De telles mesures font déjà partie des programmes en cours dans les Instituts membre de ce Groupe de travail. La poursuite de ces programmes, essentiels à la survie des forêts, nécessite très rapidement un soutien financier et en personnel plus important. Le Groupe de travail de Génétique forestière et d'Amélioration des Arbres forestiers comprend les institutions citées dans Silvae Genetica 33 (6): 177 (1984).

Variation in Seed Quantity and Quality in two Grafted Clones of European Larch (Larix decidua Mill.)

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Summary

Cone and seed yields were examined in two grafted clones of European larch over two years comparing interspecific and intraspecific crosses and open pollinated seed. Wide variation in yield was found within and between clones, between the two years and between interspecific and intraspecific crosses. In hybrid crosses both viability and germinative capacity were reduced compared to nonhybrid crosses.

Both total numbers of seed and seed weight were directly related to cone size. Percentage viability was not closely related to cone size although viability and seed size were moderately related. Cone weight, therefore, could be used to predict seed quantity (numbers, seed size) but not seed quality (percentage viable, germinative capacity).

The wide variation in yield suggest that both genetic and environmental variation is high in controlling seed yield.

Key words: *Larix decidua*, seed orchards, seed yields, hybridization, controlled pollinations.

Zusammenfassung

Bei zwei Propfklonen von Europäischer Lärche wurde die Zapfen- und Samenausbeute über einen Zweijahreszeitraum untersucht, wobei diese bei inter- und intraspezifischen Kreuzungen und frei abgeblühten Pfropflingen verglichen wurden. Innerhalb und zwischen den Klonen sowie zwischen den zwei Jahren und zwischen inter- und intraspezifischen Kreuzungen wurden große Unterschiede in der Ausbeute gefunden. Bei den Hybriden waren sowohl die Lebensfähigkeit als auch das Keimprozent gegenüber den reinen Arten reduziert.

Sowohl die Gesamtausbeute an Samen als auch das Samengewicht waren direkt mit der Zapfengröße korreliert. Das Keimprozent war mit der Zapfengröße nicht eng korreliert, obwohl Keimfähigkeit und Samengröße mäßig miteinander korreliert waren. Dagegen kann das Zapfengewicht benutzt werden, um die Samenquantität (Anzahl und Samengröße), nicht aber die Samenqualität (Keimkraft und Keimprozent) vorauszusagen.

Die große Variationsbreite bei der Ausbeute zeigt, daß sowohl genetische als auch Umweltfaktoren bei der Kontrolle der Samenausbeute eine große Rolle spielen.

Introduction

The objective of studies on the yield of seed from forest trees is to enable the better understanding of the relationship and factors affecting yields and to enable evaluation of the various clones available for seed production. An understanding of the relationship between the cone size and seed quantity and quality will assist the seed orchard manager in increasing yields through improved techniques. It is then possible to assess the reproductive fitness of different clones to assist in the roguing of the orchard. In most situations these data are missing or incompletely understood (ANDERSSON 1965).

Data on individual clones are needed over time to ensure efficient management. In hybrid larch *(L. eurolepis* HENRY) seed orchards where yields are often low but where the hybrid seed is very valuable, these data are particularly necessary.

Variation in seed yields is known to occur at several levels. At the most basic level, within-clone variation occurs in Scots pine *(Pinus sylvestris* L.) where seed weight and numbers of filled seeds varied widely between grafts (HAGMANN 1972, SHEN and LINDGREN 1981). Significant within-clone variation has been reported, however, in seed quantity and quality in black spruce *(Picea mariana* (MILL.) (B.S.P.)) (VERHEGGEN and FARMER 1983). Yields of seed have also been shown to vary among aspect and position within the crown (BROWN 1971, SHEN and LINDGREN 1981). These variations in yield attributable to aspect and position in the crown did not occur in either European or Japanese larch *(L. kaempferi* (LAM.) CARR.) (HALL 1976).

Variation in seed quantity and quality between clones and between years is large and has been reported to occur in many species. Between clone variation has been reported in Norway spruce *(P. abies* L.) (ANDERSSON 1965); Scots pine (HAGMANN 1972, SHEN and LINDGREN 1981); lodgepole pine *(P. contorta* DOUGL.) (NILSSON 1981); slash pine *(P. elliottii* ENGELM.) (SQUILLACE and GODDARD 1982); balsam fir *(Abies balsamea* L.) (POWELL 1979); black spruce (VERHEGGEN and FARMER 1983) and in *Chamaecyparis* spp. L. (YAMAMOTO and FUKUHARA 1980). This wide genetic variation partly explains why, in seed orchards, frequently most of the seed originates from a small proportion of the clones (SCHMIDTLING 1983). If production is to be concentrated on the inherently higher yielding clones the yields of individual clones must be known. Yields are affected by environment which affects clones differentially (ANDERSSON 1965; EHRENBERG *et al.* 1955; SQUILLACE 1957; NILSSON 1981). The numbers of embryonic lethal genes or genetic load controls the proportion of empty seeds per cone and affects yields in Nor-

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way spruce and Scots pine (KOSKI 1974, JOHNSSON 1976). The effects of the genetic load varies from year to year indicating that a large environmental effect is present. Effective seed orchard management requires that the nature and extent of the variation be known.

It has been shown that seed yields vary with the relationship of the parents. Seeds of hybrid origin are less likely to germinate than those of intraspecific origin and disturbances in embryogeny in *Pinus* spp. have been related to hybrid origin (DOGRA 1967). Seed sterility in *Larix lubarski* was affected by the hybrid origin of the mother trees (IL'CHENKO and NEKRASOV 1974). Interspecific crosses in *Chamaecyparis* also had the effect of reducing yields (YAMAMOTO and FUKUHARA 1980). Seed yields vary among clones and over years, and the data can be used to select the more compatible cones for production of hybrid seed.

The relationship between cone size, which is strongly controlled by the mother tree, and seed numbers, size and germinability is important. These easily-derived parameters are used to predict yields and to assist in nursery practices and in management. Cone size (weights) and numbers of seeds per cone have been shown to be related in Norway spruce (ANDERSSON 1965) and in black spruce (VERHEGGEN and FARMER 1983). The relationship varied among stands and years in Norway spruce. The close relationship between cone size and seed yields has been widely reported in Scots pine (EHRENBERG *et al.* 1955; BROWN 1971; SHEN and LINDGREN 1981). Cone weight and seed weight are also directly related in Norway spruce (ANDERSSON 1965), Scots pine (SHEN and LINDGREN 1981; SIMAK 1960), balsam fir (POWELL 1979) western white pine (*P. monticola* DOUGL. (SQUILLACE 1957) and in European larch (SINDELÁR 1969). Cone size has also been used as an index or predictor because of its relation to seed quality. Seed quality in Scots pine is predicted from cone size (EHRENBERG *et al.* 1955) and seedling quality (size) from seed weight in lodgepole pine and white spruce (ACKERMAN and GORMAN 1969) and in Japanese larch (LOGAN and POLLARD 1979).

In summary, the variations in yield of seed, its quantity and quality must be understood if management practices are to be designed to ensure maximum yields in seed orchards. This study was undertaken to determine the extent of differences in the yield of seed within and between clones, between successive years in the same clones, and in controlled and wind pollinated strobili and between inter- and intraspecific crosses in the same clones. The relationship between the variables of cone weight, seed numbers, seed weight, percentage viable and percentage full seed were evaluated using a simple correlation matrix.

Methods

The study was done in the Forestry Commission Nursery at Newton in North-east Scotland in a seed orchard designed to produce hybrid larch seed. The seed orchard is at 57° 39' north latitude and 3° 25' west longitude and at an elevation of 30 m above sea level. Two clones of European larch, numbered E1061 and E1102, were selected because of their relatively high levels of flowering and the large number of grafts available. The grafts were scattered randomly throughout the seed orchard.

Pollen was collected from ten or more clones which produced large numbers of male flowers. No pollen was used from any of the mother trees. Twigs containing the flowers were collected and dried in a well- ventilated room at 18°—25° C with relative humidity at 50—90%. After 24—48 hours the pollen was shaken off, sieved to remove foreign matter and stored in a desiccator at 4°—5° C until pollinations were done. Procedures were similar in 1974 and 1975. However, in 1975 since fewer clones flowered in the orchard and flowering levels were lower than in 1974 the composition of the pollen mixture was different from that used in 1974. Most of the same clones were represented in both mixtures.

Pollinations were done in both years using the same isolation and pollination methods. The inter- and intraspecific pollinations were not done on the same grafts. Open-pollinated cones were collected for comparison with the controlled crosses.

After collection, cones were stored at 2°—3° C until extraction. For extraction, cones were soaked for 48—72 hours in warm (30°—35° C) water then dried for 48 hours at 35°—40° C. Some of the European larch cones needed two or three of the soaking and drying treatments before the cones opened enough for extraction of seed. Some seed was removed using forceps. The seeds were counted, weighed and stored at 2°—3° C until germinated. The cones were then oven-dried at 60° C for 24 hours and weighed.

Seeds were germinated at 23°—25° C with 18 hours daylight on filter paper kept moist with distilled water. Germination was 99% complete after 25 days. Ungerminated seeds were placed in 70% Ethanol for separation by flotation of full and empty seed.

For each combination of clone, year and cross, the following data were compiled; weight of oven-dried cones, number of seeds per cone, weight of 1,000 seeds, percentage viable and percentage full seed. Means were compared as a series of two-way comparisons using Student t-statistic (STEEL and TORRIE 1960).

Results and Discussion

Variation in Yield Within the Clones

The percentage of viable seed varied within the clones and generally less than half the seed was viable (*Table 1*). In most cases the hybrids had lower viability than the European larches and controlled crosses usually had a lower percentage of viable seed than open-pollinated seed. Among open-pollinated seed viability varied widely among grafts and between the two years. No grafts had consistently high or low yields. For the hybrid crosses on clone E1102, grafts one and two in both years had lower yields than grafts 3—5. No other trends were evident. The range of seed viability is high compared to that reported in Scots pine (SHEN and LINDGREEN 1981). Other studies have indicated within-crown variation in yield but no such differences were observed within the crowns of these grafts (BROWN 1971, HALL 1976). In clone E1102 in 1974 yield after controlled pollination was higher than that from wind pollination. Some of the variability may be a result of inadequate supplies of pollen. In order to make use of yield data within the clone, the wide variation shown here indicates that yields over several years would have to be monitored in order to identify low-yielding grafts. Much of the apparent graft to graft variability may be attributable to the low numbers of cones available. The range of yields among grafts reflects the environmental differences throughout the seed orchard. Attempt at management within the orchard will be complicated by the within clone variation. Since the variability reflects environmental differences an opportunity exists to modify the site in order to influence yields.

Table 1. — Percentage of viable seed in grafts of European larch clones E1061 and E1102 in 1974 and 1975.

E1061

Graft	Cross: L. dec. x L. kaemp.[1] 1974	1975	Open pollinated 1974	1975	Graft	Cross: L. dec. x L. dec. 1974	1975	Open pollinated 1974	1975
1	9.6(7)[2]	5.9(5)	46.5(16)	32.6(4)	5	41.8(2)	11.6(4)	39.2(3)	49.1(4)
2	12.8(13)	5.3(8)	27.2(12)	47.3(5)	7	32.8(5)	6.9(11)	21.9(24)	43.0(11)
3	8.9(3)	5.2(9)	21.9(10)	16.5(6)	8	18.5(11)	7.7(3)	21.8(19)	51.4(2)
4	24.0(6)	-	28.2(4)	-	12	-	10.1(30)	-	28.4(21)
6	-	11.1(12)	-	23.2(6)	13	32.6(4)	14.5(8)	15.8(10)	32.3(8)
9	-	9.4(5)	-	43.9(5)					
10	-	4.3(6)	-	44.0(6)					

E1102

Graft	Cross: L. dec. x L. kaemp. 1974	1975	Open pollinated 1974	1975	Graft	Cross: L. dec. x L. dec. 1974	1975	Open pollinated 1974	1975
1	18.9(12)	2.7(5)	39.7(8)	25.3(5)	6	47.0(12)	19.5(22)	32.5(13)	27.0(8)
2	25.4(8)	8.2(3)	40.6(8)	4.5(1)	7	55.6(8)	13.7(13)	-	17.1(5)
3	36.9(19)	14.5(13)	29.2(12)	15.5(8)	8	53.2(15)	21.1(31)	13.5(7)	11.3(8)
4	46.4(17)	16.9(23)	27.0(12)	25.4(17)	9	60.6(36)	18.0(15)	41.1(16)	31.0(11
5	32.1(19)	17.1(24)	25.9(10)	40.7(13)	10	47.8(8)	12.0(8)	20.9(7)	12.7(8)
					11	72.1(9)	11.6(9)	38.4(7)	6.8(10

[1] *L. dec.* × *L. kaemp.* = *Larix decidua* (♀) × *Larix kaempferi* (♂).

[2] Numbers in parentheses are number of cones in the sample.

Variation in Yield Between Clones, Between Crosses and Between Years

Cone weights and seed weights were higher in clone E1061 than in E1102 (*Table 2*). Total numbers of seed per cone were similar except for E1061 in 1975 which is significantly higher than in 1974. Percentage of viable seed varied widely; in 1974 clone E1102 had the higher yield; in 1975 the differences were small but yields from crosses were higher in clone E1102.

Clone to clone differences in cone size, seed size, numbers of seed and seed viability have also been reported to occur in Norway spruce (Andersson 1965), lodgepole pine (Nilsson 1981), loblolly pine (Schmidtling 1983), balsam fir (Powell 1979) and in *Chamaecyparis* (Yamamoto and Fukuhara 1980). There is strong genotypic control of cone size in Scots pine (Ehrenberg *et al.* 1955), and this affects other cone and seed properties. It is quite possible that similar effects occur in European larch (Simak 1960). The total number of seeds per cone reflects the degree of cone serotiny which varies from tree to tree and which has a strong genetic component. The variation from year to year also suggests a significant environmental influence as well. Viability varied between clones, a factor which is under strong genetic control in Scots pine (Ehrenberg *et al.* 1955) and many be so in European larch. The differential response between years and pollen source suggests that both genotype and environment play significant roles in formation of full seed.

Table 2. — Cone weight, seed weight, seed quantity and quality in clones E1061 and E1102 for controlled crosses and open pollinated cones in 1974 and 1975.

Year	E1061 - Cross ♀ ♂	No. of cones	Wt. of cones	1,000 seed wt.	Total no. of seeds per cone	Percentage viable	Percentage full
1974	L. dec. x L. dec.	22	4.59[1]	10.44	38.7	25.5	42.6
	L. dec. x OPe[2]	56	3.88	8.66	47.7	22.5	-
	L. dec. x L. kaemp.	29	4.59	9.94	39.1	14.0	24.9
	L. dec. x OPj	42	3.82	8.88	42.0	32.4	-
1975	L. dec. x L. dec.	56	3.59	8.73	69.4	9.9	10.1
	L. dec. x OPe	47	3.78	7.74	66.8	34.1	34.1
	L. dec. x L. kaemp.	45	3.38	8.78	66.5	7.4	7.9
	L. dec. x OPj	32	3.96	8.22	69.1	34.0	34.0

Year	E1061 - Cross ♀ ♂	No. of cones	Wt. of cones	1,000 seed wt.	Total no. of seeds per cone	Percentage viable	Percentage full
1974	L. dec. x L. dec.	88	2.97	7.25	41.8	56.6	-
	L. dec. x OPe	50	2.54	5.43	48.4	30.9	–
	L. dec. x L. kaemp.	75	2.58	6.59	36.3	33.7	-
	L. dec. x OPj	50	2.41	5.49	43.3	34.7	-
1975	L. dec. x L. dec.	98	2.03	4.91	49.7	14.4	15.0
	L. dec. x OPe	50	2.23	4.96	52.3	24.5	27.4
	L. dec. x L. kaemp.	68	2.30	5.35	52.6	17.6	19.3
	L. dec. x OPj	43	2.35	4.83	51.7	14.2	15.4

[1] Means joined by a vertical line are significantly different from each other at probability level 0.95 (Steel and Torrie 1960). Year to year comparisons are to be left of the means; other compa_ risons are to the right.

[2] OPe (OPj); open pollinated cones on parent trees which were pollinated with European larch (Japanese larch) pollen.

There were differences in cone weight and seed weights between the crosses but hybrids were not consistently heavier or lighter. The total seeds per cone varied little in 1975 but in 1974 the controlled crosses yielded fewer seeds than open-pollinated cones. Only in clone E1102 in 1974 did the non-hybrid crosses yield significantly more total seed per cone than the hybrids. (Open-pollinated cones on the same grafts also had higher yields.) Thus, whether cones were artificially or naturally pollinated, there was no difference in total numbers of seed. There were differences in percent viability between controlled and open pollination and between hybrids and non-hybrids. Similar differences have been observed in *Chamaecyparis* (Yamamoto and Fukuhara 1980). In the European larch clones, the cones were larger in 1974 than in 1975, the difference reflecting environmental differences in the growing seasons. The differences were more pronounced in E1061 indicating that the genotype environment interaction affects clones differentially. Seed weights were also affected by these environmental differences and were lower in both clones in 1975. Despite 1975 being the poorer flowering year the total numbers of seed produced were higher. Viability, however, was lower in 1975 except for the open-pollinated cones in E1061. Generally clone E1102 produced a higher proportion of viable seed than E1061. The exception was the low yield from controlled crosses on E1061 in 1975. The difference in composition of the pollen mixture between the two years may also have affected yields.

The lowered levels of seed produced from hybrid crosses has been reported in various species of *Pinaceae* and has been attributed to failure of fertilization and failure in proembryo formation (DOGRA 1967). This is probably occurring in these clones. In a separate study, it was shown that in a hybrid cross with clone E1102 that failure of pollen to germinate on the micropyle occurred more frequently in hybrids than in non-hybrids (HALL and BROWN 1977). Failure in early embryo stages was not observed, but failure did occur as the embryo developed in the corrosion cavity. As the hybrid embryo develops it must be provided with the necessary maternal genes and if these are not present then the embryo will be affected. As these genes are less likely to be available in developing hybrids than in intraspecific embryos then there is a greater possibility of embryo failure resulting from an incompatibility with the maternal tissues. The presence of embryonic lethals, which has been reported to occur in eastern larch *(L. laricina* (DU ROI.) K. KOCH) would also cause the formation of empty seed (PARK and FOWLER 1982).

In both clones some of the seeds produced abnormal seedlings in the 1974 season. In clone E1061, 3.2% of the hybrids were abnormal and the 1.9% of the non-hybrids had abnormal seed. In clone E1102, the corresponding figures were 2.2% and 1.5%. This is a further reflection of differences in embryogeny between the two resulting from embryo endosperm incompatibility (HALL 1976).

The data for percentage full seed is complete, only for clone E1061. The proportion of full seed which germinated in 1975 was greater than in 1974. It is possible that the environmental conditions in 1974 allowed for the survival of weaker embryos which did not germinate. In 1975 these weak embryos did not survive and hence show up as empty seeds, leaving a higher proportion of seeds containing viable embryos.

Another factor which may be affecting the annual variation in open-pollinated cones is the possibility of natural self-fertilization in the clones. Inbreeding in European larch reduces numbers of filled seed with wide variation from clone to clone (DIECKERT 1964; FRANKLIN 1970). In 1975 when fewer clones flowered, the pollen supply was reduced and the closest pollen available was often that from the mother tree. The presence of self-pollinations could explain the lowered yield in E1102. Selfing also reduces yield in eastern Larch (PARK und FOWLER 1982). In clone E1061 the yield remained the same or increased in open-pollinated cones from 1974 to 1975. An explanation is that the genetic effects expressed as a clonal self-sterility were less pronounced in clone E1061 than in E1102.

The data show there to be clonal and environmental effects affecting the formation of seed and there to be differences in yield between interspecific and intraspecific crosses. Generally hybridization resulted in lower yields. To manage a seed orchard these data are needed for all clones over a period of several years.

Relationship Between Cone Size and Yield of Seed

The correlation coefficients (r) of the variables are listed in *Table 3* for both clones, both years and both types of controlled crosses and the corresponding open-pollinated cones.

Cone size, here represented by cone weight, was generally positively correlated with total numbers of seeds, This has been reported elsewhere for European larch (SINDELÁR 1969); for black spruce (VERHEGGEN and FARMER 1983); for western white pine (SQUILLACE 1957) and for Scots pine (BROWN 1971; EHRENBERG *et al.* 1955; SIMAK 1960). An unexplained exception occurred in clone E1061 in the controlled crosses.

Cone weight and seed weight were closely correlated; large cones produce large seed. This has been reported elsewhere for Scots pine (SIMAK 1960) and for European larch where cone length and seed weight were related (SINDELÁR 1969). The relationship reflects the larger seed scales and ovules in the larger cones. Cone size could therefore serve as an effective predictor for seed size.

Cone weight and percentage viable and full seed were generally not closely related. Significant relationships occur only on the hybridized grafts of E1061 in 1974 and on controlled crosses on E1102 in 1975. There were no consistent relationships. Percentage viability and full seed were more affected by adequacy of pollination, environmental conditions during embryo growth and the number of embryonic lethals present in the mother tree than by cone size. Studies elsewhere have shown a weak correlation between cone size and seed quality in balsam fir (POWELL 1979), Norway spruce (ANDERSSON 1965), Scots pine (BROWN 1971) and in western white pine (SQUILLACE 1957). Larger cones may, in other situations, reflect a more favourable environment which permits development of a higher proportion of fertilized embryos. The effect of polyembryony which occurs in Scots pine and Norway spruce (LINDGREN 1975), but which is not present in larch may increase the possibility of a viable seed being formed. Thus, although cone size was useful as an index of seed quantities it had little value in prediction of seed quality.

Seed numbers were not correlated with seed weight or seed quality in E1061 but most of the correlations in E1102 although low, were statistically significant. In E1061 some correlations were negative but also low. It is possible that with larger numbers of seeds the nutrients are "spread thinner" and weaker embryos die resulting in empty seed. This would explain the weak negative relationships in clone E1061. Presumably the effect does not occur to the same extent in E1102. Clone to clone and year to year differences occur in the correlations reflecting differences in cone and seed weight and seed quality.

Correlations between seed weight and viability were significant in several crosses, clone and year combinations but no trends were apparent from comparisons between hybrid and European larch from clone to clone of from year to year. Smaller seeds arising from smaller cones may fail to be fertilized as many small cones do not open fully at flowering time. This would explain the smaller seeds being less likely to be viable. This is likely to vary between clones and may also be affected by availability of pollen. A close relationship between seed weight and viability was reported to occur in lodgepole pine but not in white spruce (ACKERMAN and GORMAN 1969).

Percentage viable and full seed are, of course, significantly related. The size of the correlation coefficient is a measure of seed quality as only the full ones can germinate. The lowest coefficient is in the E1061 - 1974 hybrids were only 56.3% of full seed germinated. Few comparisons are available but hybrid correlations were lower than corresponding open-pollinated seed and lower than European controlled crosses. This is further evidence of an incompatibility between the two species.

Conclusions

These results show there to be wide variability in seed quantity and quality over all factors considered: among grafts, between clones, between hybrids and species, between controlled pollinated and open pollinated cones and

Table 3. — Correlation matrices (r) of cone weight, number of seeds, seed weight, percentage viable and percentage full for clones E1061 and E1102, controlled crosses and open pollinated for 1974 and 1975.

Clone E1061 - 1974

Hybrid Crosses

(29 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.151	1.000			
Seed wt.	.911*[1]	.167	1.000		
Percent viable	.530*	-.031	.552*	1.000	
Percent full	.692*	-.072	.656*	.639*	1.000

Open Pollinated

(42 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.438*	1.000			
Seed wt.	.820*	.407*	1.000		
Percent viable	.543*	.061	.550*	1.000	
Percent full	-	-	-	-	1.000

European Crosses

(22 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	-.008	1.000			
Seed wt.	.871*	-.033	1.000		
Percent viable	.306	.227	.493	1.000	
Percent full	.308	-.059	.553*	.842*	1.000

Open Pollinated

(56 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.374*	1.000			
Seed wt.	.823*	.151	1.000		
Percent viable	.187	-.088	.147	1.000	
Percent full	-	-	-	-	-

Clone E1102 - 1974

Hybrid Crosses

(75 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.445*	1.000			
Seed wt.	.918*	.345*	1.000		
Percent viable	.342*	.195	.409*	1.000	
Percent full	-	-	-	-	1.000

Open Pollinated

(50 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.331*	1.000			
Seed wt.	.625*	.139	1.000		
Percent viable	.234	-.069	.448*	1.000	
Percent full	-	-	-	-	1.000

European Crosses

(88 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.080	1.000			
Seed wt.	.740*	-.032	1.000		
Percent viable	.227*	-.019	.450*	1.000	
Percent full	-	-	-	-	1.000

Open Pollinated

(50 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.549*	1.000			
Seed wt.	.598*	.121	1.000		
Percent viable	.026	-.187	.232	1.000	
Percent full	-	-	-	-	1.000

~~Clone~~ E1061 - 1975

Hybrid Crosses

(45 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.851*	1.000			
Seed wt.	.816*	.637*	1.000		
Percent viable	.215	.121	.272	1.000	
Percent full	.253	.144	.301	.981*	1.000

Open Pollinated

(32 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.723*	1.000			
Seed wt.	.772*	.346	1.000		
Percent viable	.294	.287	.321	1.000	
Percent full	-	-	-	-	1.000

European Crosses

(56 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.806*	1.000			
Seed wt.	.797*	.497*	1.000		
Percent viable	.186	.280*	.277*	1.000	
Percent full	.181	.274*	.278*	.993*	1.000

Open Pollinated

(47 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.755*	1.000			
Seed wt.	.749*	.524*	1.000		
Percent viable	.190	.240	.401*	1.000	
Percent full	-	-	-	-	1.000

Clone E1102 - 1975

Hybrid Crosses

(68 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.825*	1.000			
Seed wt.	.870*	.658*	1.000		
Percent viable	.488*	.361*	.712*	1.000	
Percent full	.468*	.337*	.688*	.973*	1.000

Open Pollinated

(43 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.758*	1.000			
Seed wt.	.812*	.609*	1.000		
Percent viable	.079	.070	.391*	1.000	
Percent full	.049	.070	.364*	.991*	1.000

European Crosses

(98 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.832*	1.000			
Seed wt.	.886*	.724*	1.000		
Percent viable	.545*	.423*	.646*	1.000	
Percent full	.542*	.407*	.652*	.994*	1.000

Open Pollinated

(50 cones)	Wt. of cones	Number of seeds	Seed wt.	Percent viable	Percent full
Wt. of cones	1.000				
Number of seeds	.748*	1.000			
Seed wt.	.774	.340*	1.000		
Percent viable	.201	.322*	.238	1.000	
Percent full	.175	.300*	.191	.984*	1.000

[1]*r values statistically significant at probability level P=0.95.

between the two years sampled. The results are limited in that they describe only two of the many clones in the orchard and sample only two years, one an average year, the other a poor seed year. The results show that clones vary widely in yield, that the environmental component in seed yield variation is large and the yield from hybrid crosses, is reduced over that from intraspecific crosses. Cone size can be used to predict numbers of seed and seed size but not seed quality.

Management of seed orchards requires large amounts of quite detailed knowledge on individual clones over several years so that roguing or environmental modification can be undertaken successfully.

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On index selection I. Methods of determining economic weight

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Summary

Three methods (called partial regression, desired gain and equal emphasis) are outlined for estimating economic weights for use in selection on the index developed by SMITH and HAZEL. Under the method of partial regression economic weights are determined as the coefficients in a partial regression of phenotypic values for each trait (dependent variates) on estimates of the net economic worth of individual trees (independent variate). Partial regression is argued to be theoretically the most correct approach for estimating economic weight. Under the method of desired gain breeders are required to specify the relative responses they would like to achieve in each trait. Economic weights are then determined to give expected genetic responses from index selection which are proportional to the gains desired. Under the method of equal emphasis economic weights are determined to give equal importance to a one standard deviation change in each trait.

Each method produced different sets of weights when applied to data for *Pinus radiata* and *P. caribaea* in Australia, and the consequences of these different weights are examined in terms of expected genetic gains and the phenotypic values of individuals retained following index selection. Such checks on the consequences of index selection are always recommended. Beyond this, the method of partial regression is generally recommended where good information is available on the economic worth of trees. Where there is poor economic information but reliable information is available on genetic parameters the method of desired gain would be favoured. Equal emphasis is appropriate only where traits have approximately equal economic importance per standard deviation change.

Key words: Selection index, SMITH-HAZEL index, economic weight, economic worth, genetic gain.

Zusammenfassung

Um ökonomische Gebrauchswerte bei der Indexselektion nach SMITH und HAZEL zu schätzen, werden drei Methoden (sog. Partialregression, erwünschte Gewinne und gleiche Schwerpunkte) umrissen. Bei dem Partialregressionsverfahren werden ökonomische Gebrauchswerte als Koeffizienten einer Partialregression phänotypischer Werte für jedes Merkmal (als abhängige Variable) für Schätzungen des ökonomischen Nettowertes für Einzelbäume (als unabhän-

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