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Defining Cryptomeria Seed Sources Useful for Taiwan by Superimposing Probabilities of Good Provenance Results over Climatic Data Maps

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Abstract

One hundred cryptomeria seedlots, originally obtained from Japan in 1972 were planted in two plantations in Taiwan. At age 23, ninety-six surviving seedlots were measured for height and diameter. Superior seed sources were identified as those with greater heights and diameters than plantation means. We also received climatic data from weather stations near the seedlots. Climatic maps for the coldness index, warmth index, mean January temperature, and mean annual temperature were overlaid on top of the map of Japan. The probability of finding superior seedlots in each climatic zone was calculated and a probability was assigned to each pixel of the climatic zones using the thematic mapping technique. The four probability maps were then overlaid one on top of the others to form an average probability map. From the final layout it shows that the southwestern seedlots grow faster than the northeastern seedlots. Seedlots from the coastal area of the Pacific Ocean grew better than those from the Japan Sea coast. In terms of administrative areas, provenances from Kyushu, Shikoku, western part of Chiugoku, and southern part of Kinki grew best in our two plantations. On the other hand, seedlots from the north-central part of Toohoku were inferior to other provenances. In terms of climatic zone, the best cryptomeria seed sources should be from areas with a coldness index higher than -5 degree-months, a warmth index between 130 and 140 degree-months, mean January temperature above 9 °C, and mean annual temperature above 18 °C.

Key words: Provenance, cryptomeria, seed collection zones, GIS, thematic mapping.

FDC: 165.52; 111.24; 111.77; 111.8; 181.65; 181.22; 232.12; 561.1/.2; 174.7 *Cryptomeria japonica;* (520); (529.1).

Introduction

Cryptomeria (*Cryptomeria japonica* D. DON) trees were first introduced from Japan to Taiwan about one hundred years ago.

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Table 1. — Distribution of cryptomeria seedlots and weather stations (in parentheses) in seven physiographic regions.

Physiographic Region	Original Collections Prov.	Mother Tree	Total	Live at Age 23	No. of Weather Stations	No. of Data points
Hokkaido	1		1	1	0	0
Toohoku	23	5	28	28	27	27
Ouwu	6	1	7	7	6	6
Kantoo	10	3	13	13	10	10
Kansai		19	19	15	19	15
Shikoku		10	10	10	9	9
Kyushu	2	20	22	22	21	21
Total	42	58	100	96	92	88

It has become one of the most important commercial timber species. More than 30,000 hectares were planted. Because of poor record keeping, little was known about the history and origin of the planting materials (LIN, 1993).

The distribution range of cryptomeria in Japan covers about 10 degrees in latitude and 2800 m in elevation. Within such broad range it is reasonable to assume that some genetic differentiation may have occurred and that some provenances may be more adaptable to local environments in Taiwan. Thus, the objective of this study is to find the location of the superior provenances suitable for planting in Taiwan.

Materials and Methods

One hundred cryptomeria seedlots were collected by four forest tree breeding stations in Japan. They were the Toohoku Forest Tree Breeding Station, the Kantoo Forest Tree Breeding Station, the Kansai Forest Tree Breeding Station, and the Kyushu Forest Tree Breeding Station. *Table 1* lists the collection zone of seedlots from seven physiographic provinces of Japan (CHIANG et al., 1979). The collection was coordinated by Dr. RYOOKITA TODA of the Government Forest Experiment Station in Tokyo, Japan in 1972 which contained 42 stand seeds and 58 plus tree seed. However, in the final analysis both provenance and progeny seed have been treated as the same experimental units. The reasons will be discussed later in this paper. Two research agencies in Taiwan shared the collection: (1) The National Taiwan University Experiment Forest, and (2) Taiwan Forestry Research Institute. This paper covers the results from the Taiwan Forestry Research Institute.

Seeds were sown in Taipei and in Liu-Kuei nurseries in October 1972. Seedlings were outplanted in two plantations near the nurseries in October 1973. The two plantations are about 250 km apart but have similar rainfall and annual mean temperature. A randomized complete block design with tree to tree spacing of 3 m x 3 m was used. There were five blocks in each plantation with five trees in a linear plot.

The geographic coordinates of the seedlots were either provided directly by Dr. TODA, or filled in by us with the help of Dr. OHBA. Dr. OHBA's compilation of 28 years of weather record data from 1951 to 1978, using a PC program made by Dr. MASAYUKI ARAKI, was applied for a total of 92 weather stations. The five climatic items used for overlay are as follows: (1) a warmth index (WARM) in degree-month above the threshold of crop growth (5 °C), (2) a coldness index (COLD) in degree-month below 5 °C, (3) the mean January temperature in degrees (MJT), (4) the mean annual temperature in degree (MAT), and (5) the mean annual precipitation in cm (MAP).

Trees from all but four seedlots from the Kansai regions were still alive at the age of 23 years (*Table 1*). Diameter at breast height and total height of trees were measured at the two plantations. Provenance means from the two plantations were calculated. The average height at age 23 was 11.5 m and the average diameter was 26.0 cm. Among the 96 provenance means, tree height was not as variable as diameter, the coefficient of variation was 10% and 15% respectively. Correlation between height and diameter was significant ($r = 0.78$).

Using a general linear model for a two-way analysis of variances with interaction, we found significant plantation effect and regional effect but the interaction between the two effects was not significant. Therefore, we had the provenance means refitted to a two-way, no interaction model. The new model accounted for 65% and 44% of the sum of squares in diameter and in height respectively (*Table 2*). About 54% of the total variance in diameter was contributed by the physiographic regions, and 26% was by plantation. On the other hand, the variance components in height were 26% and 30% for region and for plantation respectively. Since the regional effect was significant, we used the DUNCAN multiple-range test (DUNCAN, 1955) for grouping regional means. The seven regions can be combined into three clear-cut groups in diameter, and four overlapping groups in height (*Table 3*). Because of the significant differences among regions and their sizeable contribution to the variance, we must consider the geographic origin in modeling cryptomeria tree growth in Taiwan.

Initial correlation analyses show that height and diameter growths of the provenances are related to many weather parameters (*Table 4*). Later, we also found out from the RSQUARES analysis (SAS, 1982) that once the first four

Table 2. — Analysis of variance for provenance height (H23) and diameter (D23).

Dependent Variable: H23

Source	DF	Sum of Squares	Mean Square	F Value	Pr. > F
Model	7	163.26	23.32	19.74	0.0001
Plantation	1	72.01	72.01	60.96	0.0001
Region	6	91.25	15.20	12.87	0.0001
Error	175	206.74	1.18		
Corrected Total	182	370.00			

R-Square	C.V.	Root MSE	H23 Mean
0.44	9.46	1.08	11.48

****

Dependent Variable: D23

Source	DF	Sum of Squares	Mean Square	F Value	Pr. > F
Model	7	2418.79	345.54	47.01	0.0001
Plantation	1	653.67	653.67	88.93	0.0001
Region	6	1765.12	294.18	40.02	0.0001
Error	175	1286.30	7.35		
Corrected Total	182	3705.09			

R-Square	C.V.	Root MSE	D23 Mean
0.65	10.53	2.71	25.73

Table 3. — DUNCAN multiple comparisons of seven regional height and diameter means. Means with the same letter are not significantly different.

Region	Mean ht. m.	Duncan Grouping	Region	Mean d.b.h. cm.	Duncan Grouping
Shikoku	12.48	A	Kyushu	29.21	A
Kyushu	12.12	A B	Shikoku	28.85	A
Kantoo	11.88	A B	Kansai	28.40	A
Kansai	11.68	A B C	Kantoo	25.70	B
Hokkaido	11.25	B C D	Toohoku	22.26	C
Toohoku	10.72	C D	Hokkaido	22.25	C
Ouwu	10.37	D	Ouwu	21.98	C

Table 4. — Correlation between cryptomeria tree growths in Taiwan and climatic factors in Japan.

Plantation	Climatic Item: Warmth Index	Coldness Index	Mean January Temp.	Mean Annual Temp.	Mean Annual Precip.
Height at age 23					
Taipei	0.50 **	0.56 **	0.46 **	0.48 **	0.23 *
Liu-Kuei	0.47 **	0.54 **	0.51 **	0.50 **	0.28 *
Average	0.47 **	0.55 **	0.48 **	0.48 **	0.24 *
Diameter at age 23					
Taipei	0.68 **	0.78 **	0.67 **	0.68 **	0.35 **
Liu-Kuei	0.61 **	0.67 **	0.63 **	0.62 **	0.30 **
Average	0.67 **	0.74 **	0.69 **	0.69 **	0.35 **

**) Significant at the 0.01 level
*) Significant at the 0.05 level

climatic parameters (WARM, COLD, MJT and MAT) were included, the last item (MAP) could be dropped, because the mean annual precipitation has minimal marginal contribution to the growth model.

Having established that performance of cryptomeria provenances was related to geographical and climatic factors in Japan, we turned our attention to the probability of obtaining good growth in various environments. Although ANDERSON (1966) had proposed that a reliable provenance would be the one producing a decent forest crop with 90% probability, we are not interested in just a single provenance with a fixed probability, but we are interested in a map that would show probability of obtaining a population in various areas of Japan that can ensure decent growth in Taiwan.

To define decent growth, we separated seedlots into four classes based on the overall average tree height and diameter

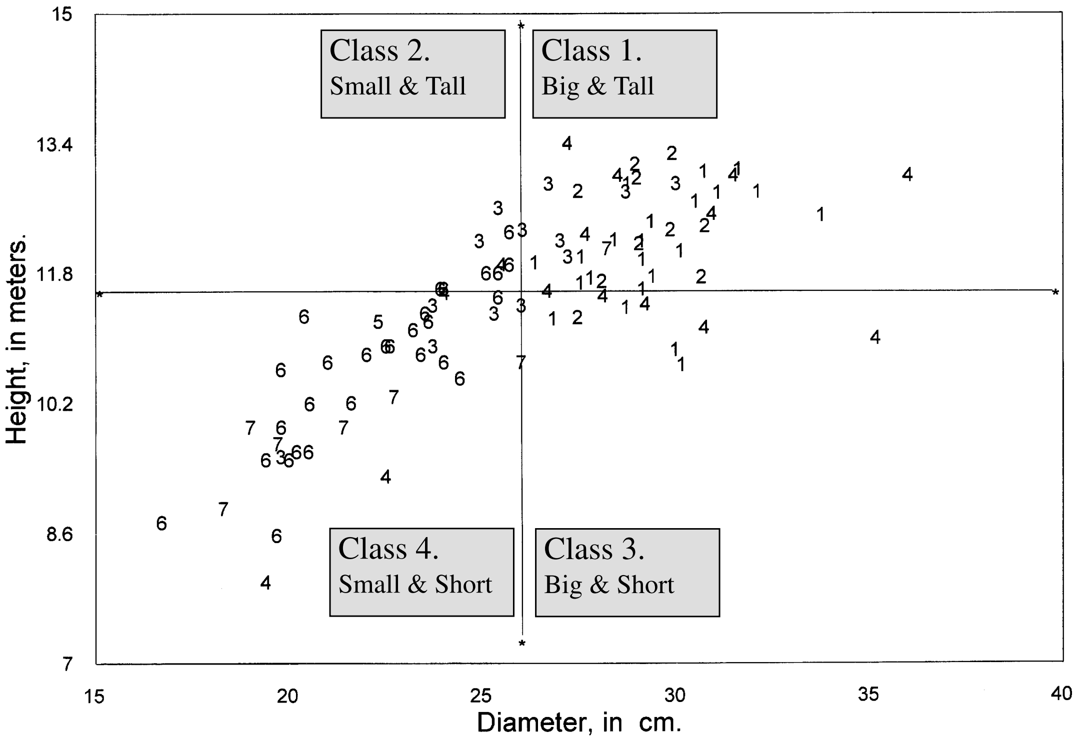

Figure 1. — Height and diameter distribution of provenance means in seven regions and in four classes of growth forms. The numeric labels of regions are 1 = Kyushu, 2 = Shikoku, 3 = Kantoo, 4 = Kansai, 5 = Hokkaido, 6 = Toohoku and 7 = Ouwu.

at 23 years of age. The distribution of provenances in the four classes is presented in *figure 1*. We considered class 1 to be a class with decent growth.

We went on to classify climatic data into six convenient intervals. For example in the coldness index, we had six zones within a range of –30 to zero degree-months. Similarly, from 60 to 150 degree-month in the warmth index we had zones at intervals of 15 degree-months. There were six zones at three degree intervals for the mean January temperature ranging from –6 °C to 12 °C, and there were also six zones at two degree intervals for the mean annual temperature ranging from 8 °C to 20 °C.

Table 5. — Probability of obtaining a seedlot that is taller and bigger than the population means at age 23 years in various climatic zones.

Zone	Coldness Index	Warmth Index	Mean January Temp.	Mean Annual Temp.
	Probability, in percent			
1	0.00	0.00	0.00	11.11
2	8.33	17.86	14.29	19.05
3	22.22	53.33	36.84	38.46
4	36.36	82.35	77.27	76.19
5	55.56	90.91	83.33	78.57
6	84.85	75.00	100.00	100.00

To see the distribution of the four classes of seedlots in each climatic zone, we run the FREQ procedure (SAS, 1982) to produce a two-way cross tabulation table. Since we are interested in the probability of finding a seedlot that is taller and bigger than the population mean, only the probabilities of obtaining a class one seedlot from the six different climatic zones are summarized in *table 5*. Zone one of the climatic items will represent the lowest interval, so that the higher the zone number, the warmer is the temperature.

Because we are interested in the spatial distribution of these probabilities, we need to plot the probability over climatic maps. From the climatic data file we first created one vector file each for the coldness index, warmth index, mean January temperature, and mean annual temperature. Each vector file then was used by the INTERPOL module of the IDRISI GIS software (EASTMAN, 1992) to create a raster image. The raster image then was overlaid on top of the map of Japan by a personal computer with ARC/INFO GIS software (ESRI, 1994).

Using a thematic mapping technique, we assigned the probability value to each pixel in each climatic zone. The four maps were then overlaid one on top of the others. The mean probability for each pixel within the overlay was calculated from the four readings of probability. For example, the overlapping area for a common zone one of the four climatic maps

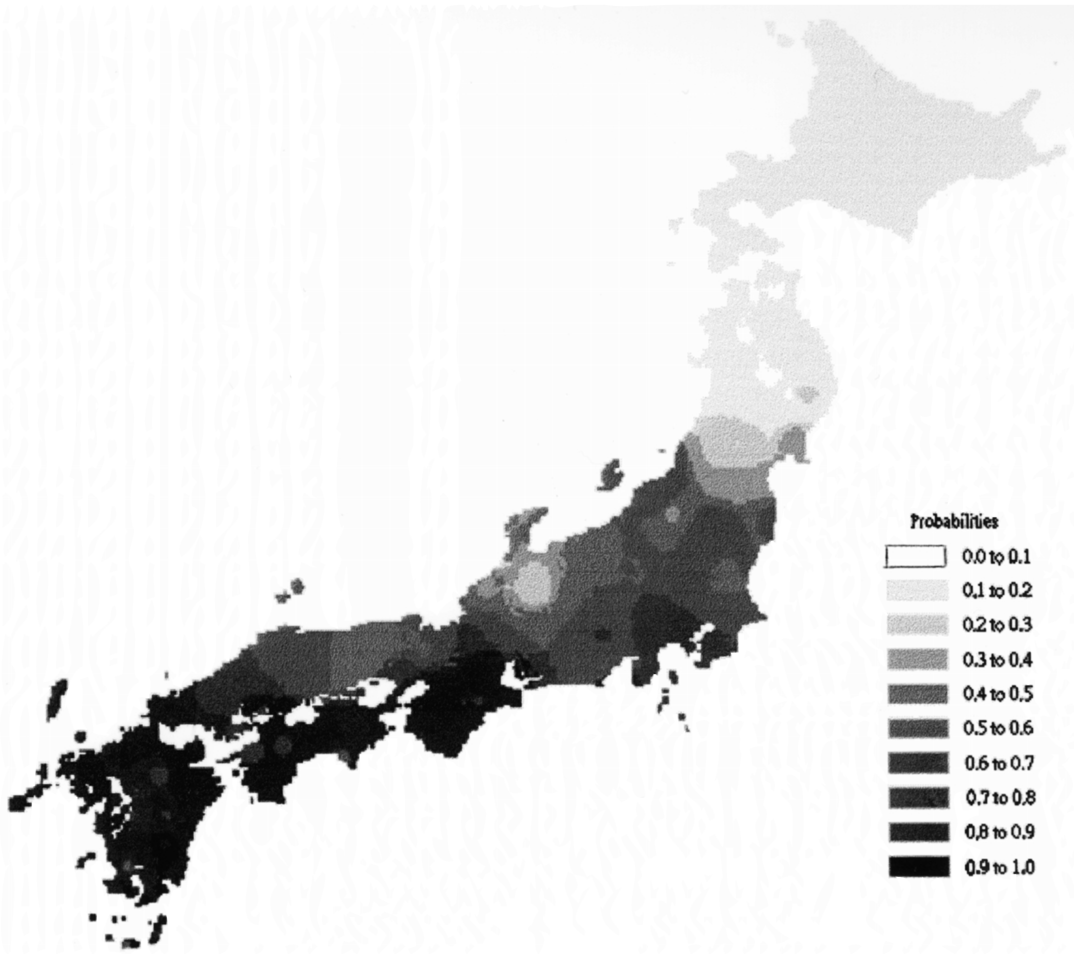

Figure 2. — Probability map of finding a seedlot in Japan that will grow tall and big in Taiwan at the age of 23 years.

will have a mean probability calculated from *table 5* as (0.00+0.00+0.00+11.11)/4=2.78%. So the chance of finding a seedlot that is taller and bigger than the population average will be less than 3%. Delineation of the overlapping areas and calculation of the mean probability in each area were done by a computer software Erdas (Erdas, 1994). The final composite of the mean probability map is presented in *figure 2*.

Results and Discussions

Although the seed collections from Japan include seeds from different cryptomeria stands and seeds from different mother trees in separate locations, we treated them simply as seedlots or provenances. We may consider the sample size of mother trees for any given provenance: if seeds were collected from a stand, the sample size is greater than one, and if seeds were collected from a single mother tree, the sample size is simply one. Therefore, in an un-weighted correlation study where sample size within an experimental unit may be ignored, a mother tree from a separate area may be treated as provenance. Combining provenance seedlots and half-sib family seedlots together as a single database yields a more efficient statistical analysis. For example, in modeling the diameter growth at age 23 and using all geographical and climatic variables, the complete data set yielded r-squares of 0.632 while the provenance data set gave 0.594 and the half-sib family data set gave 0.560 for the r-squares. In a previous study, CHIANG also did not make any distinction between provenance origins and half-sib family origins (CHIANG et al., 1979). However, one of the referees had called to our attention that: "Seed lots from clonal stands are with little genetic diversity, while the seed lots from maternal trees are probably from single old monument trees, usually from the vicinity of old temples, which being of seedling origin are probably genetically more diversified and therefore are at least as good if not better as indicators of provenance variation."

Analysis of variance shows no significant interaction between region and plantation in cryptomeria trees. In a previous study, CHIANG and WANG (1984) also found no significant interaction between plantation and provenance. Thus, regional effect, provenance effect and plantation effect may all be considered as additive. No interaction also implies that provenance and regional means rank similarly at both plantations. In this case, pooling plantation data together should be more efficient. Thus, we use the means of two plantations to build a single model, instead of building two separated models for the two plantations. Because correlations between the provenance means from two plantations and from a single plantation were high (ranged from 0.87 to 0.94), the variation patterns displayed by the means of two plantations should be a good representation for either plantation. We also have other statistical supports for using the mean of the two plantations. From the clustering of variables we found those growth traits in the Taipei plantation and growth traits in the Liu-Kuei plantation belonged to the same cluster. We also found that the canonical correlations between growth and weather items were higher when the mean of the two plantations was used instead of data from individual plantations.

Provenance research is investigation of genetic diversity associated with geography (CALLAHAM, 1964). Geographic information systems (GIS) are useful for entering, storing, manipulating, analyzing, displaying and modeling spatial data (CONGALTON and GREEN, 1992). Application of GIS to provenance study would be fruitful when the provenance performances are correlated with the spatial attributes. From the variables clustering analysis we found that variables such as latitude, longitude, warm index, cold index, mean January temperature, and mean annual temperature were grouped together as one cluster. This cluster had a high intergroup correlation (r-squares=0.807) with the cluster of growth traits. On the other hand, elevation and rainfall were classified as another separated cluster. Since this clustering had a low r-square (0.274) with the growth traits cluster, we had ignored elevation and mean annual rainfall in the growth-GIS model. However, where altitudinal variation is an important component as in the case of ponderosa pine (CALLAHAM and LIDDICOET, 1961), one may not ignore the effect of elevation and amount of rainfall.

Correlation analysis showed that both height and diameter growths of cryptomeria trees in Taiwan were highly correlated with the latitude and longitude of the seed source. We also found a correlation between the latitude and the longitude of the seed source (r=0.92). One of the referees had pointed out that: "The shape of Japan and its location on geographic coordinates assures that any country-wide collection will show a correlation of latitude with longitude, thus a correlation with NE to SW gradient would be more appropriate." Indeed, we can see such correlation as expressed in *figure 1*, where the southwestern seedlots grow faster than the northeastern seedlots. Then again in *figure 2*, the probability of finding a seedlot that is taller and bigger than the population means decreases from southwestern to northeastern Japan. Our probability map also agreed with an earlier study (CHIANG and WANG, 1984) that seedlots from the coastal area of the Pacific Ocean grew better than that from the Japanese Sea coast.

In terms of administrative areas, provenances from Kyushu, Shikoku, western part of Chiugoku, and southern part of Kinki grew best in our two plantations. In a previous study of volume increment of cryptomeria provenances planted in seven locations in Taiwan, the best provenances at age 15 were also from Kyushu, Shikoku (CHIANG et al., 1989). On the other hand, seedlots from the north-central part of Toohoku were inferior. In terms of climatic zones, we found that the best seed sources should be from areas with a coldness index higher than -5 degree-month, a warmth index among 130 and 140 degree-month, a mean January temperature above 9°C and a mean annual temperature above 18°C.

The merit of GIS in provenance study is evident when we compare the usefulness of *figure 2* and *table 5*. We can see clearly in *figure 2* that probability levels and climatic zones are tied down with the geographic areas. In this paper we have related provenance variation to a climatic map. We can expect that in the future when more ecological and environmental elements are embodied in the GIS, the application of GIS will give us even greater insight about the genetic adaption of forest trees to their locations.

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Fertility Variation and its Effect on the Relatedness of Seeds in *Pinus densiflora, Pinus thunbergii* and *Pinus koraiensis* Clonal Seed Orchards

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Abstract

The numbers of female and male strobili were counted in clonal seed orchards with 99 clones of *Pinus densiflora* and 60 clones of *P. thunbergii* and in an archive consisting of 180 clones of *P. koraiensis,* respectively. The observation data showed a great variation in both female and male strobili among clones in the three populations. It was possible to express the expected contribution of genotypes to seed crop as an inverse of cumulative function of type, $x = F(x)^{1/a}$, where x is the expected contribution of seed orchard genotypes and $F(x)$ is the ranked relative contribution of flowering production. Parameter a is a parameter which describes flowering variation. Status number and variance effective population size could be related to the square sum of contribution.

The status numbers were calculated to be 69.2 (70% of the initial census number), 54.6 (91%) and 38.8 (22%) in the expected crops of clonal seed orchards of *P. densiflora, P. thunbergii* and *P. koraiensis,* respectively. The variance effective population sizes connecting these orchards with their expected crops were estimated to be 230.3, 610.3 and 49.4, respectively. Despite the large differences in status numbers and variance effective population sizes, the group coancestry remained at a low value in all expected seed orchard crops. Relative gene diversity compared to the reference population from which plus trees were selected was quite high in all populations.

Key words: relatedness, status number, effective population size, seed crop, strobilus production, seed orchard, gene diversity.

FDC: 165.3; 165.53; 181.521/.522; 232.311.3; 174.7 *Pinus densiflora;* 174.7 *Pinus koraiensis;* 174.7 *Pinus thunbergii.*

Introduction

The genetic quality of seed crop from a clonal seed orchard is greatly affected by the genetic values and the mating system of the orchard clones. Mating conditions, which are valid for seed orchards in panmictic equilibrium, are important prerequisites if the orchard crop is to reflect both the genetic superiority and diversity present among the seed orchard clones (MUONA and HARJU, 1989; EL-KASSABY and ASKEW, 1991; CHAISURISRI and EL-KASSABY, 1993; PRAT and CAQUELARD, 1995). The differences in gamete contribution among clones in seed orchards have been shown to be genetic rather than environmental in most investigations (GRIFFIN, 1982; BYRAM *et al.,* 1986; EL-KASSABY *et al.,* 1989; EL-KASSABY and REYNOLDS, 1990; SAVOLAINEN *et al.,* 1993; EL-KASSABY and COOK, 1994; KJÆR, 1996; BURCZYK and CHALUPKA, 1997; KJÆR and WELLENDORF, 1998). Unequal gamete contributions, therefore, reduce the effective population size so that genetic drift and an increase in inbreeding take place more rapidly than would be predicted from the census number used in a seed orchard (KJÆR, 1996). The number of clones used in clonal seed orchards should be determined to maintain high effective population number and low inbreeding by optimizing the use of the clones with the best breeding values (LINDGREN, 1993). The census number in orchards should thus be adjusted to take into account the quantitative impact of unequal gamete contribution.

Differences among clones in gamete contributions influence the genetic composition of seed orchard crops by over-representing the most productive genotypes (KJÆR, 1996), which might lead to accumulation of coancestry and loss of gene diversity (LINDGREN *et al.,* 1996). Variation in fertility also has important implications in breeding (GRIFFIN, 1982; XIE and KNOWLES, 1992; EL-KASSABY, 1995) and conservation programs (SEDGLEY and GRIFFIN, 1989). Gamete contributions can be estimated in open-pollinated seeds based on genetic markers such as isozymes (RUDIN and LINDGREN, 1977; SHEN *et al.,* 1981; XIE and KNOWLES, 1994), but these investigations are expensive and it is difficult to get high accuracy on individual gamete contributions. They can also be obtained from the assessment of flowering and seed production (GRIFFIN, 1982; CHAISURISRI and EL-KASSABY, 1993; EL-KASSABY and COOK, 1994). Flowering phenology may be important in particular cases, but in general the quantitative amount of flowering is most important because the genetic composition of progeny depends most

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