Relation Between Growth and Morphological Traits and Genetic Parameters of *Robinia pseudoacacia* var. *monophylla* D.C. in Northern Greece

By O. DINI-PAPANASTASI[1]) and C. P. PANETSOS[2])

(Received 23rd November 1999)

Abstract

The relation between growth and morphological traits, and genetic parameters were studied in a progeny test of 14 open pollinated families of the black locust monophylla variety (*Robinia pseudoacacia* var. *monophylla* D. C.) established in northern Greece in 1991. Measurements included height and dbh for 5 consecutive years, number and size of leaflets per compound leaf in 1991, thorns in 1992 and 1993, and trunk form in 1993. Data were subjected to analysis of variance while heritabilities and phenotypic as well as genetic correlations were estimated. It was found that the 14 families had a high growth rate during the study period but differences began to be insignificant for height in 1995 and dbh in 1993. The ratio of family coefficient of variation to coefficient of variation was 1/3.6. Individual heritability was higher for dbh than for height while family heritability was higher than individual one in both traits. Number of leaflets per compound leaf ranged from one to 27 and the size of thorns from 0 mm to 25 mm. The variation was much smaller within families for both leaflets and thorns. On the basis of leaf morphology and thorns two types of trees were distinguished: oligophyllous, with few but large leaflets and small thorns, and polyphyllous with many but small leaflets and long thorns. Most of Pearson correlation coefficients between the various growth and morphological characters were statistically significant, but only a few of them were high enough to explain a fair amount of the variation between the various characters. On the contrary, the correlations between height and diameter were much higher while the genetic correlations between various ages of the same factor were positive and indicate their value for early testing and selection.

Key words: Robinia pseudoacacia var. *monophylla,* height, diameter, leaf morphology, thorns, phenotypic correlations, genetic correlations, Greece.

Introduction

Black locust (*Robinia pseudoacacia* L.) is a nitrogen-fixing leguminous tree, native to southeastern North America, but also naturalized in the temperate regions of North America, Europe and Asia. It is a multi-purpose species suitable for lumber, poles, fuels, land reclamation, beekeeping, forage and wood fiber (BARRETT *et al.,* 1990). It is a fast growing tree, resistant to many environmental stresses (low and high temperatures, drought, air pollutants), and tolerant to low fertility sites (HANOVER, 1990).

Although there has been substantial international interest on black locust for several decades, in general very little genetic improvement has been done. In USA, only the last decade test plantations have been established in order to quantify the magnitude and nature of genetic variability in this species (BLOESE *et al.,* 1992). In Hungary, where black locust was introduced between 1710 and 1720, a breeding program with various selection criteria (fast growth, stem straightness, frost resistance, prolongation of flowering period, increased nectar yields) has started more than a half century ago. As a result, many registered cultivars for specific uses have been developed (KERESZTESI, 1983).

In selecting black locust for specific purposes a thorough knowledge of the relation between growth and morphological characters as well as genetic parameters is needed. This relation is particularly useful for thorns which are an undesirable trait causing significant problems during tending of young plantations and harvesting of mature trees or injuries to grazing animals (MEBRAHTU and HANOVER, 1989; BONGARTEN, 1992). For this reason, selecting cultivars with no or few thorns is of great economic interest. KENNEDY (1983) has found weak positive but statistically significant relationships between thorn length and height, and diameter in one-year old seedlings. Similar results were also found by BLOESE *et al.* (1992) in older saplings (2 to 5 years old) who came to the conclusion that selection for higher growth rates results in a tendency for longer thorns. Since thorniness however is mainly associated with young age (BONGARTEN, 1992), it is doubtful whether a significant relationship exists, between thorn length and growth in older ages.

Growth of trees is also related to leaf size. KENNEDY (1983) has found a positive relationship between height and number of leaflets per compound leaf, but the equivalent relationship with diameter was weaker. He also found a positive relationship between the number of leaflets per compound leaf and the length of rachis, while the relationship with the thorn length was weaker. All these studies were carried out in one-year old seedlings in the nursery, and remain to be seen if the same relationships are valid in older saplings.

Finally, of special importance is the relation between the growth characters themselves, namely between height and diameter at various ages. A strong phenotypic and genetic correlation between any of these two characters at different ages, could be used for prediction and consequently for early selection of this particular character (BLOESE *et al.,* 1992).

In Greece, the species is popular in plantations for torrent stabilization in the mountains and for soil erosion control on river, road and railway banks. Moreover, it is widely used as an ornamental tree in parks, boulevards and households (DINI-PAPANASTASI, 1991). Since 1993, however, when the EU directive on afforestation of farm lands for timber production (No. 2080/1992) was initiated, large areas of private-owned plantations were established with the species because it is considered as a fast growing and well adapted to marginal lands. The demand for establishing black locust plantations on private-owned land is increasing each year (DINI-PAPANASTASI, 1996).

Monophylla black locust (*Robinia pseudoacacia* var. *monophylla* CARR. or *unifolia* TALOU) (KAVVADAS, 1956; KERESZTESI, 1983) is a botanical variety with a few leaflets per compound leaf and very promising for wood, biomass and forage produc-

---

[1]) National Agricultural Research Foundation, Forest Research Institute, GR-570 06 Vassilika, Thessaloniki, Greece

[2]) Laboratory of Forest Genetics and Plant Breeding, Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, GR-540 06 Thessaloniki, Greece

tion in Greece (Dini-Papanastasi, 1997). In this paper, the relation between growth and morphological characters was investigated and genetic parameters were estimated in order to initiate selection programmes for its improvement for specific purposes.

Materials and Methods

The experiment was carried out in the farm of the Forest Research Institute, 20 km NE of the city of Thessaloniki, northern Greece (40° 35' N and 22° 58' E). Soils of the study area are sandy loams, derived from deposits of the tertiary period, fairly deep (1 m to 2 m) and alkaline (pH 7.7). Climate is semi-arid Mediterranean with 416 mm long-term mean annual rainfall, 31.7 °C mean maximum air temperature in July and 0.2 °C mean minimum in January (Tsiontsis, 1995).

In May 1990, a trial was established with 14 open pollinated tree-families (symbolized with the numbers 1 to 14) of *Robinia pseudoacacia* var. *monophylla* in a randomized complete block design (RCB) with row plots of 15 plants per family, in three replications, (the third one included 11 plots, because three mother trees produced restricted number of seeds). Spacing was 1.5 m within and 2 m among the rows. A buffer zone of one row was also planted around. Seeds were sown in paper pots in March 1, 1990 and after two months the plants raised were transplanted in the field. Irrigation was applied to ensure good establishment of the plants, and soil cultivation to avoid competition from the weeds. Soil cultivation was repeated in 1991. Also, pruning up to 2 meters high was applied after the completion of the third growing period.

The seedlings used to establish the experimental trial were raised from seeds of three trees growing in the study area and eleven trees growing in the Chrysopigi Experimental Station, about 100 km NE of Thessaloniki. The mother trees were selected for their few thorns and the small number of leaflets per compound leaf. All the sampled trees were offspring, of a single tree, which was growing in a plantation of black locust established for erosion control in the catchment area of a torrent near the town of Serres. This particular tree was distinguished from the rest, because its branches were nearly thornless, and had compound leaves with few (3 to 5) large leaflets. According to Liacos *et al.* (1983) the crude protein content of its leaves was up to 28%.

Measurements of growth characters, namely height and diameter at breast height (dbh), were initiated after the completion of the second growing season, in late autumn 1991, and repeated in the following 4 years 1992 to 1995 at the same period. Leaf morphology measurements were carried out only in October 1991 and they were restricted to the 10th compound leaf from the top of each tree so that comparable results are ensured. They included number of leaflets per compound leaf, length of rachis of the compound leaf, length of petiole of the uppermost and lowermost leaflets and its surface area by measuring two symmetric axes and using the formula for ellipse.

Thorns were measured in two ways. The first one involved counting of the number of thorn pairs and recording of the maximum thorn length at 50 cm from the top of each tree. Measurements were carried out during February of 1992, when no leaves were on trees. The second method involved visual estimation of the thorn length and classifying the trees into levels of thorniness on the basis of a 1 to 5 scale, similar to the one used by Mebrahtu and Hanover (1989): 1= practically no thorns, 2= small and few thorns, 3= moderate in number and size thorns, 4= long and many thorns, and 5= very long and many thorns. This estimation was carried out in March 1993, when again no leaves were on the trees.

Finally, the form of the trunk was visually assessed on a three point scale in March 1993, also used by Mebrahtu and Hanover (1989): 1= trees with many leader shoots, 2= trees with an intermediate form and 3= trees with a strong tendency to form a main and straight trunk.

Data were subjected to analysis of variance. Narrow sense family (h^2_F) and single tree (h^2_T) heritabilities were calculated using the variance components generated from the analysis of variance. The following formulae were used to estimate the heritabilities (Zobel and Talbert, 1984; Panetsos, 1986):

$$h_F^2 = \frac{\sigma_F^2}{\frac{\sigma_W^2}{T \times R} + \frac{\sigma_{RF}^2}{R} + \sigma_F^2} \qquad (1)$$

$$h_T^2 = \frac{4\sigma_F^2}{\sigma_W^2 + \sigma_{RF}^2 + \sigma_F^2} \qquad (2)$$

where:

R, T= number of replications and trees per family replication plot, respectively

σ^2_F, σ^2_w, σ^2_{RF} = family, within-plot, replication X family variance component, respectively

In the equation (1) the harmonic mean of the number of plants per plot (H) was used instead of the number of trees per family-replication plot (T) (Matziris and Zobel, 1973; Namkoong and Conkle, 1976).

Phenotypic correlations (Pearson correlation coefficients) were estimated for all characters from individual tree values.

Genetic correlations between growth traits as well as between growth and morphological ones, which were measured during the same period, were calculated (using plot means) from analysis of covariance (Steel and Torrie, 1980). The equation used to estimate genetic correlations was (Zobel and Talbert, 1984; Falconer, 1985):

$$r_A = \frac{\sigma F_{xy}}{\sqrt{\sigma^2_{F_x} \sigma^2_{F_y}}}$$

r_A= the additive genetic correlation coefficient,

σ_{Fxy}= half-sib component of covariance for traits X and Y,

σ^2_{Fx}= half-sib component of variance for trait X, and

σ^2_{Fy}= half-sib component of variance for trait Y.

The t-test (for independent samples) was employed to detect differences in height, dbh and thorns.

Results and Discussion

Height and diameter

The mean values of height and dbh per family for each of the five years of experimentation (1991 to 1995) are presented on *figures 1* and *2* respectively for the two traits. The 14 families appeared to have a high growth rate during the study period, but in the last year of measurements (1995) both traits and especially height was remarkably reduced. This evolution of growth rate seems not to be related to annual rainfall, since precipitation in 1995 was at the average level of the five-year experimental period (Dini-Papanastasi, 1997). It should be rather attributed to the growth pattern of the species. This pattern was continued in the following years 1996, 1997 and

1998 (data not shown). HALUPA and REDEI (1988) found in Hungary that height growth peaks within the first five years, while diameter growth in the first decade. Similar results were also reported by PAGES (1986) in France.

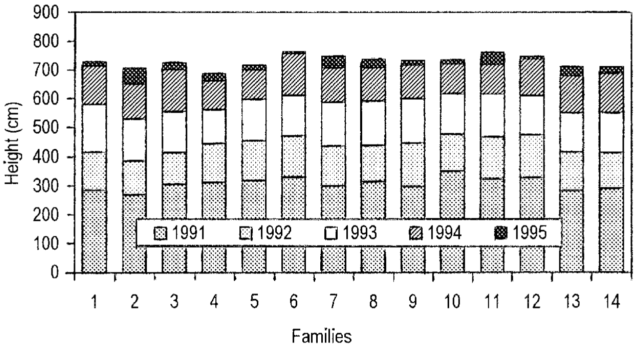

Figure 1. – Mean height (cm) of the 14 families during the years 1991 to 1995.

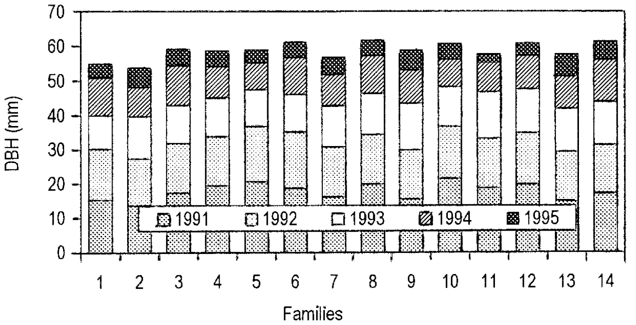

Figure 2. – Mean dbh (mm) of the 14 families during the years 1991 to 1995.

The overall means of height and dbh of the whole plantation with their standard errors for each year are given in *table 1.* These results should be considered as satisfactory since HALUPA and REDEI (1988) and REDEI (1992) have found in Hungary similar performances but in better sites and under a wider spacing. Also, results from a 10-years old plantation in USA, grown in a fairly good site, showed mean dbh 7 cm and mean height 8.20 m (FOWELS, 1965).

The analysis of variance for height and dbh is presented in *table 2.* The behaviour of height and dbh parameter in relation to the time element can also be appreciated by the result presented in the above table. This gradual elimination of differences among families was most probably due to the increasing competition with age, since the demands of trees kept increasing while the available growing space remained the same (no thinning was applied).

The gradual decrease of variation among families with respect to age was also confirmed by the coefficient of variation (CV) and the family coefficient of variation (FCV) which are given in *table 3* for each year and growth trait. The values of CV, which is an estimate of the total phenotypic variation existing among and within families, followed a decreasing trend for both growth traits, so the variation at the end of the 5-year period became 50% of the initial. The values of the second coefficient, FCV, which represents the variation among families, presented the same decreasing trend with age as CV and agrees with relevant results for the same species found by BONGARTEN (1992). The ratio of the two coefficients (*Table 3*), actually expressing the percentage of total variation existing among families, ranged from 1/3.5 to 1/4 (mean 1/3.6) for height, while for dbh from 1/3 to 1/5 (mean 1/4) presenting a decreasing trend as well. This indicates that about 1/4 of the total variation accounts for differences among families, while the remaining 3/4 for differences among individual trees. This partition of the total phenotypic variation between and within families is in accordance with the general principle for additive genetic variation in half sib families (FALCONER, 1985).

The narrow sense heritability estimates for dbh were higher than those for height. However, family heritability was higher than the individuals' heritability in both cases (*Table 3*).

It has been reported that heritability estimates for other tree species showed changes over time because of changes in genetic control and the external environment with age (NAMKOONG and CONKLE, 1976). Therefore, heritability estimates apply only to the particular population growing in a given environment at a particular time. Since parental trees are relatives (cov=1/4 V_A) then probably heritability estimates will be affected. In order to find out if it is over – or under – estimated with the formula used, we need more information on potential pollen donors.

Morphological characters

The plants produced from the seeds of the 14 families exhibited great variation in the number of leaflets per compound leaf. The number ranged from one (which was actually a single leaf) to 27 leaflets. The fewer the leaflets the larger their size was. In fact, variation was manifested not only between trees, but also within the same tree, with a tendency the number of leaflets per compound leaf to increase from the bottom to the top of the tree.

Great variation was also detected in the size of thorns among the trees of each one of the 14 families in 1992. More specifically, the maximum length of thorns at the top 50 cm ranged from 0 mm to 25 mm. Similar variation was found by MEBRAHTU and HANOVER (1989) in the trees of 434 families of common *Robinia* in USA.

Variation among the 14 families, with respect to morphological characters, was much reduced compared to within family variation. More specifically, the numer of leaf ranged from 12 to 17, the mean length of thorn from 6.8 mm to 9.2 mm. In addition, the mean rachis length of the compound leaf, and the petiole of the top and bottom leaflets ranged from 15.1 mm to 18.7 mm, 1.4 mm to 2.0 mm and 0.4 mm to 0.7 mm respectively for the three characters; and the surface of the top and bottom leaflets from 12.0 mm^2 to 17.6 mm^2 and 7.1 mm^2 to 10.0 mm^2 respectively for the two characters (*Table 4*).

Table 1. – Mean height and DBH with their standard errors of the whole progeny test plantation during 5 years (1991 to 1995).

	Years				
Trait	1991	1992	1993	1994	1995
Height (cm)	306.0±4.0	437.0±4.0	580.0±5.0	701.0±5.0	728.0±5.0
DBH (mm)	17.7±0.4	32.4±0.5	44.1±0.5	53.7±0.6	58.6±0.6

Table 2. – Analysis of variance for height and DBH (1991 to 1995).

		Height (cm)			DBH (mm)		
Year	Source of variation	df	MS	F	df	MS	F
1991	Replications	2	247,499.5		2	129,956.8	
	Families	13	13,470.3	3.544**	13	16,990.0	4.014**
	Families X Replications	23	10,265.1		23	9,304.2	
	Trees within plots	418	3,801.3		418	4,232.3	
1992	Replications	2	522,078.2		2	257,357.5	
	Families	13	15,624.7	3.357**	13	21,431.0	2.955**
	Families X Replications	23	13,743.4		23	12,237.7	
	Trees within plots	418	4,654.0		418	7,252.0	
1993	Replications	2	1,033,503.0		2	360,213.0	
	Families	13	17,424.5	3.097**	13	18,622.7	1.805*
	Families X Replications	23	11,491.2		23	15,577.7	
	Trees within plots	418	5,626.0		418	10,316.8	
1994	Replications	2	439,782.6		2	138,656.0	
	Families	13	14,866.4	2.586**	13	19,294.6	1.527
	Families X Replications	23	9,165.1		23	12,986.4	
	Trees within plots	317	5,747.7		318	12,638.4	
1995	Replications	2	346,337.7		2	35,393.3	
	Families	13	10,057.6	1.748	13	17,007.7	1.248
	Families X Replications	23	6,534.6		23	12,794.3	
	Trees within plots	317	5,753.2		318	13,625.9	

*P<0.05, **P<0.01

Relations between characters

Leaf morphology types and thorns

On the basis of the general leaf physiognomy of trees, two distinct types were visually identified:

Type I: Trees with compound leaves composed of a few (no more than 11) but large leaflets (oligophyllous trees) and

Type II: Trees with compound leaves composed of many (up to 27) but small leaflets (polyphyllous trees).

Both types were observed within families in ratios close to 1:1.

These two types started to be differentiated in growth characters at the beginning of the 5th year of age and continued up to the 6th year. Type II grew significantly taller, with greater dbh than type I (*Table 5*). The length of the thorns however was found to be significantly longer in type II as compared to type I, in the 2nd year, while thorniness of type II was higher than in type I in the 3rd year, as well (*Table 5*). The results suggest that the small size of thorns or the reduced thorniness is associated with reduced tree growth. These findings do not agree with KIM and LEE (1974) who observed no differences in growth between thornless and thorny types of common *Robinia* as the age of the plant increased. It remains to be seen if the differences in the two tree types distinguished in this study will be maintained in the future.

As far as the distribution of the two tree types in the five classes of thorn length identified in 1992 is concerned, *figure 3*

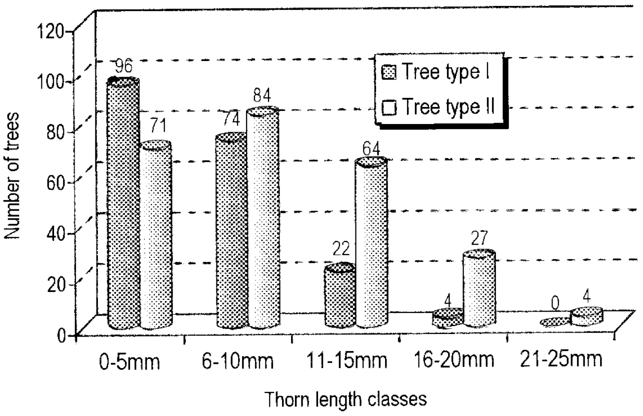

Figure 3. – Frequency ditribution of the two types of trees (identified on the basis of their compound leaf morphology) in the five classes of thorn length (1992).

Table 3. – Coefficient of Variation (CV%), Family Coefficient of Variation (FCV%) and estimates of heritability (familiy & individual) for height and DBH (1991 to 1995).

Trait	Year	Age*(yrs)	CV%**	FCV*** (%)	FCV/ CV	Heritability	
						Family	Individual
Height	1991	2	25	7	1/3.6	0.39	0.25
	1992	3	21	6	1/3.5	0.33	0.21
	1993	4	18	5	1/3.6	0.49	0.26
	1994	5	14	4	1/3.5	0.42	0.18
	1995	6	12	3	1/4	a	a
DBH	1991	2	42	14	1/3	0.61	0.43
	1992	3	30	9	1/3.3	0.64	0.38
	1993	4	25	6	1/4.2	a	a
	1994	5	22	5	1/4.3	a	a
	1995	6	20	4	1/5	a	a

*) Age in years from seed gemination

**)CV = Standard deviation of trait means as a percentage of the overall mean of the progeny test plantation (Freeze, 1967; Fasoulas, 1979).

***)FCV = Standard deviation of family means as percentage of the overall means (Bongarten, 1992).

(a) Could not be calculated due to lack of significant differences among families included in the specific progeny test (Mebrahtu and Hanover, 1989).

clearly shows that the majority of trees had thorn lengths less than 10 mm but trees of type I had smaller thorns than trees of type II. More specifically, type I dominated in the "very small" class (0 mm to 5 mm) but declined thereafter as the size of thorns increased, while type II dominated in the middle and upper classes of thorn length.

Similar results were also found in 1993, when thorniness of trees was evaluated. The distribution of the two types of trees on the five-class scale indicates that trees of type I were predominant in the classes with few and small thorns while trees of type II were predominant in the classes with many and long thorns (*Figure 4*).

Statistical analysis of the differences in thorniness among the 14 families produced no significant results in both years. For this reason, the heritability for this particular character could not be estimated. On the contrary, Mebrahtu and Hano-

Table 4. – Mean values of the morphological characters of the 14 families of *Robinia pseudoacacia* var. *monophylla* evaluated in the progeny test (October 1991).

Family	Morphological characters						
	No of leaflets/ compound leaf	Thorn length (mm)	Compound leaf rachis length (cm)	Petiole length of upper leaflet (cm)	Petiole length of base leaflet (cm)	Surface of upper leaflet (cm²)	Surface of base leaflet (cm²)
1	16	9.2	17.9	1.4	0.4	12.0	7.6
2	14	8.1	14.8	1.7	0.4	13.2	6.9
3	14	8.1	15.8	1.7	0.5	14.9	8.9
4	14	7.6	16.9	1.6	0.4	16.5	10.1
5	17	8.9	18.2	1.4	0.4	13.5	8.0
6	16	7.6	18.1	1.7	0.4	15.2	9.6
7	12	6.8	14.4	1.8	0.4	17.2	8.9
8	14	7.8	16.7	1.7	0.4	12.4	7.1
9	15	7.7	17.3	1.5	0.4	13.5	7.8
10	15	5.9	17.2	1.8	0.5	15.1	8.9
11	17	8.6	18.7	1.7	0.4	16.9	9.7
12	15	8.0	17.9	1.8	0.7	16.3	9.5
13	14	7.9	15.3	1.7	0.4	13.1	7.6
14	12	8.8	15.1	2.0	0.5	17.6	10.0

Table 5. – Means of the two types of trees of *Robinia pseudoacacia* var. *monophylla* with their standard errors for the various traits with t-test values and 2-tail significance.

Traits	Age (years)	Type I	Type II	t-test value	2-tail significance
Height (cm)	2	305±5.5	308±4.6	-0.40^{NS}	0.686
	3	429±6.8	443±5.3	-1.59^{NS}	0.113
	4	570±7.8	587±6.4	-1.78^{NS}	0.075
	5	685±7.8	714±6.3	-2.92**	0.004
	6	718±7.3	737±6.3	-2.07**	0.039
DBH (mm)	2	17.2±5.3	18.1±4.8	-1.25^{NS}	0.211
	3	31.5±6.9	33.1±6.1	-1.74^{NS}	0.082
	4	43.0±8.0	44.9±7.0	-1.78^{NS}	0.076
	5	52.3±9.1	55.0±8.1	-2.23**	0.026
	6	56.8±9.1	60.1±8.1	-2.74**	0.006
Thorn length (mm)	2	6.1±0.29	9.2±5.15	-6.82**	0.000
Thorniness (visually)	3	3.4±0.06	3.8±0.05	-4.58**	0.000

*P< 0.05, **P< 0.01 and NS not significant at the 5% level

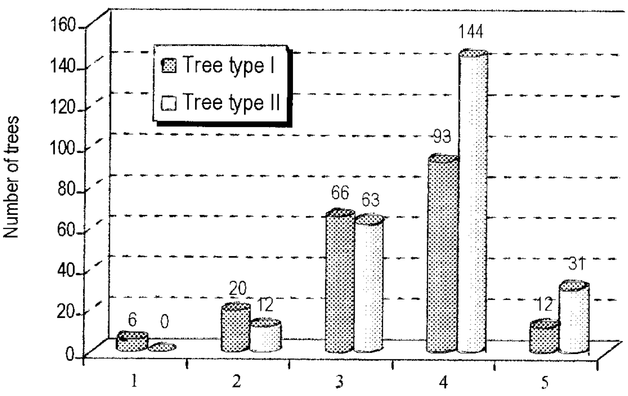

Figure 4. – Frequency ditribution of the two types of trees (identified on the basis of their compound leaf morphology) in the five classes of thorniness (1993).

VER (1989) estimated high heritabilities for thorn length in USA, which ranged from 0.48 to 0.62 for families and 0.74 to 1.16 for individual trees. Statistically significant coefficients (but at a lower order of magnitude) were also calculated by BLOESE *et al.* (1992) for the same character in 2-years old black locust plantations.

Phenotypic correlations between growth and morphological characters

Table 6 shows the PEARSON correlation coefficients between the various growth and morphological characters. It is clear that most of these coefficients turned out to be statistically significant ($P \leq 0.001$), apparently due to the high number of degrees of freedom, but only a few of them were high enough to explain a fair amount of the variation between the various characters.

Although height and dbh were highly correlated, both of them produced very low correlation coefficients with the morphological characters of the trees. For example, height and diameter accounted for no more than 8.4% and 5.8% respectively of the variation in the length of leaf petiole (*Table 6*). On the contrary, KENNEDY (1983) found much higher correlations between diameter and leaf petiole in one-year old saplings of common *Robinia*. In addition, the same author found that height and diameter accounted for 26% and 24% respectively of the variation in the number of leaflets per compound leaf while in our experiment it did not exceed 2%.

Substantially higher correlation coefficients were found between various morphological characters (*Table 6*). For example, a high positive coefficient (0.90) was produced between leaf morphology type and number of leaflets per compound leaf, thus confirming our visual identification of the two types (*Table 5*). The same identification was also confirmed by the relatively high but negative coefficient (–0.74) between the surface of the upper leaf and the number of leaflets per compound leaf combined by the also relatively high but negative (–0.73) coefficient between the type of tree and the surface of the upper leaf. All these correlations suggest that type I had fewer and larger leaflets than type II.

A very high positive correlation coefficient (0.92) was produced between length of rachis and number of leaflets per compound leaf (*Table 6*). As a result, length of rachis was also highly correlated (0.80) with type of tree since its identification was mainly based on the number of leaflets per compound leaf. KENNEDY (1983) found a much lower correlation coefficient (0.69) between length of rachis and number of leaflets per compound leaf for common *Robinia;* the latter variability in the number of leaflets per compound leaf, is not the same as in *monophylla.*

As far as the pair of thorns and the length of the thornless upper part of the trees are concerned, these produced very weak correlation coefficients when compared to the number of leaflets per compound leaf, the surfaces of the leaflets and the rachis of compound leaf. Also, very low coefficients were estimated among the thorn length and all leaf characteristics. KENNEDY (1983) found similar results, although the respective coefficients were higher than the ones in our experiment. Moreover, a low correlation coefficient (0.32) was produced between thorn length and type of trees. This is not surprising since thorn length is a complex morphological character affected by various factors including shade and age of trees (KENNEDY, 1983). Larger leaflets were also observed by KIM and LEE (1974) in a thornless mutant tree when compared to common

Table 6. – Phenotypic correlations between morphological and growth characters in the progeny test of *Robinia pseudoacacia* var. *monophylla.*

	Surface of lower leaflet	Surface of upper leaflet	Petiole of lower leaflet	Petiole of upper leaflet	Rachis length	Thorn pairs	Length of the thornless top part of the main stem	Tree type	Thorn length	DBH	Height
Number of leaflets	-0.476**	-0.738**	-0.118*	-0.55**	0.908**	-0.046NS	-0.147**	0.902**	0.255**	0.146**	0.13**
Surface of lower leaflet		0.80**	0.278**	0.554**	-0.23**	-0.252**	0.06NS	-0.528**	0.266**	0.191**	0.322**
Surface of upper leaflet			0.222**	0.595**	-0.562**	-0.159**	0.108*	-0.726**	-0.258**	0.091NS	0.185**
Petiole of lower leaflet				0.323**	-0.018NS	-0.115*	0.04NS	-0.175**	-0.112*	0.092NS	0.16**
Petiole of upper leaflet					-0.374**	-0.036NS	0.054NS	-0.576**	-0.233**	0.005NS	0.127**
Rachis length						-0.184**	-0.139**	0.80**	0.198**	0.236**	0.287**
Thorn pairs							-0.65**	0.029NS	0.255**	-0.318**	-0.385**
Length of the thornless top part of the main stem								-0.20**	-0.32**	0.108*	0.15**
Tree type									0.324**	0.054NS	0.028NS
Thorn length										-0.248**	-0.356**
Thorniness (visually)								0.212**	0.506**		

*P< 0.05, **P< 0.01 and NS not significant at the 5% level

Table 7. – Phenotypic correlations between growth parameters (lower diagonal) and genetic correlations between growth parameters and traits (upper diagonal) in the progeny test of *Robinia pseudoacacia* var. *monophylla* (the age of plantation is shown in brackets).

	DBH (2)	Height (2)	DBH (3)	Height (3)	DBH (4)	Height (4)	DBH (5)	Height (5)	DBH (6)	Height (6)	Thorn length	Trunk form
DBH (2)											a	
Height (2)	0.90**										a	
DBH (3)	0.943**	0.857**		0.94					0.87	-0.39		-0.97
Height (3)	0.790**	0.902**	0.816**							0.61		
DBH (4)	0.841**	0.770**	0.935**	0.764**								
Height (4)	0.624**	0.773**	0.680**	0.888**	0.707**							
DBH (5)	0.759**	0.667**	0.854**	0.633**	0.945**	0.567**						
Height (5)	0.606**	0.706**	0.667**	0.799**	0.728**	0.870**	0.682**					
DBH (6)	0.690**	0.591**	0.778**	0.540**	0.879**	0.466**	0.965**	0.623**		-0.77		
Height (6)	0.539**	0.616**	0.613*	0.719**	0.693**	0.816**	0.671**	0.947**	0.626**			

*P< 0.05, **P< 0.01 and NS not significant at the 5% level

(a) Could not be calculated due to lack of significant differences among families included in the specific progeny test.

black locust. Evidently, there is a positive correlation between small thorns and larger leaflets. Finally, thorniness did not produce a substantial correlation coefficient with type of tree, although its coefficient with the thorn length was much higher (0.51, *Table 6*).

Phenotypic correlations between growth characters

With regards to the relations between height and diameter, *table 7* shows that all correlations with respect to growth characters were statistically significant and correlation coefficients were much higher in the early than in the older ages of the plantation. For example, height could explain 81% of the variation in the diameter in 2 years old trees and only 39% in 6 years old trees. Similar results were also found by Bloese *et al.* (1992) and Kennedy (1983) in U.S.A. for common black locust.

The correlations involving diameter (in different ages) were generally slightly stronger (5%) than those of height, while Bloese *et al.* (1992) also reported stronger correlation between 3rd and 5th year diameter (31%).

Genetic correlations

Table 7 shows the genetic correlations of some growth and morphological characters. It is clear that there was a high and positive correlation between diameter and height in the 3rd year, but a lower and negative one in the 6th year. This may be attributed to pruning that was applied between the two periods. Also, a low and negative correlation was found between height in the 6th year and diameter in the 3rd year. These results are different from the ones found by Bloese *et al.* (1992) who detected a high and positive correlation between these two growth factors in the 5th year.

On the other hand, the genetic correlation between various ages of the same parameter were positive; high between diameters in the age 3 and 6 and less high between heights in the ages 3 and 6. Higher correlation between diameters than between heights was also found by Bloese *et al.* (1992).

Finally, the correlation between diameter in the 3rd year and trunk form was high but negative. Since no pruning has been applied to that period, this relation can most probably be attributed to the fact that larger diameter and undesirable trunk form may be due to strong branching at breast height.

Conclusions

The following conclusions may come out of this study:

1. The growth performance of the *monophylla* variety should be considered very satisfactory compared to the one of common black locust.

2. Based on the results of this study, selection of polyphyllous type individuals from the *monophylla* black locust could lead to increased growth and also to an increased thorn size. Therefore, this should be taken into account when the selection criteria for a breeding programme are set out.

3. Strong genetic correlations of dbh as well as height, to a lesser extend, have been detected between the 3rd and the 6th year of the experiment. If this trend continues in the future, then juvenile selection could be based on dbh and height growth.

Acknowledgements

This research was financed by the Greek Ministry of Agriculture and by the CAMAR programme of the European Commission (8001 – CT 90 – 0030). The genetic material was collected from trees planted by Prof. emeritus Leonidas Liacos. The authors express their appreciation to Dr. F. A. Aravanopoulos for his valuable comments on the manuscript and to an unknown reviewer for his helpful remarks.

References

Barrett, R. P., Mebrahtu, T. and Hanover, J. W.: Black locust: A multipurpose tree species for temperate climates. pp. 278–283. In: J. Janick and J. E. Simon (eds.) Advances in new crops. Timber Press, Portland, OR (1990). — Bloese, P., Hanover, J. W. and Bongarten, B. C.: Inheritance of Juvenile traits and Predicted Gains from Selection in Black Locust Progeny Tests in Michigan and Georgia. In: Proceedings of International Congress on: Black Locust: Biology, Culture and Utilization. Held June 17 to 21, 1991. East Lansing, Michigan, USA. pp. 97–107 (1992). — Bongarten, B.: Genetic variation in Black locust within its native range. In: Proceedings of International Congress on: Black Locust: Biology, Culture and Utilization. Held June 17 to 21, 1991. East Lansing, Michigan, USA. pp. 78–97 (1992). — Dini-Papanastasi, O.: Black locust: A neglected forest tree. Geotechnic Scientific Issue **4**: 55–58. (In Greek with English summary) (1991). — Dini-Papanastasi, O.: Exploitation of arable and forest lands with plantations of *Robinia pseudoacacia* L. In: Proceedings of the 7th Panhellenic Forestry Congress. Held in Karditsa, Greece, 11 to 13 October, 1995. pp. 96–103 (1996). — Dini-Papanastasi, O.: Inheritance of traits of *Robinia pseudoacacia* L. and their relation with biomass production. PhD Thesis, Aristotle University of Thessaloniki, Greece 152 p. (1997). — Falconer, D. S.: Introduction to Quantitative Genetics. 2nd Edition. Longman Group Ltd., London. 340 p. (1985). — Fasoulas, A. K.: Elements of Experimental Statistics. Thessaloniki. 255 p. (1979). — Fowells, H. (Ed.): Silvics of Forest Trees of the United States. Agriculture Handbook No. 271. U.S. Department of Agriculture, Washington D.C.20250. 762 p. (1965). — Freeze, F.: Elementary Statistical Methods for Foresters. Agriculture Handbook 317. U.S. Department of Agriculture. Forest Service. (1967). — Halupa, L. and Redei, K.: Tending operations in Black Locust stands established by seedlings and coppicing. In: The Black Locust. Forestry Monograph - Series of the Agricultural Science Department of the Hungarian Academy of Science. Ed. B. Keresztesi. Budapest. 197 p. (1988). — Hanover, J. W.: Physiological genetics of black locust (*Robinia pseudoacacia* L.): a model multipurpose tree species. 175–183. In: Werner, D. and P. Móller (Eds.). Fast Growing Trees and Nitrogen Fixing Trees, Intl. Conf., Oct. 8 to 12, 1989, Marburg, Germany (1990). — Kavvadas, D.: Illustrated Botanical Dictionary. Volumes I to IX. Athens (1956). — Kennedy, J. M., Jr.: Geographic variation in black locust (*Robinia pseudoacacia* L.). M. S. Thesis, The Univ. of Georgia, Athens, G.A. 66 p. (1983). — Keresztesi, B.: Breeding and Cultivation of Black Locust, *Robinia pseudoacacia,* in Hungary. Forest Ecology and Management **6**: 217–244 (1983). — Kim, C. S. and Lee, S. K.: Studies on Characteristics of Selected Thornless Black Locust. Research Report No. 11: 1–12 of the Institute of Forest Genetics. Suwon, Korea (1974). — Liacos, G. L., Nastis, A. S. and Tsiouvaras, C. N.: Forage value of Selected Brush Species. FAO Working group on: Forage values of Mediterranean plants and byproducts. Zaragoza, Spain (1983). — Matziris, D. I. and Zobel, B. J.: Inheritance and Correlations of Juvenile Characteristics in Loblolly Pine (*Pinus taeda* L.). Silvae Genetica **22**, 1–2: 38–44 (1973). — Mebrahtu, T. and Hanover, J. W.: Heritability and expected gain estimates for traits of black locust in Michigan. Silvae Genet. **38**: 125–130 (1989). — Namkoong, G. and Conkle, M. T.: Time Trends in Genetic Control of Height Growth in Ponderosa Pine. Forest Science **22**: 2–12 (1976). — Pages, L.: Lois de croissance en biomasse du taillis: le robinier dans le Val-de-Loire. Ann. Sci. For. **43** (4): 533–550 (1986). — Panetsos, K. P.: Forest Tree Breeding. Yiahoudis – Yiapoulis. Thessaloniki, 308 p. (In Greek) (1986). — Redei, K.: Management of Black Locust Stands in Hungary. In: Proceedings of International Congress on: Black Locust: Biology, Culture and Utilization. Held June 17 to 21 1991. East Lansing, Michigan, USA pp. 38–43 (1992). — Steel, R. G. D. and Torrie, J. H.: Principles and Procedures of Statistics. McGraw-Hill Book Co., Sydney. 633 p. (1980). — Tsiontsis, A.: Meteorological data of the Forest Meteorological Stations of Northern Greece. Forest Research Institute Bulletin, Thessaloniki, Greece (1995). — Zobel, B. J. and Talbert, J. T.: Applied Forest Tree Improvement. John Wiley & Sons, New York, Toronto. 505 p. (1984).