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Growth characters and number of strobili in clonal seed orchards of *Pinus sylvestris*

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Abstract Observations were made on six grafts for each of 25 clones in three Scots pine (*Pinus sylvestris*) seed orchards in Turkey. The characters studied were number of female and male strobili, height below and above the longest branch, total height; diameter at base and breast height, crown diameter, and number of branches. Variation, broad-sense heritability (H^2) and correlations between characters were estimated.

Variation among clones was lower than among grafts within clone for all characters. The genetic variation for number of strobili varied between 0 and 17% of total variation, while that for growth characters values varied between 2 and 13%. The number of female strobili appeared more variable among trees than the number of male strobili. H^2 was not consistently high for any character or seed orchard. The number of strobili increased with the size of the tree, but not dramatically. Correlations between measures of tree size (both on clone level and individual graft level) and the number of strobili were in the magnitude $r \approx 0.3$. Diameter at breast height seems a reasonable predictor for number of strobili.

Keywords Flowering · Graft size · Heritability · Scots pine · Variation

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Introduction

Seed orchards are an important seed source for forest plantations. They constitute the most important link between tree breeding and plantation forestry. Considerable progress has been made in understanding the reproductive biology of conifers in seed orchards (e.g., Kang 2001). Reproductive differences in seed orchards will affect the seed crop. The economy of seed orchards is dependent on a high seed production, which is convenient to collect. Thus, it is important to get information of variation in reproductive characters. Production of seed and pollen, and feasibility of cone collection, depend on the size and morphology of the tree. Thus, it is important to know how reproductive characters vary and relate to growth characters. Although rather many studies have been done on variation in reproductive output, few have considered the relation with growth characters (Bhumibhamon 1978; Nikkanen and Velling 1987; Burczyk and Chalupka 1997).

Scots pine (*Pinus sylvestris* L.) is one of the economically and ecologically most important forest tree species. In Turkey, Scots pine forests cover about 757,000 ha, which is nearly 4% of the total forest area (Anonymous 2005). The annual planting is about 37 million seedlings (Mikola 1991). While Turkey has 21 Scots pine seed orchards on 114 ha (Anonymous 2001), only 9.2% of annual seed demand for plantations was covered from the orchards at the beginning of the millenium (Cengiz 2003). Most plants originate from phenotypically selected seed stands, but seed orchards are becoming gradually more important.

The purposes of this study were to evaluate variation broad-sense heritability and correlations, for number of strobili and growth characters among clones and grafts in Scots pine seed orchards. The results of the study are also discussed with respect to the management of seed orchards.

Material and methods

The study considered three clonal seed orchard populations of *P. sylvestris* (Table 1; Anonymous 2001).

Each seed orchard was established with grafted clones of plus trees selected in a specific seed stand, thus the genotypes in each seed orchard could be viewed as separate populations. No artificial pruning had been done in the orchards.

Data were collected on six grafts, chosen at random, from each of 25 clones, chosen at random, in each seed orchard in the spring and summer 2005. The following observations were made:

- number of female strobili (cone maturation 2006, $N_{♀}$);
- number of male strobili ($N_{♂}$);
- height below the longest branch ($H_<$, cm);
- height above the longest branch ($H_>$, cm);
- total height (H_T, cm);
- crown diameter (C_D, cm), the largest distance between branch tips projected horizontally;
- diameter immediately above the grafting point, basal diameter (D_0, cm);
- diameter at breast height (D_{BH}, cm); and
- total number of branches (N_B).

In order to consider co-variation of characters that are less dependent on development over time and in different environments, we also calculated the following quotients of observations:

- quotient of height below the longest branch and total ($H_q = H_</H_T$); and
- quotient of diameter at breast height and basal diameter ($D_q = D_{BH}/D_0$).

Table 1 Studied seed orchards

Seed orchard code	SO_1	SO_2	SO_3
Region	Adapazari	Bolu	Kastamonu
Location name	Sogutlu	Mengen	Taskopru
Orchard latitude	40°52′N	40°56′N	41°36′N
Orchard longitude	30°42′E	32°13′E	35°05′E
Orchard altitude	120 m	850 m	1500 m
Establishment year	1986	1988	1995
Clones	29	30	30
Remaining grafts 2005	1265	1034	1987
Remaining grafts per ha	204	203	276
Spacing at planting (m)	7*7	7*7	6*6
Origin name	Dirgine	Aladag	Arac
Origin province	Zonguldak	Bolu	Kastamonu
Origin latitude	41°02′N	40°35′N	41°10′N
Origin longitude	31°57′E	31°42′E	33°15′E
Origin altitude	900 m	1500 m	1500 m

Genetic parameters

The following linear model was used for the analysis:

$$Y_{ij} = \mu + C_i + e_{ij}$$

where Y_{ij} is the observation from the jth graft of the ith clone, μ is overall mean, C_i is the random effect of the ith clone, and e_{ij} is random error. The error includes environmental variation as well as random sources of genetic deviation due to somatic mutations and genetic variation among rootstocks.

Broad-sense heritability (the fraction of the variance which is genetic among clones, H^2) was estimated as:

$$H^2 = \frac{\sigma^2_{\mathrm{C}}}{\sigma^2_{\mathrm{C}} + \sigma^2_{\mathrm{e}}}$$

where $\sigma^2{}_{\mathrm{C}}$ is the variance among clones, $\sigma^2{}_{\mathrm{e}}$ is the variance within clone.

Variance components, expressed as coefficient of variation among clones ($\mathrm{CV_C}$) and within clone ($\mathrm{CV_e}$), were estimated as: $\mathrm{CV_C} = 100\sigma_{\mathrm{C}}/\bar{x}$ and $\mathrm{CV_e} = 100\sigma_{\mathrm{e}}/\bar{x}$, where $\bar{x}$ is overall character mean.

Correlations among characters were calculated at the levels of individual grafts and clonal means.

Results

Results from observations and calculations including variation and heritability were compiled (Table 2). There were considerable differences among the orchards for most characters. Almost all characters were highest in the oldest seed orchard ($\mathrm{SO_1}$) and lowest (except $N_{♂}$) in the youngest seed orchard ($\mathrm{SO_3}$).

From the data presented in Tables 1 and 2, we calculated the per-hectare number of male and female strobili. Numbers of female strobili, $N_{♀}$, were 51,600, 33,100 and 48,900 in $\mathrm{SO_1}$, $\mathrm{SO_2}$ and $\mathrm{SO_3}$, respectively. Numbers of male strobili, $N_{♂}$, were 149,700, 82,200 and 64,500, respectively. Furthermore, the ratio between male and female strobili was calculated to 2.9, 2.5 and 1.3 from the oldest to the youngest seed orchard, respectively, suggesting that pollen production increases as a seed orchard matures.

Figure 1(a–c) illustrates how the number of strobili relates to diameter at breast height, crown diameter and the fraction of stem that is below the longest branch on the number of strobili. The graphs were obtained by fitting second-degree polynomials for individual graft values.

The number of strobili increases with increasing stem diameter, but it appears that the number approaches a maximum, beyond which an increase in diameter does not produce more strobili (Fig. 1a). Regarding crown diameter, neither $\mathrm{SO_1}$ nor $\mathrm{SO_3}$ reached a maximum strobili production and the increase with crown diameter was nonlinear (Fig. 1b). Figure 1c indicates that it can be favorable for strobili number if the crown is tall and the low branches active (H_{q} is low), since the number of strobili often decreases with increasing H_{q}.

Table 2 Average ($\bar{x}$); coefficient of variation among ($\mathrm{CV_C}$, %) and within clones ($\mathrm{CV_e}$, %); and broad sense heritability (H^2)

	$\mathrm{SO_1}$				$\mathrm{SO_2}$				$\mathrm{SO_3}$				Average		
	$\bar{x}$	$\mathrm{CV_C}$	$\mathrm{CV_e}$	H^2	$\bar{x}$	$\mathrm{CV_C}$	$\mathrm{CV_e}$	H^2	$\bar{x}$	$\mathrm{CV_C}$	$\mathrm{CV_e}$	H^2	$\mathrm{CV_C}$	$\mathrm{CV_e}$	H^2
$N_{♀}$	253	8.7	20.9	0.15	163	0	28.3	0	177	17.4	42.2	0.14	8.7	30.5	0.10
$N_{♂}$	734	8.7	19.8	0.16	405	0	23.2	0	234	12.8	23.6	0.23	7.2	22.2	0.13
$H_<$	154	13.4	31.4	0.16	181	7.8	18.7	0.15	86	5.3	25.1	0.04	8.8	25.1	0.12
$H_>$	545	12.9	17.1	0.36	490	5.2	20.5	0.06	253	8.1	15.5	0.21	8.7	17.7	0.21
H_{T}	700	11.9	12.6	0.47	671	4.2	15.7	0.07	339	6.3	10.4	0.27	7.5	12.9	0.27
H_{q}	0.23	9.8	35.0	0.07	0.28	11.9	22.9	0.21	0.26	11.1	27.0	0.27	10.9	28.3	0.18
C_{D}	467	9.5	14.8	0.29	349	12.3	20.3	0.27	234	4.0	22.2	0.03	8.6	19.1	0.20
D_0	24.0	8.6	10.5	0.40	14.2	6.2	16.9	0.12	10.0	3.7	17.7	0.04	6.2	15.0	0.19
D_{BH}	21.1	9.2	10.6	0.43	12.6	6.3	18.5	0.10	6.6	6.3	19.9	0.09	7.3	16.3	0.21
D_{q}	0.88	2.6	6.6	0.14	0.89	1.6	9.2	0.03	0.6	7.1	11.9	0.26	3.8	9.2	0.14
N_{B}	45.2	4.7	22.7	0.04	55.1	6.0	22.2	0.08	33.3	6.7	17.5	0.13	5.8	20.8	0.08

The genetic variation, here expressed as the coefficient of variation among clones (CV_C), was always lower (Table 2) than the variation among individual grafts within clones (CV_e). Genetic variation for the number of strobili varied between 0 and 17%, and the variation within clones

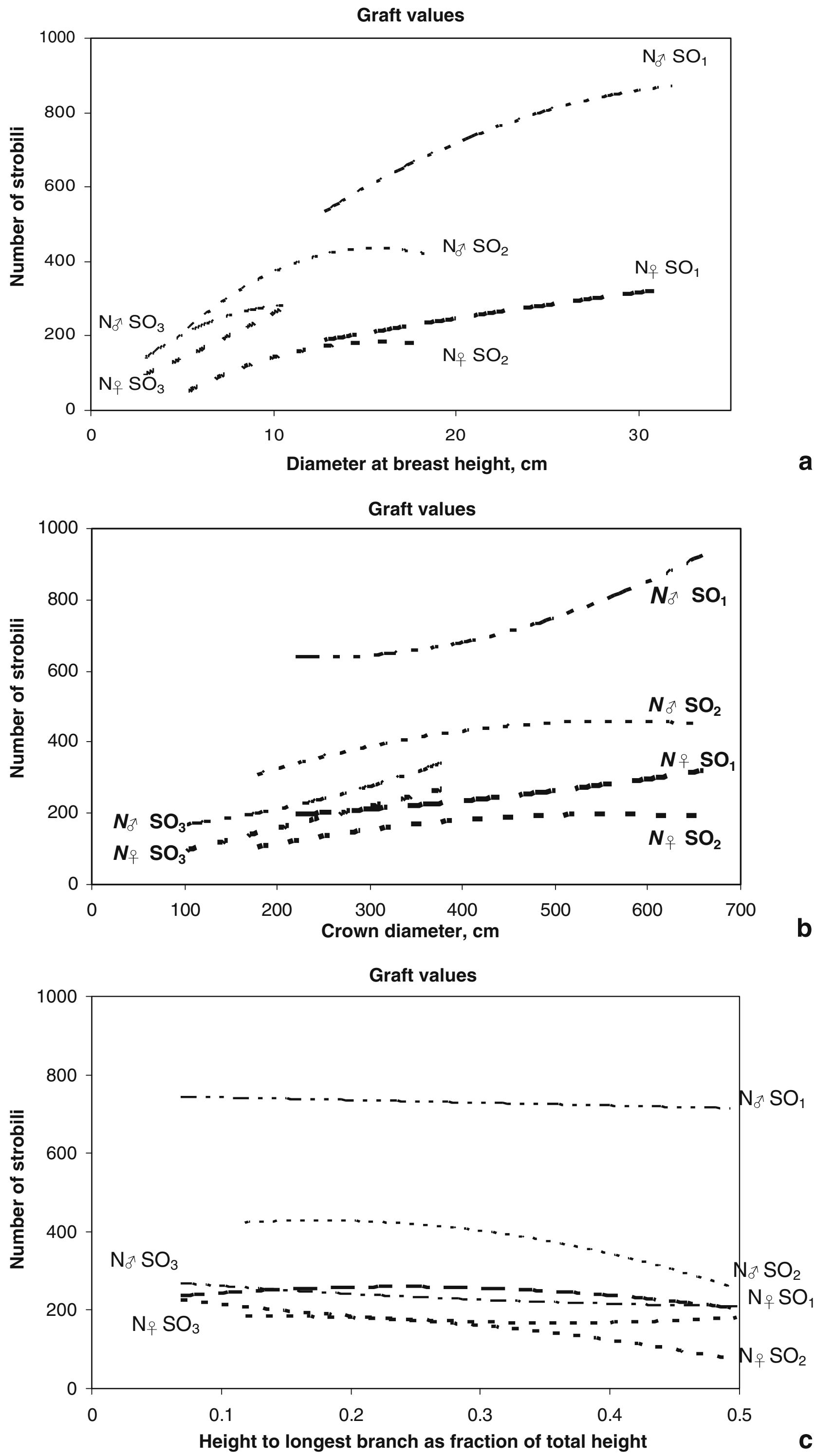

Fig. 1 The relation between number of female and male strobili and: (**a**) diameter at breast height; (**b**) crown diameter; (**c**) height to longest branch (fraction of total height) in the three orchards

among individual grafts between 20 and 42% (Table 2). Even less variation was found for growth characters; the CV_C ranging between 1.6 (D_q) and 13.4% ($H_<$); CV_e between 1.6 (D_q) and 31.4% ($H_<$).

As seen in Table 2, there were large differences among the orchards and characters for broad-sense heritability. As there was no observed clonal variation for number of strobili in SO_2, H^2 becomes 0. H^2 ranged from 0.04 (N_B) to 0.47 (H_T) in SO_1; from 0.0 ($N_♀$ and $N_♂$) to 0.27 (C_D) in SO_2; from 0.03 (C_D) to 0.27 (H_T and H_q) in SO_3. That broad-sense heritability never exceeded 0.5 reflects that the variation among grafts caused by environmental variation was always higher than that caused by the genetic variation, thus environment was more important than genetics in this study!

The variation seemed higher for the number of male strobili than for that of female strobili among clones; the difference seemed marginal among clones while it appeared considerable within clones. The heritability of $N_♂$ seemed higher than that of $N_♀$ (Table 2). As genetic difference among clones and the broad-sense heritability appeared low, in the following attention was focused on how different observations correlate with the number of strobili at the graft level.

The correlations were relatively high for diameter at breast height and appeared stable over seed orchards and strobili gender compared to the other correlations (Table 3). Some combinations of characters not shown (e.g., H_T*C_D*N_B) were also computed, but did not appear better than those shown. Diameter at breast height is easy to measure, it is the most established measure of tree size and it is not much affected by pruning (a common practice in many seed orchards), and thus seems a logical choice for measurement of graft size.

The number of female and male strobili had a correlation that was positive, significant ($P \leq 0.05$) and rather high, both for individual grafts and for clonal averages (Table 3). Correlations between growth characters and numbers of strobili varied. For clonal averages most correlations were positive, but few significant. For grafts, almost all growth characters were significantly positively correlated to numbers of male and female strobili (Table 3).

The height to the longest branch is clearly negatively correlated to the number of strobili in SO_2 (Table 3, Fig. 1c), indicating that trees where the crown starts high up and the lowest branches are not well developed did not produce as many strobili as trees with better development of the lower branches. For SO_1 and SO_3 there was, however, no evident relationship (Fig. 1c). The number of branches was positively correlated with the number of strobili only in SO_2 (Table 3).

The numbers of strobili increased with the size of the trees in all seed orchards (Fig. 1). From the oldest seed orchard, the impression is that the number of male strobili increases faster with tree size than the number of female strobili, but this does not appear to be the case in the younger seed orchards. The curves seem to overlap among seed orchards. There seems to be a tendency that the increase of number of strobili is declining for the largest orchard trees. Trees in SO_1 and SO_2 have similar height and similar crown diameter, but SO_1 has a much larger breast height diameter and more strobili.

In Fig. 2, the cumulative strobili contribution over diameter at breast height for individual trees is presented. The figure is based on the average of the relative female and male contribution. The graphs show the cumulated contribution of trees below a certain diameter. The figure is an effort to graphically visualize the summed genetic impact of trees of a size group. The graphs are almost linear, which means that all trees in a diameter interval contribute about as much together.

Discussion

Seed orchard characters (growth, morphology, number of strobili) appear to have limited genetic variation and low broad-sense heritability. This indicates that it is not efficient to put much weight on graft characters that are desirable in a seed orchard when selecting orchard clones (like high seed yield and pollen production or easily harvestable cones). The environmental within-clone variation is large even under uniform seed orchard conditions. Considerable differences in fer-

Table 3 Correlations between grafts (below diagonal) and clones (above diagonal) in the three orchards

		$N_♀$	$N_♂$	$H_<$	H_T	H_q	C_D	D_{BH}	D_q	N_B
$N_♀$	SO_1		0.832[a]	0.319[b]	0.398[a]	–0.019[b]	0.516[a]	0.376[b]	0.274[b]	0.283[b]
	SO_2	–	0.767[a]	–0.064[b]	0.580[a]	–0.355[c]	0.394[b]	0.602[a]	0.120[b]	0.028[b]
	SO_3		0.431[c]	0.081[b]	–0.225[b]	0.249[b]	0.088[b]	0.003[b]	–0.296[b]	–0.552[a]
$N_♂$	SO_1	0.776[a]		0.323[b]	0.323[b]	0.088[b]	0.484[c]	0.316[b]	0.405[c]	0.281[b]
	SO_2	0.857[a]	–	–0.284[b]	0.321[b]	–0.374[c]	0.292[b]	0.526[c]	0.070[b]	–0.018[b]
	SO_3	0.557[a]		0.173[b]	–0.087[b]	0.224[b]	0.289[b]	0.082[b]	–0.222[b]	–0.584[a]
$H_<$	SO_1	0.135[b]	0.109[b]		0.509[a]	0.605[a]	0.185[b]	0.432[c]	0.447[c]	0.343[b]
	SO_2	–0.011[b]	0.002[b]	–	0.354[b]	0.664[a]	–0.080[b]	0.062[b]	0.342[b]	–0.091[b]
	SO_3	–0.029[b]	–0.034[b]		0.162[b]	0.675[a]	0.317[b]	0.466[c]	0.678[a]	–0.310[b]
H_T	SO_1	0.274[a]	0.251[a]	0.291[a]		–0.290[b]	–0.248[b]	–0.127[b]	–0.023[b]	–0.091[b]
	SO_2	0.449[a]	0.334[a]	0.316[a]	–	–1905[b]	–0.067[b]	–0.183[b]	0.061[b]	–0.088[b]
	SO_3	0.238[a]	0.306[a]	0.117[b]		–0.438[c]	–0.161[b]	–0.052[b]	0.289[b]	–0.545[a]
H_q	SO_1	–0.330[b]	–0.027[b]	0.801[a]	–0.263[a]		0.521[c]	0.704[a]	0.622[a]	0.523[a]
	SO_2	–0.325[a]	–0.237[a]	0.621[a]	–0.426[c]	–	0.464[c]	0.762[a]	0.336[b]	0.106[b]
	SO_3	–0.104[b]	–0.143[b]	0.842[a]	–0.347[a]		0.584[a]	0.717[a]	0.423[c]	0.329[b]
C_D	SO_1	0.420[a]	0.382[a]	0.003[b]	–0.253[a]	0.466[a]		0.605[a]	0.436[c]	0.583[a]
	SO_2	0.450[a]	0.364[a]	0.101[b]	–0.247[a]	0.599[a]	–	0.746[a]	0.059[b]	0.363[b]
	SO_3	0.404[a]	0.514[a]	0.015[b]	–0.297[a]	0.664[a]		0.557[a]	0.222[b]	–0.073[b]
D_{BH}	SO_1	0.381[a]	0.351[a]	0.144[b]	–0.197[c]	0.622[a]	0.584[a]		0.318[b]	0.493[c]
	SO_2	0.462[a]	0.362[a]	0.133[b]	–0.393[a]	0.789[a]	0.755[a]	–	0.312[b]	0.185[b]
	SO_3	0.400[a]	0.407[a]	0.083[b]	–0.250[a]	0.758[a]	0.691[a]		0.621[a]	0.077[b]
D_q	SO_1	0.133[b]	0.151[b]	0.128[b]	–0.003[b]	0.278[a]	0.152[b]	0.298[a]		0.332[b]
	SO_2	0.137[b]	0.119[b]	0.078[b]	–0.190[b]	0.350[a]	0.176[c]	0.406[a]	–	0.009[b]
	SO_3	–0.078[b]	–0.056[b]	0.291[b]	0.124[b]	0.351[a]	0.112[b]	0.517[a]		0.053[b]
N_B	SO_1	–0.011[b]	–0.002[b]	0.244[a]	0.044[b]	0.353[a]	0.238[a]	0.248[a]	0.109[b]	
	SO_2	0.306[a]	0.265[a]	0.166[b]	–0.107[b]	0.336[a]	0.380[a]	0.374[a]	0.094[b]	–
	SO_3	–0.111[b]	–0.124[b]	–0.063[b]	–0.195[b]	0.223[a]	0.101[b]	0.140[b]	–0.001[b]	

[a]Statistically significant at 0.01 probability level

[b]Non-significant

[c]Statistically significant at 0.05 probability level

tility between ramets of clones were reported in clonal seed orchards of *Tectona grandis* by Varghese et al. (2006). This means that to create desirable characters in seed orchard trees, there ought to be a large potential of management, which affects "the environment". Examples of management are forming tree crowns by pruning and applying suitable fertilizing regimes. Differences in gamete contribution among clones could be genetic (Eriksson et al. 1973), environmental (Hedergart 1976) and management of orchard (Zobel and Talbert 1984). As the environmental variation seems larger for female than for male strobili (Table 2), the potential to increase seed production by management may be higher than that of increasing pollen production. Variable flowering occurs among seed orchard locations and years. Many factors may be involved (Lindgren et al. 1977). Thus, many other factors than considered here may influence the differences among the orchard crops studied. Still, age and the associated tree size, which are the only factors registered here, are likely to be important reasons for differences between the youngest (SO_3) and older (SO_1 and SO_2) seed orchards.

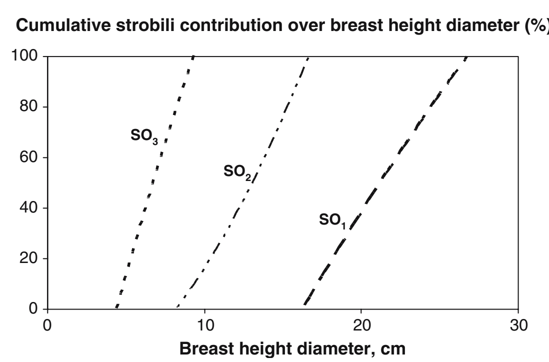

Fig. 2 Cumulative contribution (average of female and male contributions) over diameter at breast height for grafts in the three orchards

A seed orchard can be regarded as a clonal trial based on which the clones with the most desirable characteristics for forestry are selected. Tree growth can be regarded as such a characteristic. The CV_C for growth seems to be in the magnitude 7%. The environment is not representative for forestry and there are no replications at other localities; it is an odd type of experiment; and the clone genotypes reflect more than additive variance, but it still seems likely a selection of the best 20% of clones based on this clonal test for use in new seed orchards or for long term breeding would give improvement in breeding value for growth corresponding to something like 3% in production. Removing (genetic thinning) clones characterized by slow growth can probably raise the breeding value for production in the existing seed orchard by a percent or so.

Clonal means are the average of six grafts and this is subject to sampling error, we did not adjust for that when discussing relationships among characters, thus genetic correlations would be expected to be higher than reported in Table 3.

Variance among clones (genetic variances) was rather low within the orchards (Table 2); it was actually estimated to zero in SO_2. Each seed orchard was established with plus trees phenotypically selected in a specific seed stand (Table 1). That the genetic variation in these seed orchards only reflects genetic variation within a single stand could be one reason for genetic variation to be low, but genetic variation in forest trees is generally dominated by variation within stands. In a series of forest tree studies, including three with Scots pine, reviewed by El-Kassaby (1991), only a few percent of the variation is among stands. Turna (2003) estimated, based on isozymes studies in 11 Turkish Scots pine seed stand populations that (0.014/0.220=) 6% of the average gene diversity was among populations and the rest within, indicating that Scots pine in Turkey fits into the pattern indicated by El-Kassaby (1991). Two of the base populations used for two of the seed orchards in this study were included in the study by Turna (2003). It does not seem that they have a marked low diversity compared to other Turkish stands or other Scots pine, thus base stands with low diversity does not explain the low genetic variation found here.

The differences in heritability among the characters in the orchards could be caused by differences among the seed stand populations that were used for selecting clones for the seed orchards. Heritability was low for strobilus production (0.10 for $N_♀$ and 0.13 for $N_♂$ in average). Therefore, management strategy for orchards should be prepared at orchard level. It is also supported by heritability differences among orchards. For instance, H^2 was 0.47 in SO_1, 0.07 in SO_2 and 0.27 in SO_3 for H_T (Table 2). Clonal repeatability (broad-sense heritability) was 0.26 for $N_♀$ and 0.18 for $N_♂$ in SO_1 according to 2001 data by Bilir (2002). Nikkanen and Ruotsalainen (2000) mentioned that broad-sense heritability averaged 0.36 and 0.37 for female and male flowering in Norway spruce. Almqvist et al. (2001) reported for *Picea abies* clonal trials that broad-sense heritability values derived for cone-set varied from 0.29 to 0.57, and were two to three times higher than those for growth traits. Heritability of $N_♂$ was higher than that of $N_♀$. Narrow-sense heritability of male strobilus production (0.64 and 0.39) was higher than that of female (0.42 and 0.13) in *Pinus contorta* for different years (Hannerz et al. 2001). It was generally opposite in *Pinus densiflora*, depending on year (Kang 2000).

Intensive selection of plus trees may reduce the variation in the selected characters like growth characters, but if the heritability is low, selection is not expected to reduce variance much, and as the heritability was low even in environmentally uniform seed orchards, selection is not a likely reason for low genetic variation. Clones/plus trees are selected initially according to their phenotypes for traits such as vigor, form, wood quality or other desired characteristics, which include general adaptability (Zobel and Talbert 1984). Cone set is sometimes used as a criterion for selecting clones to seed orchards. In this study, the heritability was rather low and the genetic variation limited for the number of female strobili, suggesting that high gain in cone set cannot be expected by selecting clones where a few ramets have been observed with many cones. However, when we know genetic information (e.g., genetic value, fertility), such information could also be used as a criterion of selection for seed production in seed orchards (Bilir et al.

2004). So, a population of plus trees, which has high heritability for strobili or cone set, can be examined for that purpose.

Strobilus production increases with size of grafts (Fig. 1), thus thinning out grafts with slow growth would probably, in the same time as improving the growth of the seed orchard trees, also increase seed production and internal pollination. The increasing could possible be as number of strobili per area reach a maximum value for a mature seed orchard. Bhumibhamon (1978) reported positive correlations among number of strobili and length, diameter and volume of graft crowns in Scots pine. Similar findings were reported in *Picea abies* by Nikkanen and Ruotsalainen (2000). A tree can allocate its resources for vegetative growth or reproduction. A selection (intentional or unintentional) favoring reproduction could have a negative effect on growth in the forest. Negative genetic correlations between flowering and growth were reported in a natural forest of *P. taeda* by Schmidtling (1981) and in *P. sylvestris* by Nikkanen and Velling (1987), while low genetic correlations between height and flowering were reported in *P. contorta* by Hannerz et al. (2001) and in *Picea abies* by Almqvist et al. (2001).

It is considered that narrow crown is a desirable trait. Trees with wide crowns probably have thicker branches and more of the biomass in less valuable branches and wide-crowned trees probably suffer more from crowding in stands. It would be natural to believe that trees with wider crowns have more cones. If so, that could mean a risk that a negative character would be overrepresented at cone harvest. However, the increase of strobili amount as a function of crown width found in Fig. 1b is very marginal ($P = 0.01$, Table 3). A change in crown width by a factor of 2 (and an approximately double as large change in the size of the crown surface) does not seem to be accompanied by more than some 10% increase in strobili number. Thus, the risk that a higher production of gametes by trees with genetically wider crowns would lead to trees with wider crowns in the progeny seems negligible. It can be assumed that larger trees have room for more strobili. Number of strobili and tree size was generally positively correlated (in spite of some non-significant negative values). Strobili are formed on shoots. The seed orchard grafts are of equal age and it is therefore not certain that larger trees have more shoots. Tree size and number of branches seem correlated (Table 3), and that could be one reason larger trees have more strobili. This could also be taken into consideration during establishment (e.g., spacing) or management (e.g., thinning) of orchards.

It is surprising that the number of branches has only a low positive or even negative correlation with the number of strobili in this study. Strobili are physically attached to branches and branch tips, and therefore the amount of potential places should play an important role and that increases with the branch number.

When top pruning a seed orchard, the apical dominance is broken. Cutting of tops and branches result in a decrease in strobili production for a couple of years, but the production of vegetative shoots increase, thus also the potential places for new strobili. Some years after the pruning, the number of strobili can exceed the number before pruning, and this despite the tree is smaller. Fries (1994) found for *Pinus contorta* a positive correlation between number of strobili and size of the graft, which was higher for male strobili than female. For management reasons, it is economically advantageous to collect cones and seeds from small trees. Low cones which can be picked from the ground are cheaper to collect than if a lifting device has to be used (Lindgren et al. 2005). This is one reason pruning is an important tool for the seed orchard manager.

For SO_1 Bilir et al. (2002) reported the number of strobili per graft 2001; a comparison with 2005 is done:

	Age	$N_♀$	$N_♂$	$N_♂/N_♀$
2001	16	201	531	2.6
2005	20	253	734	2.9

The number of strobili rises over time and the number of male strobili rises faster than the female. This was also reported by Bhumibhamon (1978). Positive and significant correlations between $N_♂$ and $N_♀$ were found (Table 3). This is in good accordance with other Scots pine studies

(Jonsson et al. 1976; Bhumibhamon 1978; Burczyk and Chalupka 1997; Bilir et al. 2002).

Quotients of $N_{♂}$ and $N_{♀}$ indicate that the number of male strobili increases more than that of female when an orchard gets older. More male strobili will result in a higher genetic impact (e.g., father effect) of the seed orchard clones as pollen parents and reduced impact of pollen parents outside the seed orchard, and thus increased genetic quality of the seeds. It may also raise the production of improved seeds if pollen is scarce for full pollination.

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