syllepsis is environmentally sensitive, with the involvement of several genes affecting syllepsis; under favourable climatic conditions (such as more sunlight and warmer weather), and well-irrigated cultural conditions plants produce more sylleptic branches. Under unfavourable environment (lower light, cooler and un-irrigated conditions) few or no sylleptic branches are produced [36, 37]. Broad-sense heritability for sylleptic branch number in *Populus* in an earlier study was found to be 0.47 and 0.50 in two different environments [37]. Syllepsis plays a critical role in maximizing the carbon productivity of a tree's crown. The additional photosynthates available from sylleptic branches make an important contribution to overall growth of poplar trees early in the growing season [38].

Plant height, stem diameter and trunk volume showed significant positive genotypic and phenotypic correlations among themselves as presented in Table 4. This indicates that improvement in one character will be accompanied by improvement in another. In comparison with plant height, stem diameter had stronger positive genotypic correlation (0.97) with trunk volume and the value remained steady for three years. Diameter seems to be a better selection criterion than height for predicting volume at the target age due to its stronger genetic correlation with volume at all ages. Furthermore, diameter is easier to measure and the measurements are more precise. It has been suggested to use stem diameter or trunk volume in preference to tree height for early evaluations in *Populus* [30]. The results from the present investigation for relationships are corroborated by similar findings *Pinus radiata* [32], *P. deltoides* [39, 40], *Picea sitchensis* [41] and *Populus* species [42].

Pearson's correlation was tested for the relation

Table 3. Mean, range, estimated genetic variance and genetic advance for nursery performance at age of three years

Parameters/ variances	Mean ± S.E.	Range	F-cal	C.D. (5%)	C.V. (%)	G.C.V. (%)	P.C.V. (%)	h^2 ± S.E.	G.A.	G.G. (%)
nHt3	4.64±0.34	2.65-6.81	7.97**	0.68	9.11	13.90	16.62	0.69± 0.050	1.11	23.92
nDbh3	28.66±3.23	14.86-45.30	6.25**	6.40	13.82	18.29	22.93	0.63± 0.057	8.61	30.04
nD^2h3	0.0042±0.0013	0.0006-0.0140	5.81**	0.0027	38.47	48.76	62.11	0.61±0.060	0.003	75.00

** - significant at $p < 0.01$, * - significant at $p < 0.05$; nHt3, mDbh3 and nD^2h3 are height, stem diameter and trunk volume of plants in nursery at age of 3 years

Table 4. Genotypic and phenotypic correlation between early measurements in the field trial of three years age

Parameters	Year one	Year two	Year three
HT *vs.* DBH	$r_G = 0.76$** $r_P = 0.64$**	$r_P = 0.73$** $r_G = 0.60$**	$r_G = 0.57$** $r_P = 0.25$*
HT *vs.* D^2H	$r_G = 0.86$** $r_P = 0.78$**	$r_P = 0.84$** $r_G = 0.77$**	$r_G = 0.72$** $r_P = 0.46$**
DBH *vs.* D^2H	$r_G = 0.97$** $r_P = 0.96$**	$r_P = 0.96$** $r_G = 0.97$**	$r_G = 0.97$** $r_P = 0.97$**

** - significant at $p < 0.01$, * - significant at $p < 0.05$; HT, DBH and D^2H indicate plant height, stem diameter and trunk volume in field trial, r_G = genotypic correlation; r_P = phenotypic correlation

in performance between third year nursery trial and field trial (Table 5). Significant positive correlation existed for height (r=0.38) and dbh (r=0.30). Nursery performance was found comparable to third year field performance with significant (p<0.01) correlations between nursery height and age 3 field height and between nursery diameter and field stem diameter. The findings are in line with studies on *P. deltoides* [43, 32], hybrid poplars [44] and *P. tremuloides* [45]. A few studies [46, 47] indicate that early performance may be reflective of later field performance and help in reducing the time required to make selections. Early selection for traits of interest is to be supported by high additive variance and heritability, and better expression at juvenile stage, besides high juvenile-mature correlation. Due to the low to moderate heritabilities observed for plant height, stem diameter and trunk volume in the field trial in this study, it would be suggested to do early selection for these traits cautiously applying low selection intensity. Selection intensities of 60%, 33%, 13% and 5% have been suggested at age 2, 3, 4 and 5 years respectively based on D^2H [48] in *P. deltoides.* The final decision about selection may be made when data of field trial at harvest age are analysed.

SYLL2 showed a positive correlation with DBH2 (0.39) followed by HT2 (0.38) in the second year of planting (Table 5), indicating that carbon export by sylleptic branches contribute significantly to diameter and height growth. The number of sylleptic branches in the first year was not recorded which could provide information about the possible association between sylleptic branches and plant growth during the first year. It is worth mentioning that SYLL2 had significant correlation with HT1 and DBH1 too. This may be due to correlation between number of sylleptic branches per plant during first and second year of *Populus* growth in the field [38]. The result for this correlation suggests that clones selected for this type of branching confer potential productivity advantages to clone expressing greater syllepsis.

The age-age correlation serves as a basis for decision-making to determine the best selection age in a tree improvement programme in order to get clones into commercial production as soon as possible [49]. Successful early selection requires strong genetic correlations between the early age and target age performances in respect of the selection criteria. In this study, high age-age correlation among height, diameter and trunk volume existed for all the three years (Table 6). Genotypic age-age correlation was higher than phenotypic correlation, which is consistent with reports from previous works [50, 51]. Our findings

Table 5. Pearson's correlation between three years field trial and year 3 nursery performance

Characters	HT2	HT3	nHt3	DBH1	DBH2	DBH3	nDbh3	SYLL2
HT1	0.87**	0.34**	0.26*	0.87**	0.86**	0.18	0.22	0.34**
HT2		0.38**	0.20	0.78**	0.87**	0.19	0.17	0.38**
HT3			0.38**	0.24*	0.31**	0.39**	0.32**	0.18
nHt3				0.25*	0.17	0.30**	0.89**	0.01
DBH1					0.88**	0.29*	0.24*	0.36**
DBH2						0.32**	0.22	0.39**
DBH3							0.30**	0.06
nDbh3								-0.02

** significant at $p < 0.01$, * significant at $p < 0.05$; HT, DBH and SYLL indicate plant height, stem diameter and number of sylleptic branches in field trial. Suffixes 1, 2 and 3 denote the age (in years) of measurement. nHt3 and nDbh3 are plant height and stem diameter in nursery at 3 years of age

Table 6. Age-age correlation for the field performance

Parameters	Year 1 *vs* year 2	Year 2 *vs* year 3	Year 1 *vs* year 3
Height	$r_G = 0.66^{**}$	$r_P = 0.60^{**}$	$r_G = 0.70^{**}$
	$r_P = 0.41^{**}$	$r_G = 0.58^{**}$	$r_P = 0.22^{NS}$
Stem diameter	$r_G = 0.73^{**}$	$r_P = 0.73^{**}$	$r_G = 0.63^{**}$
	$r_P = 0.33^{**}$	$r_G = 0.62^{**}$	$r_P = 0.33^{**}$
Trunk volume	$r_G = 0.76^{**}$	$r_P = 0.74^{**}$	$r_G = 0.67^{**}$
	$r_P = 0.41^{**}$	$r_G = 0.64^{**}$	$r_P = 0.34^{**}$

**significant at $p<0.01$; *significant at $p<0.05$; ^{NS}not significant at $p<0.01$; r_G = genotypic correlation; r_P = phenotypic correlation

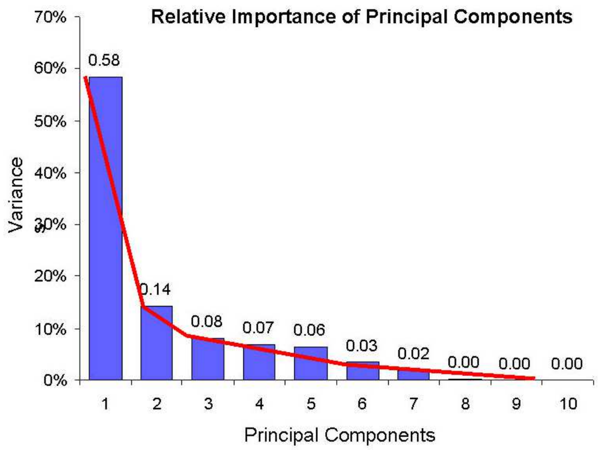
for the correlation are in accordance with earlier reports on *Pinus banksiana* [51], *Eucalyptus grandis* [49], hybrid poplars [44], *P. deltoides* [48] and *Casuarina equisetifolia* [52] among others.

Principal component analysis

Principal component analysis (PCA) was used to simplify identification and achieve more comprehensive conclusions as viable alternative to selection index. The first principal component axis (PCA1) captured maximum variance (58%) followed by PCA2 (14%), PCA3 (8%), and so on. In the present study, only the first principal component (PCA1) was preferred for computing the scoring, which accounted for a large part of the total variance (Fig 1a). PCA1 is mainly

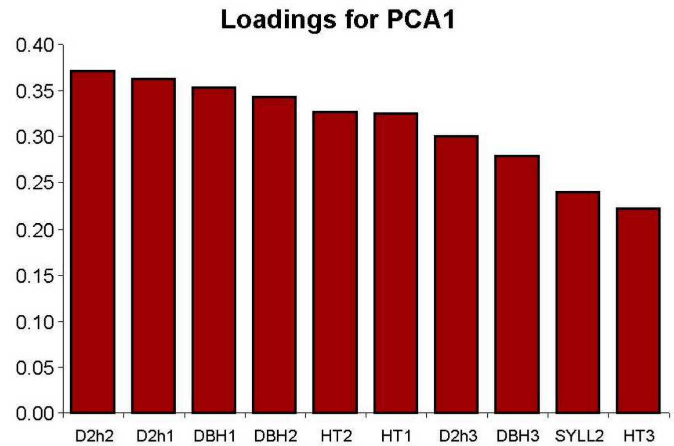
Table 7. Performance on the basis of PCA1 and height (third year at nursery trial) for the top 25 clones

Rank	Treatment (County)	PCA1 (score)	Rank	Treatment (County)	nHt3 (Nursery-yr 3)
1	FRI-AM-53 (Lee)	5.798	1	FRI-AM-6 (Itawamba)	6.81
2	FRI-AM-70 (Washington)	5.701	2	FRI-AM-41 (Newberry)	5.77
3	FRI-AM-51 (Newberry)	5.293	3	FRI-AM-15 (Northampton)	5.70
4	FRI-AM-6 (Itawamba)	4.086	4	FRI-AM-57 (Lee)	5.70
5	FRI-AM-45 (Newberry)	3.337	5	FRI-AM-40 (Newberry)	5.66
6	G-48 (Check 1)	3.191	6	FRI-AM-64 (Washington)	5.56
7	FRI-AM-13 (Northampton)	2.887	7	FRI-AM-96 (Roane)	5.52
8	FRI-AM-48 (Newberry)	2.877	8	FRI-AM-105 (Benton)	5.27
9	FRI-AM-76 (Washington)	2.668	9	FRI-AM-72 (Washington)	5.26
10	FRI-AM-33 (Northampton)	2.523	10	FRI-AM-48 (Newberry)	5.24
11	FRI-AM-44 (Newberry)	2.518	11	FRI-AM-37 (Dorchester)	5.21
12	FRI-AM-98 (Roane)	2.472	12	FRI-AM-9 (Itawamba)	5.17
13	FRI-AM-46 (Newberry)	2.455	13	FRI-AM-49 (Newberry)	5.16
14	UD-4707 (Check 2)	2.215	14	FRI-AM-50 (Newberry)	5.13
15	FRI-AM-71 (Washington)	2.012	15	FRI-AM-110 (Gadsen)	5.13
16	FRI-AM-109 (Benton)	1.986	16	FRI-AM-7 (Itawamba)	5.09
17	FRI-AM-40 (Newberry)	1.942	17	FRI-AM-93 (Benton)	5.09
18	FRI-AM-21 (Northampton)	1.782	18	FRI-AM-13 (Northampton)	5.08
19	FRI-AM-12 (Northampton)	1.566	19	FRI-AM-76 (Itawamba)	5.05
20	FRI-AM-50 (Newberry)	1.209	20	FRI-AM-74 (Washington)	5.04
21	FRI-AM-59 (Lee)	1.130	21	FRI-AM-70 (Washington)	5.03
22	FRI-AM-72 (Washington)	0.988	22	G-48 (Check 1)	5.03
23	FRI-AM-73 (Washington)	0.754	23	FRI-AM-98 (Roane)	5.02
24	FRI-AM-23 (Northampton)	0.694	24	FRI-AM-78 (Itawamba)	5.01
25	FRI-AM-35 (Dorchester)	0.592	25	FRI-AM-35 (Dorchester)	4.91



(a)

Fig. 1a. Scree plot for PCA (1 to 10)



(b)

Fig. 1b. Bar diagram on loadings for PCA1, ascending with their importance

associated with the prime growth factor with positive loadings (Fig. 1b) for D^2H2 (0.371) followed by D^2H1 (0.362), DBH1 (0.354), DBH2 (0.342), HT2 (0.326), HT1 (0.326), D^2H3 (0.300), DBH3 (0.223), SYLL2 (0.241) and HT3 (0.223). Here, the volume and diameter reflect the most potential components in order of importance involved with the prime growth of the tree. The scoring system is dominated in accordance with the loadings pertaining to the PCA1 which illustrate differences among clones. It has been earlier suggested that selection of fastest growing clones of *P. deltoides* on diameter basis could be done after age 1 to 3 [32]. Past works on selection process [17, 30, 32, 44, 49] suggest that diameter and volume constitute the most effective predictive traits for early selection in *Populus* spp.

In the present study, top 25 clones (35% of the total set) on the basis of scoring obtained from the loadings of PCA1 were identified, of which 7 clones belonged to a single family from the county Newberry. Clones with large scores of PCA1 were FRI-AM-53, -70, -51, -6 and -45 which outperformed commercial clone C_1 (G-48) followed by FRI-AM-13, -48, -76, -33 and -44. Further, 10 clones that performed well in the third year nursery data for plant height were found grouped among the 25 top ranking field clones based on PCA1 (Table 7). Similarity in ranking was found when *Populus* clones were tested for growth in growth chamber and field [53]. The first year height growth in the field and in the controlled environment were, however, not found as good predictors for ranking of hybrid poplar clones after five growing seasons [44]. Hence, strong age-age correlations for field height, diameter and volume (Table 5) in this study are indicative of good trait predictability from early measurements. Clonal ranking based on PCA1 was useful and reliable to identify promising top ranking clones for age 3 years. Its reliability for judging superiority of clones for tree harvest age needs to be further examined for greater use in poplar improvement.

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