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Performance of 43 *Pinus pinaster* Ait. Provenances on 5 Locations in Central Spain

By R. ALIA[1]), L. GIL[2]) and J. A. PARDOS[2])

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Summary

The paper present results of a 5-location all range *Pinus pinaster* provenance study in Spain, conducted in four-replicated complete block design provenance tests. Total height, diameter, survival and stem form were analysed at age 19 years. An analysis of variance over locations was made and two methods of studying stability of provenances were used, ecovalence and joint regression analysis.

For stem form, provenance was the most important effect, and site was statistically not significant. For height and diameter, site was the predominant effect, but high provenance – site interaction was present. Significance of interaction and implications on the use of the species were discussed.

Key words: Provenance x environment interaction, provenances experiments, genotypic stability, *Pinus pinaster.*

FDC: 232.12; 165.5; 174.7 *Pinus pinaster;* (460).

Introduction

Maritime pine (*Pinus pinaster* AIT.) is one of the most important forest species in the Occidental Mediterranean basin and the Atlantic coastal region of Southern Europe. It grows in natural stands on an extremely wide range of soil types and a variety of climatic conditions which characterize the plains, coastal regions and mountain slopes in an altitudianl range of about 2.000 meters.

Maritime pine is commonly planted at all conditions within its range and was intensively used in production and protection plantings. In Spain, 780,000 ha were afforested with this species between 1940 and 1982.

The performance of maritime pine provenances has been studied on numerous occasions, mainly in atlantic climates, (RYCROFT and WITCH, 1947; SWEET and THULIN, 1963; HOPKINS, 1964; MOLINA, 1965; BELLEFONTAINE, 1975, 1979; MATZIRIS, 1982); and it is considered a highly plastic species (HARRIS, 1966; BUTCHER, 1974; MATZIRIS, 1982) in the sense that the best genotypes or provenances usually display superior performance in a wide variety of conditions. On some occasion the species has been cited as an example of stability (ZOBEL et al., 1987).

However, when the diversity of locations tested or the number of provenances involved increase, stability ceases to be a general feature. Susceptibility to frost (BOUVAREL, 1960; ILLY, 1966) and drought (GUYON and KREMER, 1982; SARRAUSTE, 1982; NGUYEN and LAMANT, 1989) varies according to provenance, and therefore performances in diverse conditions are not homogeneous.

Because of the great genetic variability displayed in this species, which has been subdivided into 18 elementary geographical races (BARADAT and MARPEAU, 1988), and the different performance of provenances, it is necessary to study the behaviour of maritime pine in mediterranean conditions.

This paper examines the performance of 43 provenances of *Pinus pinaster* in 5 sites in West-Central Spain, located in mediterranean phytoclimates. The importance of the factors site and provenance are analysed, likewise the interaction of these, for survival, height, diameter and stem form. Stability of the provenances for each of the traits is also examined.

Material and Methods

A series of trials was planted at 5 locations in 1967 with 1-0 seedlings for the purpose of evaluating performance of maritime pine provenances. *Figure 1* shows the location of the provenance tests under analysis, and details of the sites included in this study are presented in *table 1.*

Each plantation followed a randomized complete block design with 16-tree plots and 4 replications. Spacing was 2.5 m x 2.5m. They include as many as 52 provenances of the species, 43 of which were chosen for this study.

Seeds were collected both in natural stands and plantations (*Table 2*), covering the entire range of the species (*Figure 1*).

Three response variables were measured on each surviving tree in each plot; i.e.: height (HTOT), diameter at breast height (DBH) and stem form (FORM, on a subjective scale from 1-good quality- to 9-poor quality- according to straightness and verticality), and the survival (SUR) of each plot was evaluated. Acebo, Cabañeros and Riofrío plantations were measured 18 years after planting, and Miravete and Espinoso tests were measured after 19 years. For height and diameter in Acebo,

[1]) Dpto. Sistemas Forestales, CIT-INIA, Aptdo. 8.111, E-28080 Madrid (Spain)

[2]) Dpto. Silvopascicultura, ETSI MONTES, Ciudad Universitaria s/n, E-28040 Madrid (Spain)

Table 1. – Features of Fields Trials.

	Acebo	Miravete	Cabañeros	Riofrio	Espinoso
Altitude	500 m	655 m	1045 m	775 m	830 m
Rainfall	1053 mm	918 mm	800 mm	723.9 mm	715.7 mm
Mean temperature	15.6 °C	15.7 °C	12.8 °C	10.2 °C	13.4 °C
Phytoclimate (ALLUE, 1990)	Nemoromediterranean	Mediterranean True	Mediterranean Subnemoral	Mediterranean True	Mediterranean True
Soil depth	120 cm.	125 cm.	40 cm.	120 cm.	90 cm.
% Fine earth	59.2	66.9	64.9	85.0	63.4
% Organic Matter	1.2	1.6	3.4	1.4	1.7
% Sand	34.0	48.3	53.1	50.4	60.5
% Silt	43.3	40.5	17.0	33.3	33.5
% Clay	22.7	11.2	29.9	22.2	16.0
pH	4.8	4.7	5.0	5.2	4.8
Litology	Quartz ferric slates	Quartz sandstone, ferric slates	Quartz	Quartz	Silicon slates

Cabañeros and Riofrío tests, the 18-year measurement was adjusted by adding average annual plot growth between 13 and 18 years.

All analyses are based on mean values per plot. Survival is analysed in terms of percentage with respect to the experimental unit, using the transformation arcsin $\sqrt{x}$.

Analysis of variance was done for all sites using the mixed statistical model:

Table 2. – Location, climate and characteristics of the 43 stands from which seed was collected.

Provenance	Country	Origin Zone	H	P	t
1.Cambados	Spain	Galicia Costera	60	1300	14.8
2.Carballo	Spain	Galicia Costera	150	1120	13.7
3.Ribadeo	Spain	Galicia Costera	180	1050	13.1
4.Pravia	Spain	Galicia Costera	185	1220	13.2
5.Entrimo	Spain	Galicia Interior	600	1810	10.5
6.Carballino	Spain	Galicia Interior	470	1370	12.8
7.Tabuyo	Spain	Sª del Teleno	900	750	9.7
8.Oña	Spain	La Bureba	700	685	10.8
9.S. Leonardo	Spain	Soria–Burgos	1200	641	8.7
10.Bayubas	Spain	Meseta Castellana	910	550	10.8
11.Villanueva	Spain	Meseta Castellana	870	500	10.9
12.Traspinedo	Spain	Meseta Castellana	730	510	11.5
13.Ataquines	Spain	Meseta Castellana	800	450	11.5
14.Coca	Spain	Meseta Castellana	810	475	11.4
15.Moraleja	Spain	Meseta Castellana	800	475	11.4
16.Arévalo	Spain	Meseta Castellana	830	410	11.3
17.Turégano	Spain	Meseta Castellana	925	580	9.9
18.Arenas	Spain	Sª de Gredos	750	1190	12.2
19.Solanillos	Spain	Alcarria	1215	585	11.4
20.Poyatos	Spain	Sª de Cuenca	1400	654	11.8
21.Boniches 1	Spain	Sª de Cuenca	1120	663	10.8
22.Boniches 2	Spain	Sª de Cuenca	1120	663	10.8
23.Almodóvar	Spain	Sª de Cuenca	900	650	12.2
24.Chelva	Spain	Sª de Cuenca	790	495	12.7
25.Rubielos	Spain	Maestrazgo	800	495	12.7
26.Cortes Payás	Spain	Levante	800	495	15.5
27.Paterna	Spain	Segura–Cazorla	1180	785	12.3
28.Yeste	Spain	Segura–Cazorla	1100	710	12.9
29.Orcera	Spain	Segura–Cazorla	1070	830	13.7
30.Cazorla	Spain	Segura–Cazorla	820	985	14.0
31.Caravaca	Spain	Sª Subbéticas	1100	510	13.6
32.Sª Espuña	Spain	Sª Subbéticas	1480	435	14.3
33.Albuñuelas	Spain	Sª Almijara	1280	600	14.4
34.Cómpeta	Spain	Sª Almijara-Nevada	900	752	9.7
35.La Garganta	Spain	Landes	--	--	--
36.Lanjarón	Spain	Corsica	--	--	--
37.Almonáster	Spain	Unknown	--	--	--
38.Leiria	Portugal	Leiria	--	--	--
39.Pisa	Italy	Italy	--	--	--
40.Córcega 1	France	Corsica	--	--	--
41.Córcega 2	France	Corsica	--	--	--
42.Tamjout	Morocco	Morocco	1600	650	--
43.Ibel-Tassali	Morocco	Morocco	2100	391	--

H: Altitude (m) P: Rainfall (mm) t: Annual mean temperature (°C)

$$X_{ijk} = m + P_i + S_j + PS_{ij} + B_{k(j)} + E_{ijk}$$

Where,

X_{ijk}: value of the k^{th} block of the i^{th} provenance at the site j.

m = Overall mean.

P_i = effect of the i^{th} provenance.

S_j = effect of the j^{th} site.

PS_{ij} = interaction between the i^{th} provenance and the j^{th} site.

$B_{k(j)}$ = effect of the k^{th} block within the j^{th} site.

E_{ijk} = experimental error.

The model has 1 fixed factor (provenance), and 2 ramdom factors (site and block). The test plantations are considered a random sample within the area in study.

Genotype x environment interaction may be analysed in various different ways (FREEMAN, 1971; SHELBOURNE, 1972; KREMER, 1981; DENIS and VINCOURT, 1982; SKRØPPA, 1984), most of which have been repeatedly followed in tree breeding for the study of progenies or provenances. In this case, 3 different stability parameters were computed:

1) Ecovalence (WRICKE, 1962): Contribution of the provenance to the interaction sum of squares. The percentage value of ecovalence is calculated for each provenance: Wi.

2) Joint regression analysis (FINLAY and WILKINSON, 1963; EBERHART and RUSSELL, 1966). This method regresses the value of each genotype upon some environmental index:

$$PS_{ij} = ß_i \bullet I_j + \delta_{ij}$$

where:

$ß_i$ = departure of the linear regression coefficient of the i^{th} provenance from the overall linear regression coefficient.

I_j = environmental index of the j^{th} site.

δ_{ij} = deviations from the regression line of the i^{th} provenance at the j^{th} site.

If the environmental index is taken to be the mean value of all provenances in that environment, then I_j becomes the site effect S_j.

Two stability parameters are used:

a) The regression coefficient of each provenance upon the site effect, b_i, where this coefficient estimates $1+ß_i$, (FINLAY and WILKINSON, 1963). We may say that provenances are highly stable and better adapted to poor sites if $b_i<1$. A provenance with $b_i=1$ was considered to be an average stability and equally adapted to poor and good sites. If $b_i>1$, the provenance was of low stability and better adapted to good sites. As

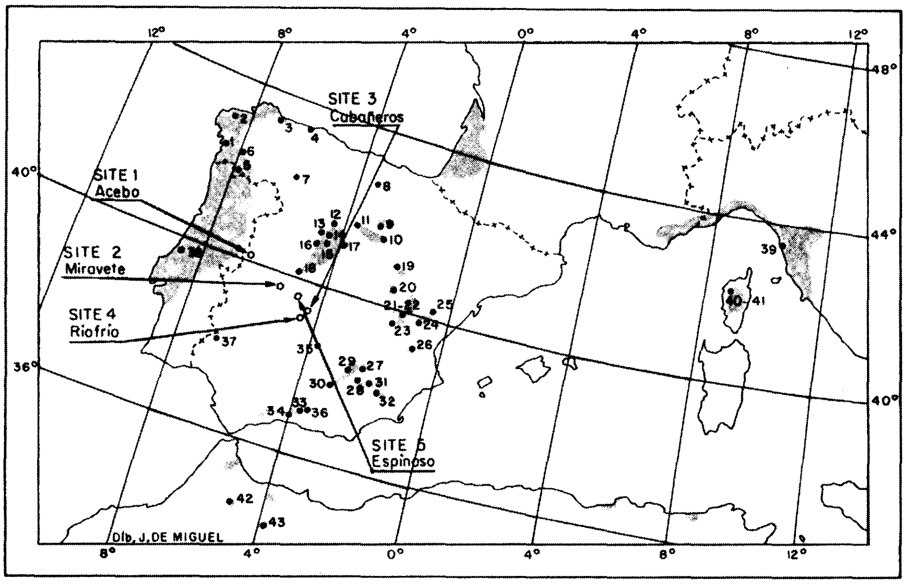

Figure 1. – Natural range (shaded) of maritime pine, location of stands where the seed was collected (numbered dots) and test plantations used in the present study.

suggested by these authors, this value is used in conjunction with the mean value for the provenance over all 5 sites.

b) The Mean square deviations from the regression for each provenance, S^2d_i (EBERHART and RUSSEL, 1966). This value indicates the predictability of the response of a provenance according to the environmental effect with the previous linear model.

Analyses were performed using the GLM procedure (SAS Institute, 1989) and own programs.

Results

A summary of the analyses of variance is shown in *table 3*. Provenance, site and provenance – site interaction were significant ($P<0.01$) or highly significant ($P<0.001$) for survival, height and diameter. For stem form, however, site is not significant.

The importance of the site effect depends upon the trait concerned, and it is underlined by the mean value of all the provenances in each site (*Table 4*). In the cases of height and diameter, these differences may be associated with climatic characteristics of the test sites relating to drought and temperature, as the variation in soil characteristics is minor. The climatic gradient of rainfall and mean temperature allow to rank the sites according to the growth attained by the species in each test site. The same order, in more attenuated form, occurs for survival.

Table 4. – Mean values of the response variables by locations.

SITE	Response variables[1] SUR %	HTOT m.	DBH cm.	FORM
ACEBO	98	9.8	16.3	3.74
MIRAVETE	88	7.3	13.8	3.15
CABAÑEROS	90	6.4	13.5	3.57
RIOFRIO	76	5.1	11.2	3.78
ESPINOSO	86	4.8	10.5	3.17

[1]) SUR: survival, HTOT: Height, DBH: Diameter, FORM: Stem form

Stem form is not significantly influenced by site, each of the provenance test giving similar mean values. In interpreting provenance – site interaction with reference to this trait, it must therefore be assumed that the importance of the provenance factor is such that even slight variations deriving from the site will show up as large variations when taken for different provenances.

The provenance effect is highly significant, and is quantitatively the most important in stem form. Mean values for each provenance are shown in *table 5*. Particularly poor quality stems were observed in seed sources from the Castilian plain and other marginal stands close to this region (i.e.: no. 8, no. 7

Table 3. – Summary of analysis of variance over locations for survival, Height, diameter and stem form, showing the components of the provenance-site interaction as estimated by joint regression.

		Response Variable: Survival		Height		Diameter		Stem form	
Source	DF	Mean Sq.	F Value	Mean Sq.	F Value	Mean Sq.	F Value	Mean Sq.	F Value
PROVENANCE	42	0.19469	3.53***	5.03953	3.32***	15.60011	2.34***	14.59727	15.39***
SITE	4	1.24829	12.47***	537.64314	50.54***	734.78847	36.08***	14.97347	2.30ns
SITE*PROVENANCE	168	0.05550	1.39**	1.52541	1.53***	6.70522	1.89***	0.95218	1.25*
Regression	42	0.06269	1.57*	2.16855	2.18***	8.14494	2.29***	--	--
Deviations	126	0.05311	1.33**	1.31102	1.32**	6.22531	1.75***	--	--
BLOCK(SITE)	15	0.10072	2.52**	10.63785	10.70***	20.36422	5.74***	6.51688	8.56***
ERROR	591	0.03991		0.99450		3.54746		0.76149	

and no. 14). Mountain provenances, in the sense used by SCOTT (1962) to describe highland provenances with straight stems, were identifiable from the mountains of Central Spain (seed sources no. 21, no. 22, no. 18, and no. 9) and from Corsica. Atlantic provenances from Portugal, Landes and Galicia have intermediate values.

For the other traits, given the significance level of the interaction effect and its value relative to the provenance effect, the performance of each provenance must be modified to take into account the location. Then, the significance of interaction requires more detail examination.

The value of the F test for the heterogeneity of the regressions confirms the significance of provenance-site interaction, except for stem form (*Table 3*). This means of breaking down interaction is inadequate in the case of survival, as there is only one site with a relatively low mean survival value (SKRØPPA, 1984).

There is a high degree of correlation among some of the stability parameters applied (*Table 6*), such as the ecovalence and the mean square deviations of the regression. It should be noted that there is no relationship linking the value of the regression coefficient, which indicates the response of the provenance to site quality, with any other stability parameter. Existence of a significant correlation between height and the regression coefficient indicates linearity of reactions norms for the height growth. There is a negative correlation between diameter and ecovalence, that means the higher the diameter the lower are the provenances differences. This could be caused by the existence of minimum factors, i.e. drought and frost, acting on Riofrío and Espinoso sites.

Mean values of survival for each provenance are shown in *table 5*. Regarding the scant utility of the values of the regression coefficients and the mean square deviations for survival, analysis of this trait was based on the mean value for each

Table 5. – Mean values over locations of the measured characters, Stability parameters for Height and Diameter (b_i: regression coefficient of each provenance upon the site effect; S^2d_i: Mean square deviations from the regression for each provenance) and Rank (R) of entries.

	Survival		Height						Diameter						Stem form	
Provenance	Mean	R	Mean	R	S^2d_i	R	b_i	R	Mean	R	S^2d_i	R	b_i	R	Mean	R
1	0.73	37	7.34	7	0.14	34	1.31	4	12.9	25	1.296	20	1.54	3	2.88	15
2	0.71	41	7.11	10	0.21	25	1.16	7	12.1	35	0.411	37	1.32	7	3.19	21
3	0.72	40	6.53	23	0.03	42	1.48	2	11.1	43	0.742	29	1.81	1	3.14	20
4	0.69	43	7.40	6	0.36	14	1.25	6	12.6	31	1.799	13	1.13	15	2.90	17
5	0.72	39	7.42	5	0.18	30	1.15	8	12.9	22	5.533	2	1.20	11	2.81	12
6	0.73	38	6.94	14	0.23	24	1.28	5	11.9	37	0.167	41	1.44	4	2.94	18
7	0.88	17	6.31	34	0.38	12	0.52	43	12.9	26	0.437	36	0.52	40	4.20	32
8	0.93	7	6.51	24	0.20	27	0.81	39	13.6	9	1.899	12	0.77	32	5.32	43
9	0.92	10	7.32	8	0.14	35	0.82	38	14.2	6	0.526	34	0.48	42	2.65	5
10	0.87	26	6.21	38	0.04	40	0.78	40	12.7	28	0.018	43	0.74	35	5.11	42
11	0.88	23	6.26	37	0.20	28	1.00	20	12.7	29	2.142	10	1.16	13	4.68	39
12	0.88	16	6.63	21	0.71	5	0.98	23	13.2	19	1.515	17	0.89	26	4.49	35
13	0.87	25	6.35	32	0.39	10	0.93	26	12.5	32	0.730	30	0.71	37	4.99	41
14	0.85	32	6.35	32	0.32	17	0.91	29	13.4	16	1.109	24	1.04	18	4.91	40
15	0.81	34	6.47	25	0.39	11	0.85	35	13.5	12	2.189	9	0.71	37	4.62	38
16	0.93	6	6.46	26	0.27	20	1.05	12	12.9	27	0.113	42	0.94	25	4.50	36
17	0.87	28	6.69	19	0.14	36	0.98	23	12.9	22	0.981	25	0.95	24	4.21	34
18	0.96	1	7.45	4	0.04	41	0.92	28	14.6	2	1.331	19	0.58	39	2.71	9
19	0.90	13	6.67	20	0.41	9	0.76	41	12.4	34	1.111	23	0.79	31	2.70	8
20	0.88	18	6.84	15	0.26	21	1.05	12	13.5	13	2.071	11	1.13	15	3.25	22
21	0.90	14	7.00	12	0.37	13	1.07	11	14.0	8	2.453	6	1.43	5	2.54	4
22	0.95	3	6.98	13	0.21	26	1.01	17	13.4	17	0.326	38	0.80	29	2.67	6
23	0.88	18	6.61	22	0.14	37	1.01	17	12.7	30	0.168	40	1.17	12	3.57	25
24	0.91	12	6.37	30	0.67	6	0.88	33	13.4	15	1.172	22	1.03	19	4.21	33
25	0.86	29	6.29	35	0.17	31	1.01	17	13.0	20	1.666	16	0.84	28	3.93	29
26	0.86	31	6.38	29	0.30	18	0.85	35	12.5	33	1.425	18	1.02	20	2.75	11
27	0.95	3	6.43	28	0.52	8	0.91	29	13.3	18	2.361	7	0.88	27	2.85	13
28	0.95	2	7.14	9	0.32	16	0.88	33	14.3	4	0.483	35	0.80	29	2.67	7
29	0.93	9	6.72	17	0.35	15	1.00	20	14.2	5	0.317	39	1.27	8	4.16	30
30	0.87	26	6.44	27	0.19	29	1.11	9	13.5	11	0.929	26	1.13	15	3.63	28
31	0.94	5	6.71	18	0.15	32	1.03	15	13.6	10	2.221	8	0.98	22	2.87	14
32	0.93	7	7.02	11	0.92	2	1.01	17	14.7	1	2.715	5	1.23	10	2.88	16
33	0.86	29	6.08	40	0.05	39	0.88	33	13.5	13	0.531	33	1.13	15	3.62	27
34	0.89	15	6.21	38	0.53	7	0.94	25	12.9	24	0.808	28	0.96	23	4.51	37
35	0.88	20	7.61	3	0.30	19	0.99	22	14.1	7	0.563	32	1.01	21	3.49	24
36	0.91	11	7.98	1	0.02	43	1.04	14	14.6	3	0.699	31	0.74	35	3.29	23
37	0.77	36	6.83	16	0.26	22	1.37	3	11.9	36	1.774	14	1.39	6	3.59	26
38	0.70	42	7.74	2	0.24	23	1.55	1	13.0	20	1.285	21	1.72	2	3.08	19
39	0.88	22	6.37	30	0.14	33	0.93	26	11.7	41	0.857	27	0.75	34	4.19	31
40	0.80	35	6.29	35	0.13	38	0.89	31	11.8	40	1.741	15	0.76	33	2.05	2
41	0.81	33	6.05	41	0.87	4	1.10	10	11.8	38	3.466	4	1.27	8	2.72	10
42	0.87	24	5.65	43	0.91	3	0.67	42	11.1	42	4.555	3	0.31	43	2.04	1
43	0.88	21	5.68	42	1.48	1	0.83	37	11.8	39	0.176	1	0.51	41	2.08	3

Table 6. – Rank correlation coefficients of the stability parameters[1]), by trait[2]).

		S^2d_i	b_i	Mean
S^2d_i	SUR	-0.37143*		
	HTOT	-0.24011		
	DBH	-0.45696**		
b_i	SUR	-0.33207*	0.12240	
	HTOT	0.49018***	-0.22908	
	DBH	-0.08668	-0.12821	
W_i	SUR	-0.21943	0.82300***	-0.03134
	HTOT	-0.11190	0.69647***	-0.00966
	DBH	-0.41966**	0.88810***	-0.11130

[1]) b_i: regression coefficient of each provenance upon the site effect
S^2d_i: Mean square deviations from the regression for each provenance
W_i: Ecovalence
[2]) SUR: survival, HTOT: Height, DBH: Diameter

provenance over all five sites, and on ecovalence (*Fig. 2*). Based on this parameter, 2 of the provenances are highly unstable, with a contribution of about 20% to the total ecovalence. The other provenances are of medium or high stability. Survival was strongly associated with provenance origin. Atlantic provenances from Portugal and Spain have low values of survival, while Mediterranean provenances show high survival values over all 5 sites.

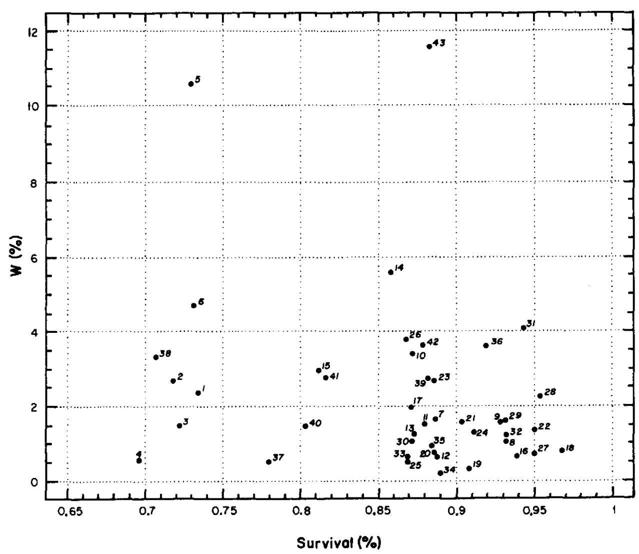

Figure 2. – Plot of Ecovalence (W_i) against overall provenance survival means.

Height and Diameter are highly correlated (r=0.89), as are the stability parameters of both traits. Thus, the rank correlation coefficient for the regression coefficient between the 2 traits is r=0.85, and for mean square deviations r=0.70. The values of the regression coefficients and mean square deviations of each provenance are shown in *table 5*.

For height, the value of b_i fluctuates between 0.52 (no. 7) and 1.55 (no. 38). Atlantic seed sources have b_i>1, althought one atlantic origin, (no. 35) has intermediate stability and attains a greater average height than the other provenances.

Moroccan origins are stable (b_i<0.8), but with a bad prediction of these values at the different sites by means of the regression. Origins from Corsica and Center of Spain are stable with intermediate values of stability and height growth. *Figure 3* shows the regression lines of 6 origins for height.

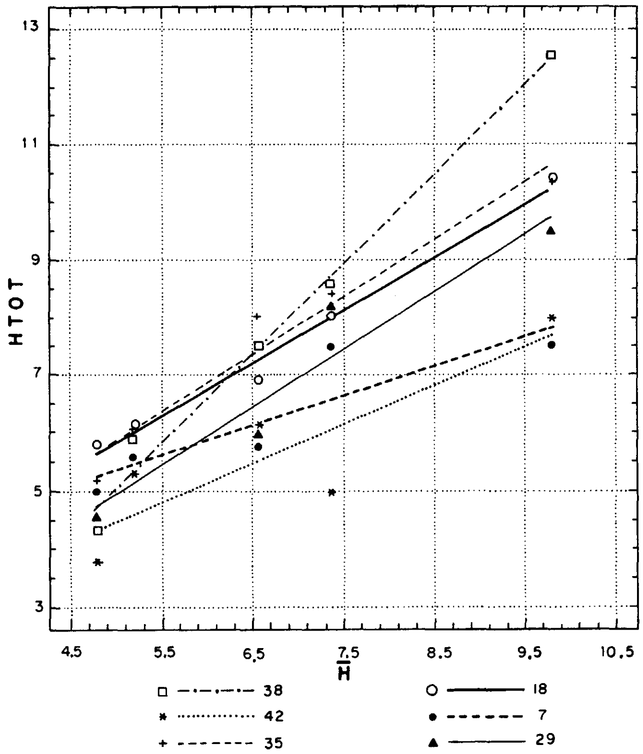

Figure 3. – Plot of provenance height means (HTOT) against site means (H) and estimated regression lines for 6 provenances.

Discussion

Despite being small the area of study in which the test plantation are located, site is the preponderant effect in traits relating to the volume production of *Pinus pinaster,* although not for the stem form. The sites analysed here fall into environments ranging from typically Mediterranean (Riofrío and Espinoso locations) to phytoclimates verging on the Atlantic (Acebo). These sites cover most of the environments in which the maritime pine occurs naturally and in which at the same time artificial afforestation is an economically viable proposition.

Stem form is one of the most important selection criteria in breeding maritime pine. The poor quality seed sources are those from the plains, and coastal areas, while seed sources from Morocco, Corse and Mountains of Central Spain show a good stem quality. Ranking of provenances is the same in other sites (SWEET and THULIN, 1962; MOLINA, 1965; ILLY, 1966; MATZIRIS, 1982) that confirm stability of stem form. Thus, interracial hybrids is a useful method for improving stem quality of some seed sources (BARADAT and PUSTUSZKA, 1990).

The differences found in survial can be related with the climate of the seed sources. Maritime pine is found in Atlantic climates and it has adapted to mediterranean climates where temperatures and drought are higher. Rainfall in the place of origin is the main factor affecting survival in the tests analysed. Atlantic provenances, have low values of survival over all the locations, and they are highly unstable. These origins have a lower water-use efficiency than other more mediterranean ones (GUYON and KREMER, 1982; NGUYEN and LAMANT, 1989). Frost is not an important factor affecting survival in the sites studied, althought 2 of the tests have the longer dry season and the lower temperatures. Thus, the effect of each factor can be hardly separable.

Althought height and diameter are strongly correlated, there are different pattens of variation among origins. Those from Morocco and Southern Spain have a lower diameter growth rate and their growth initiation is later than the Atlantic ones in the test conditions (ALIA and GIL, 1992).

The major groups in which *Pinus pinaster* has been divided (BARADAT and MARPEAU, 1988) are in concordance with the performance in provenance tests. Within group variation is high, and the 16 elementary races in which maritime pine has been subdivided is a better approach for explaining their performance. The Leiria provenance (and in general all the Atlantic group) shows the best growth and adaptation in coastal subhumid zones, without too cold conditions, and where the dry period is short or non-existent (RYCROFT and WITCH, 1947; SWEET and THULIN, 1962; HOPKINS, 1964; MOLINA, 1965; MATZIRIS, 1982; BELLEFONTAINE, 1975, 1979). This origin reacts well to the improvement of the annual station quality (KREMER, 1982) and grows well in humid conditions (SARRAUSTE, 1982). However, their growth is lower than that of higher-altitude or more continental origins when test conditions harden (DESTREMAU et al., 1976; BELLEFONTAINE, 1979).

This is highlighted by the regression coefficients of the Leiria and Galician provenances for height and diameter. In the Riofrío and Espinoso sites, where the dry period is longer, and in Cabañeros, where the winter cold is longer, other more continental provenances are clearly superior to these atlantic provenances.

North-Western Spain populations, in the sense of BARADAT and MARPEAU (1988), show a large difference in their performance. The origins from the Castilian Plain, (no. 10 to 17) are clearly different from those of Gallice and Portugal in terms of growth and response to the increase of site quality. This can be caused by the poor conditions in which maritime pine grow, i.e. interior dunes, with low rainfall and winter cold.

The origin 18-Arenas combines good adaptation to different environments with acceptable growth when climatic conditions are not too mild. Otherwise, it is inferior to the Leiria or Galician provenances (SWEET and THULIN, 1962; MOLINA, 1965).

Perimediterranean populations from Spain have high genetic variation, probably because the large isolation, and the great climatic and soil variation between them. Among the Spanish provenances, no. 7-Tabuyo displayed greater stability, but with a low height growth in very favourable growing conditions for the species (MOLINA, 1965; ILLY, 1966).

The Moroccan provenances responded very poorly to increasing fertility at the station. This is linked with their hydric behaviour (GUYON and KREMER, 1982; SARRAUSTE, 1982) and with the initiation and rate of height growth (KREMER and ROUSSELL, 1986).

Several non-indigenous provenances display a good performance over locations, probably for the breakdown of homozigosity in these populations. That is the case of provenances from different geographical zones as provenances no. 35, 36 and 37 from Landes, Corsica and an unknown origin.

Conclusions

From the analysis of 19-years old provenance tests of maritime pine, grown on 5 sites in Spain, the main conclusions are the following,

– There is high seed source variation in all the variables studied, providing opportunity for good genetics gain by selection of superior provenances. However, the existence of provenance-site interaction for *Pinus pinaster* is important for the utilisation of the species.

– Joint regression analysis is an adecuate way of studying provenance-environment interaction for height and diameter, but not for survival.

– After this study, some remarks could be done about the performance of the provenances:

1. The selection of seed sources might be based on highly predictable performance and the mean height for seed sources. Arenas, Lanjarón, Garganta and S. Leonardo provenances provided acceptable yields over the entire range of situations.

2. Atlantic provenances from Leiria and from North-Western Spain have lower survival and growth in drier Mediterranean conditions.

3. Some provenances display unpredictable performance, the best examples of which are the Moroccan provenances and those deriving from artifical reforestation.

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The Breeding Seedling Orchard in the Multiple Population Breeding Strategy

By R. D. BARNES

Oxford Forestry Institute, Department of Plant Sciences,
University of Oxford, South Parks Road, Oxford OX1 3RB, United Kingdom

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Summary

Genetic improvement includes selection, testing and breeding from the species down to the clonal level. Tree breeding programmes in tropical countries are often required to work with many provenances of many species for many sites. A Multiple Population Breeding Strategy (MPBS) was proposed in response to this need and the breeding seedling orchard (BSO) devised to combine the conventional hierarchy of sequential testing, selection and seed production populations in a single planting.

In the MPBS the breeding population is divided into sub-populations which are kept separate so as to produce trees with different gene complexes. These can then be used as replicate populations (to avoid inbreeding effects in the operational seed), diversified populations (to exploit genotype-environment interaction), heterotic populations (to exploit heterosis) or structured populations (to place more emphasis on the elite elements).

The BSO lies between a Seedling Seed Orchard (SSO) and a progeny test (PT). The functions of the SSO or PT are inevitably compromised in the BSO; the nearer it lies to the SSO the higher the selection intensity and seed production whereas the nearer it is to the PT the better the genetic information and the selection precision. Objectives should be clearly stated before the BSO is designed if these conflicts are to be resolved.

Breeding intensity within the BSO can be simple (mass selection), intermediate (half-sib pedigree control) or intensive (full-sib pedigree control). In determining the genetic constitution of the BSO the crucial issues are: sampling the base population effectively, avoiding inbreeding and selecting the genetic checks. The elements of environmental design, plot size, shape and spacing, replication and sub-blocking, and siting can all be crucial in achieving the objectives of the BSO. Genetic gain is dependent on the effectiveness of selection which in turn is dependent on its intensity, precision and the number of criteria.

The conclusion is that this strategy is flexible, provides the potential to respond to new materials and new demands and allows the breeder freedom to be adventurous without taking unacceptable risks. At the same time it accommodates the need to work with many populations of many species at different levels; and it conserves variation.

Key words: multiple population breeding strategy, breeding seedling orchard, progeny test, selection, experimental design, inbreeding, seed orchard, genetic checks, juvenile-mature correlations, genotype-environment interaction.

FDC: 232.311.3; 232.11; 165.4; 165.62.

Introduction

A genetic improvement strategy in its broadest sense includes the whole process of selection and testing from the species level, through the population and family, down to the clonal level, and the conservation of variation within them. Most tree improvement programmes in tropical countries are concerned with many provenances of many species for many sites. This has been especially true in the last 30 years when there has been an expansion of species and provenance testing which has brought about a need for a strategy with which to manage this proliferation of potentially valuable material. A Multiple Population Breeding Strategy (MPBS) was proposed in response to this need (NAMKOONG *et al.,* 1980).

When adopting the MPBS, it is usually impracticable to maintain the full hierarchy of the sequential testing, selection and seed production plantings of a conventional programme for every population of every species. These functions may have to be combined in various degrees, depending on the structure of the multiple populations, in a single planting which is now formally known as the Breeding Seedling Orchard or BSO (BARNES, 1981), although such plantings have been used in tree breeding programmes since the early 1960s (*e.g.* MULLIN *et al.,* 1981; REDDY *et al.,* 1986). Since the concept of the BSO in the