Effect of Fertilization on Flowering and Seed Crop in Scots Pine Seed Orchards

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The aim of the study was to obtain the information needed in preparing more precise fertilization recommendations for seed orchards. The fertilization requirement was estimated on the basis of soil and needle analyses, and by investigating the effects of different fertilization treatments on male and female flowering, the size of the seed crop and seed quality.

The study was carried out in two Scots pine (*Pinus sylvestris* L.) seed orchards in southern Finland, one of which was established on forest soil in 1971 and 1972, and the other on a peat field in 1974. 10 clones and 39 grafts from each clone were selected randomly from both orchards in autumn 1985. There were 13 treatments per clone, with three replications. The treatments consisted of N, P and K in various combinations, micronutrients, wood ash and grass control. The orchards were fertilized in spring 1986 and the seed crops collected in 1985–1990.

There were statistically significant differences between the clones in both orchards as regards amount of flowers, size of the seed crop and seed quality. The annual variation in flowering and the size of the seed crop were also large. In general, the seeds from cones collected in October matured well and their germination percentage was high. The effects of fertilization on flowering, the size of the seed crop and seed quality were small. It would appear that the size of the crop can be affected to a much greater extent by favouring clones with a high seed-producing capacity than through fertilization. Fertilization is unnecessary if the nutrient status of the soil is satisfactory.

Keywords *Pinus sylvestris*, seed orchards, fertilization, flowers, cones, seed crops, seed weight, germination.
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1 Introduction

A seed orchard is a seed-producing population consisting of grafts derived from selected plus trees. Orchards are used to produce seed of high genetical and physiological quality for forest regeneration purposes (e.g. Sarvas 1953, 1970).

Although the first orchards for producing forest tree seed in Finland were established during the 1950's, most of them were planted at the end of the 1960's and beginning of the 1970's. In 1993 there were 176 approved pine seed orchards, with a total area of 2718 ha, in the National Register of Forest Genetics. Almost 90 % of the orchards are owned by the Finnish Forest and Park Service (Pajamäki and Karvinen 1993).

The seed production of Scots pine varies considerably from year to year. Three favourable summers in succession are needed for a good seed crop: formation of the flower primordia during the first summer, flowering during the second, and maturation of the seed in the third. The weather during the summer preceding flowering has the greatest effect on flowering abundance: a dry and warm period in mid-summer promotes flowering (Eriksson 1980, Leikola et al. 1982).

Large amounts of nutrients are consumed in flowering and seed production. Soil fertility is usually considered to be important for seed production (Werner 1975). It can therefore be assumed that fertilization would increase seed production.

The size of the tree crown affects flowering abundance in pine (Koski 1975, Nikkanen and Velling 1987). Fertilization has therefore been applied to increase the size of the crown, and thus speed up the onset of seed production. Grass control has to be carried out in conjunction with fertilization in order to prevent excessive competition from grasses for the added nutrients. Grass control alone has been found to increase the seed crop (Rosvall 1983, Mikola 1987).

Although there is a rather long tradition of forest fertilization research in Finland, little information has so far become available about the effects of nutrient addition on the flowering and seed crop of trees. Despite this, the fertilization of seed orchards has become a common practice in Finland and elsewhere in the world.

Ever since 1981 the need for fertilization in the seed orchards owned by the Finnish Forest and Park Service (FPS) has been estimated on the basis of soil samples. A four-year fertilization cycle is used. The FPS has published guidelines for interpreting the results of soil analyses and for determining the fertilization requirements of seed orchards (Huurre 1983).

Lipas (1986) has compared soil chemical parameters in a number of the FPS's low- and high-yielding seed orchards established on forest soil. The average soil pH and extractable potassium and phosphorus contents were slightly lower in low-yield orchards, although the differences were not statistically significant. No corresponding trend was found for calcium. According to Lipas (1986), the FPS's minimum recommended levels for potassium in the humus layer and mineral soil, as well as phosphorus in the humus layer, appear to be unnecessarily high.

Although fertilization has been reported to increase the size of the cone or seed crop (Kozubov 1971, Savstuk 1981, Hadders 1984, Mikola 1987), the differences between the fertilization treatments have not always been statistically significant. This has been due to the natural variation in the growing conditions within seed orchards, as well as to the variation between clones. Fertilization does not always have an effect on fertile sites (Beloborodov et al. 1983, Werner and Hellström 1984), and in some cases it has been only slight (Danusjavitshjus 1982).

Nitrogen is the main nutrient used in fertilization trials in seed orchards, as has usually been the case in forest fertilization research. However, phosphorus, potassium and micronutrients have also been included in the fertilization programme in order to maintain a balanced nutrient status. Most studies have centered on the combined effects of NPK fertilizers on the cone and seed crops. However, information is required about the effects of individual nutrients on cone and seed crops if the fertilization recommendations are to be made more specific.

The aim of the study is to obtain the information needed in drawing up more precise fertilization recommendations for seed orchards. An attempt is made to estimate the fertilizer requirements of orchards by means of soil and needle analyses, and by investigating the effects of different fertilizer treatments on male and female flowering, the size of the seed crop and the quality of the seed. The extent to which the variation in flowering and the cone and seed crop in Scots pine is determined by genetic factors, and how much is determined by environmental factors or a combination of both, are also investigated.

The study was carried out as a joint effort by the Finnish Forest and Park Service and the Finnish Forest Research Institute. The field trials were carried out in seed orchards owned by the FPS. The FPS supplied the fertilizers, arranged for the soil analyses to be carried out by Viljavuuspalvelu Oy (Soil analysis service), and was responsible for the upkeep of the trials, collection of the cones and extraction of the seed. The Finnish Forest Research Institute was responsible for all other aspects of the study.

The different sections of the study have been carried out by the following persons: nutrient status of the seed orchards and the cone and seed crops by Saarsalmi and Lipas, weather conditions and seed quality by Savonen, and flowering by Nikkanen. Mikola participated in designing the experiment and made constructive comments on the final manuscript.

2 Material and Methods

2.1 Experimental Design

The study was carried out in two Scots pine (*Pinus sylvestris* L.) seed orchards: seed orchard N:o 249 (Metsäväärä) in Pertunmaa, and seed orchard N:o 301 (Manteresaari) in Joutseno (Fig. 1). The orchards are owned by the FPS and are situated in the Mikkeli forestry district. Orchard N:o 249 was established on forest land in 1971 and 1972, and orchard N:o 301 on peat soil in 1974. Both orchards were planted using a spacing of 3.5 × 7 m.

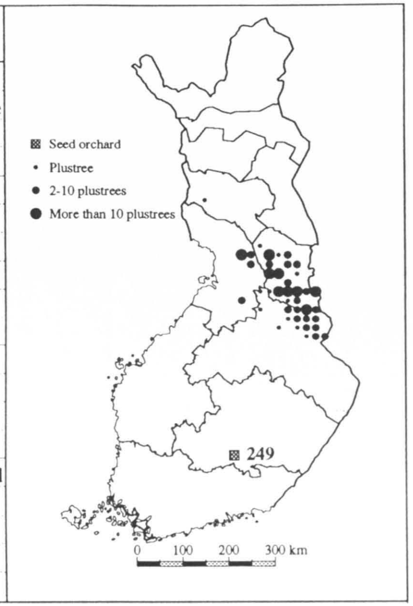
Ten clones, and 39 grafts from each clone, were selected randomly in each orchard. The experimental layout was a completely random design: a factorial 2^3 experiment with five additional treatments (Table 1). There were 13 treatments per clone, with three replications. The location of the clones and the treatments within each replication block were randomly selected.

The fertilizers were applied in spring 1986 in a circular area (radius 3.5 m) around each graft, a 3.5 m-wide unfertilized area being left between each treatment. A solution of Gardoprim was applied as grass control in summer 1986, and repeated in summer 1988.

Table 1. Fertilization treatments and grass control in seed orchards N:o 249 (Metsäväärä) and N:o 301 (Manteresaari). Fertilization was applied in spring 1986 and grass control in summer 1986 and 1988. The treatments included in the factorial experiment are connected with vertical line.

Treatment	Explanation to the symbols	
0	g:	grass control Gardoprim 80 26 kg/ha
g	h:	micronutrient fertilizer 255 kg/ha (Mn 2, Cu 1, Zn 2.2,
gt		Fe 1.8, B 0.4, Se 0.0006, Mo 0.04 %)
NPKg (N:o 249)	t:	wood ash 3000 kg/ha (P 0.4, K 1.1, Ca 12.8, Mg 0.8, Mn 0.6,
PKg (N:o 301)		Cu 0.006, Zn 0.20, Fe 0.82, B 1.46 %)
gh	N:	ammonium nitrate with lime (N 28, Ca 4, Mg 2 %) 150 kg N/ha
Ngh	N_2:	300 "
Pgh	P:	superphosphate (P 9 %) 100 kg P/ha
Kgh	P_2:	200 "
NPgh	K:	potassium sulphate (K 42 %) 200 kg K/ha
NKgh	K_2:	400 "
PKgh		
NPKgh		
N_2PKgh (N:o 249)		
P_2K_2gh (N:o 301)		

Seed orchard 249 Metsäväärä	
Species:	*Pinus sylvestris*
Owner:	Finnish Forest and Park Service
Year of establishment:	1972
Seed class:	A3
Commune:	Pertunmaa
Location:	61°34'N 26°18'E 130 m a.s.l.
Temperature sums:	
Seed orchard site	1202 d.d.
Origins sites (mean)	910 d.d.
Difference	302 d.d.
Area:	58,5 ha
Number of clones:	429
Number of grafts:	16264
Spacing:	3.5 x 7.0 m
Further information:	Established on forest land



Seed orchard 301 Manteresaari I	
Species:	*Pinus sylvestris*
Owner:	Finnish Forest and Park Service
Year of establishment:	1974
Seed class:	A3
Commune:	Joutseno
Location:	61°02'N 28°31'E 50 m a.s.l.
Temperature sums:	
Seed orchard site	1291 d.d.
Origin sites (mean)	980 d.d.
Difference	311 d.d.
Area:	34,5 ha
Number of clones:	295
Number of grafts:	10469
Spacing:	3.5 x 7.0 m
Further information:	Established on arable peatland

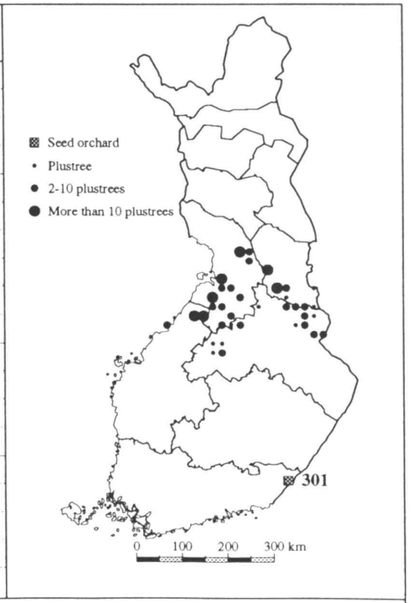


Fig. 1. Basic information about the seed orchards.

2.2 Collection and Treatment of the Material

The air temperature in the orchards was measured using thermohygrographs located at a height of 2 m in weather recording boxes from the 16th of May, 1986. Temperature data prior to this date and during periods when the thermographs were malfunctioning, as well as precipitation data, were obtained for orchard N:o 249 from the Pertunmaa weather station (145 m a.s.l.) located 5 km away, and for orchard N:o 301 from Lappeenranta Airport (105 m a.s.l.) located 18 km away. The thermohygrographs in orchard N:o 249 were replaced by a datalogger (Squirrel, type SQ16-16V) with mini-thermistor probes in December 1987.

Soil samples were taken down to a depth of 20 cm systematically at four points on each plot in autumn 1985. The samples were bulked to give one composite sample per plot. One composite humus sample comprising four sub-samples per plot was also taken from orchard N:o 249.

After drying the samples, plant available P, K, Ca and Mg were determined by extraction with acidic 1N ammonium acetate (pH 4.65) and analysed by inductively couple plasma atomic emission spectrometry (ICP/AES), total N by the Kjeldahl method and pH from a soil/water suspension (Halonen et al. 1983). Hot-water soluble B and total Cu and Zn, after dry ashing followed by extraction of the ash with 2N hydrochloric acid, were determined by ICP/AES.

The height of the grafts was measured in autumn 1985 to an accuracy of 10 cm and the diameter at breast height in two directions at right angles to one another, to an accuracy of 1 mm. The measurements were repeated in spring 1989 three growing seasons after fertilization.

Needle samples were taken from each graft in March 1986 before fertilization, and again in March 1989 three years after fertilization. The needle samples contained 80–100 g of the youngest needles from the southern side of the 3rd to 5th branch whorl counting downwards.

Needle nutrient concentrations (P, K, Ca, Mg, Mn, Cu, Zn, B) were determined by dry ashing followed by extraction of the ash with hydrochloric acid (Halonen et al. 1983). The element concentrations were determined by ICP/AES. Nitrogen was determined on a CHN analyser (LECO CHN-600).

The numbers of male and female flowers were estimated in both orchards during 1987–1990. The work was carried out in mid-summer a few weeks after flowering had commenced. The number of flowers was counted on one sample branch in each whorl on each graft. The number of flowers per graft was calculated by multiplying the number of male and female flowers on the sample branches by the number of branches in the same whorl, and then summing the values for all the whorls on the graft. At the time the first measurements were made the mean number of sample branches per graft was 15; one additional branch was selected each year from the newly formed branch whorls.

Cones were collected during 1985–1990: from replication 1 at the beginning of October, from replication 2 at the beginning of January, and from replication 3 in the middle of March. The fresh weight of the cones was determined. The seed was extracted from the cones and the dry weight of the seed was determined. The cone and seed crops were determined for each graft separately, except in 1985 when the crops were determined for each clone. The cones collected at different times of the year were not treated separately in the crop analysis. The collection year was defined as the year when the seed had ripened. Analysis of seed germination includes only those seeds collected in October each year. Information about the germination of seed collected at different times of the year will be published in another article.

The 1000-seed weight and germination percentage were determined in accordance with the forest tree seed handling and analysis instructions (Metsäpuiden...1980).

Analysis of variance was mainly used in the statistical treatment of the results (BMDP, 1985). In cases where analysis of variance could not be used owing to the unequalness of the variance, the two-way Brown-Forsythe test was used (BMDP 1985). Pairwise comparison of the differences between the treatments was performed at the clone level by means of the Tukey test.

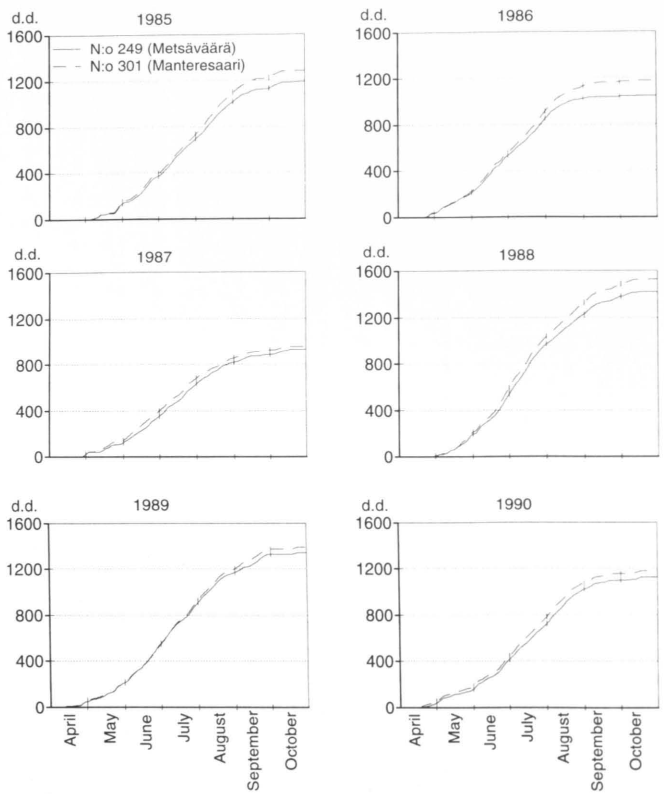


Fig. 2. Development of the effective temperature sum (threshold value +5 °C) in the seed orchards during the course of the study.

2.3 Weather Conditions during the Study Period

The weather conditions varied considerably from year to year. The effective temperature sum (degree days, d.d., threshold value +5 °C) during the coldest growing season (1987) was only 928 d.d. in orchard N:o 249 and 953 d.d. in orchard N:o 301 (Fig. 2). During the next growing season, which was the warmest one throughout the study period, the effective temperature sum was 1421 d.d. (N:o 249) and 1527 d.d. (N:o 301). The winter temperature conditions during the study period also varied considerably from year to year. Winter 1986/87 was exceptionally cold. For instance, the mean January temperature at Lappeenranta airport weather station was –20.3 °C, the corresponding long-term mean temperature (1961–1990) being –9.4 °C. The winters during the latter half of the study period were much milder than normal. For instance, the mean temperature in February 1990 was +0.2 °C.

The wettest summers were the cool summer of 1987 and the warm summer of 1988. Between the beginning of May and the end of September the amount of precipitation recorded at the Pertunmaa weather station was 468 mm in 1987 and 448 mm in 1988, and at the Lappeenranta airport weather station 404 and 345 mm, respectively. The driest summer occurred in 1990 when the precipitation at Pertunmaa during the corresponding period was 250 mm, and at Lappeenranta 220 mm.

Table 2. The concentrations of total nitrogen, plant-available phosphorus, potassium, calcium and magnesium, hot water soluble boron, total Cu and Zn and pH(water) in soil in autumn 1985. CV = coefficient of variation.

Nutrient		N:o 249 (Metsäväärä) Humus layer $\bar{x}$	Humus layer CV %	Mineral soil (0–20 cm) $\bar{x}$	Mineral soil (0–20 cm) CV %	N:o 301 (Manteresaari) Uppermost soil layer (0–20 cm) $\bar{x}$	CV %
N	g/kg	12.7	35	2.2	91	5.4	30
P	mg/l	8.0	58	0.6	200	11.2	29
K	"	121	26	30	57	82	29
Ca	"	786	24	133	140	1400	31
Mg	"	93	29	22	77	160	26
B	"	0.3	33	0.2	50	0.3	33
Cu	"	2.4	25	2.4	38	5.7	70
Zn	"	11.0	51	7.0	44	15.0	39
pH		4.6	7	4.9	6	5.1	8

2.4 Nutrient Status of the Seed Orchards

The soil in orchard N:o 249 consisted of fine sand till. The organic horizon consisted of raw humus in those places where it had not been mixed into the underlying mineral soil. The site was suitable for growing pine, and the original forest site type appears to have been of the *Myrtillus* type.

The nutrient concentrations and pH of the soil in orchard N:o 249 (Table 2) were equal or slightly better than the average nutrient concentrations for seed orchards established on mineral soil (Lipas 1986). The phosphorus concentration in the mineral soil was somewhat low but, in contrast, rather high in the organic layer.

The soil in orchard N:o 301 was of the mull type, and in places consisted of sand or fine sand till with an extremely high mull content. The site differed from the normal sort of forested peat field in that it had previously been an intensively cultivated agricultural field. The site differed from mineral soil fields in its high mull content.

The nutrient concentrations and pH of the soil in orchard N:o 301 (Table 2) were rather high compared to the average nutrient concentrations for seed orchards established on peat soil (Lipas 1986). Only nitrogen and boron were close to the lower limits of the recommended levels. However, this does not mean that there was a deficiency of these nutrients.

Judging by the needle nutrient concentrations, the nutrient status at the start of the study period was rather good, apart from magnesium, in both orchards (Table 3). The needle nutrient concentrations in orchard N:o 301 were even somewhat higher than those of orchard N:o 249, which was a mineral soil site. The average needle dry weight in orchard N:o 301 was half that in orchard N:o 249 but, despite this, slightly greater than the average value for pine needles (Mälkönen 1991). The fact that the nutrient concentrations were high, despite the high needle dry weight, further supports the conclusion that the site was rather fertile.

Three years after fertilization the needle dry weight as well as the needle nitrogen, phosphorus, copper and boron concentrations were higher, but the magnesium concentrations lower, than at the start of the experiment (Tables 3 and 4). Needle tip-yellowing, possibly due to a shortage of magnesium, was observed in the old needles in both orchards at the end of summer 1986, but not later on.

Micronutrient fertilization increased the nee-

Table 3. The average needle dry weight, nutrient concentrations and nutrient ratios in needles from all grafts combined in March 1986 before fertilization. CV = coefficient of variation.

	N:o 249 (Metsäväärä) x̄	N:o 249 (Metsäväärä) CV %	N:o 301 (Manteresaari) x̄	N:o 301 (Manteresaari) CV %
Dry weight, mg/needle	27	25	14	20
N g/kg	15.0	9	15.9	9
P "	1.59	11	1.86	11
K "	5.73	11	6.03	9
Ca "	2.42	23	3.05	23
Mg "	0.77	15	0.90	14
Mn mg/kg	505	34	539	31
Cu "	3.0	17	3.4	29
Zn "	42	19	54	19
Fe "	54	16	81	16
B "	13	21	14	19
P/N	0.11	9	0.12	9
K/N	0.38	12	0.38	13
Ca/N	0.16	23	0.19	22
Mg/N	0.05	17	0.06	15
P/K	0.28	11	0.31	11
Number of observations	390		390	

Table 4. The average needle dry weight, nutrient concentrations and nutrient ratios in needles from all grafts and treatments combined in March 1989. CV = coefficient of variation.

	N:o 249 (Metsäväärä) x̄	N:o 249 (Metsäväärä) CV %	N:o 301 (Manteresaari) x̄	N:o 301 (Manteresaari) CV %
Dry weight, mg/needle	33	22	38	16
N g/kg	16.5	11	19.0	11
P "	1.75***	10	2.07	12
K "	5.24	13	6.58	11
Ca "	2.28	22	2.68	30
Mg "	0.66	18	0.80	15
Mn mg/kg	669***	31	493	34
Cu "	4.8	28	5.7	31
Zn "	37*	22	61	15
Fe "	54	27	65	21
B "	23***	22	20***	23
P/N	0.11***	12	0.11	12
K/N	0.32	17	0.35	15
Ca/N	0.14	21	0.14	25
Mg/N	0.04*	20	0.04	16
P/K	0.34***	15	0.32	12
Number of observations	306[1)]		116[2)]	

Statistical significance of difference between treatments:
* p < 0.05, ** p < 0.01, *** p < 0.001.
1) Clones P 1106 and P 5281 excluded.
2) Clones P 139, P 1038, P 3222, P 3816, P 3831, P 3835 and P 4112 excluded.

dle boron concentrations in both orchards, and the manganese concentrations in orchard N:o 249. The needle phosphorus concentrations in the latter orchard had also increased in those treatments including phosphorus. Neither nitrogen nor potassium fertilization, not even at a double dosage level, had any effect on the needle nitrogen or potassium concentrations. This was the case when the clones were analysed either individually or combined.

2.5 Growth of the Grafts

The mean height of the grafts in autumn 1985 was 4.9±0.8 m in orchard N:o 249, and 3.9±0.5 m in orchard N:o 301. The diameter at breast height was 9.5±2.3 cm and 7.3±1.6 cm, respectively (Fig. 3). The differences between the clones in height and diameter at breast height were statistically significant in both orchards. Three years after fertilization the mean height of the grafts was 5.9±0.9 m and the diameter at breast height 13.9±2.5 cm in orchard N:o 249, and correspondingly 4.9±0.7 m and 10.7±2.0 cm in orchard N:o 301. None of the treatments had any effect on graft growth. However, potassium addition in orchard N:o 249 significantly increased the graft diameter of clones P 731 and P 3589, and the height of clone P 3576.

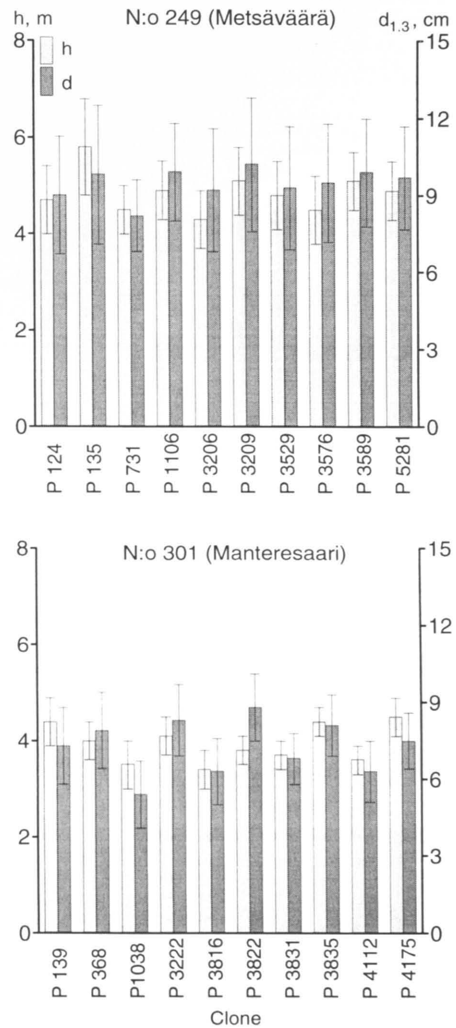


Fig. 3. Mean height (h) and diameter at breast height ($d_{1.3}$) of the grafts from different clones in autumn, 1985.

3 Results

3.1 Flowering

3.1.1 Annual and Inter-Clonal Variation in Male and Female Flowering

Female flowering during the first year after fertilization was more abundant than later on during the study, and continuously more abundant in orchard N:o 249 than in orchard N:o 301 (Table 5). In 1990 there were no female flowers left in orchard N:o 301, presumably partly due to frost during the flowering period (–5 °C on 29.5.90). Frost also occurred in orchard N:o 301 on 22.5.89 (–7 °C). Male flowering increased in both orchards during the study period, and was more abundant in orchard N:o 249 than in the other orchard. At the beginning of the study period the mean number of female flowers per graft was greater than that of male flowers, but at the end of the study period the situation was reversed.

Some clones in orchard N:o 249 were clearly female flowerers (P731, P3529, P 3589), and other ones male flowerers (P 1106, P3576) (Fig. 4). This tendency for heavy male flowering became accentuated in some of the clones towards the end of the study period. However, the material did not contain any clones which produced only female or male flowers. The differences in the flowering pattern between the clones remained constant from year to year. The variation between the clones in both female and male flow-

Table 5. Mean annual female and male flowering.

Seed orchard	1987 female	1987 male	1988 female	1988 male	1989 female	1989 male	1990 female	1990 male
	Number of flowers/graft							
N:o 249	612	259	311	210	480	359	370	792
N:o 301	450	38	103	79	38	180	0	386

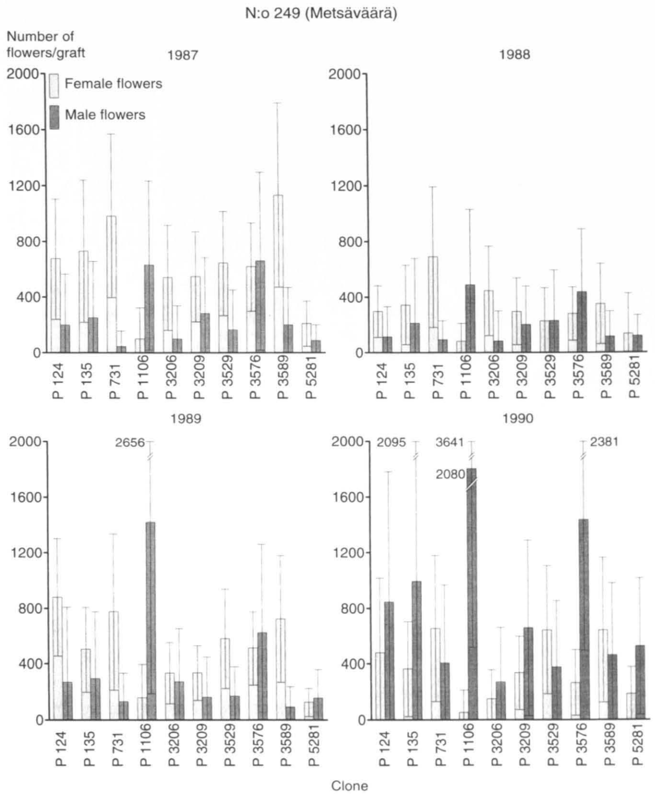


Fig. 4. Abundance of female and male flowering on the different clones in seed orchard N:o 249 during 1987–1990.

ering was statistically highly significant in all years of the study.

The differences in flowering between the clones were statistically significant also in orchard N:o 301 (Fig. 5). However, it is difficult to draw any conclusions about the tendency of the clones in this orchard for either male or female flowering because male flowering had only just started on the grafts at the start of the study, and there were no female flowers on the grafts during the last years of the study.

3.1.2 Effect of the Treatments on Male and Female Flowering

There were significant differences in female flowering between the treatments in orchard N:o 249 in 1987 only, i.e. one year after fertilization (Fig. 6). The grafts producing the greatest number of female flowers had received phosphorus, potassium, micronutrients and a double dose of nitrogen (N_2PKgh). The differences in male flowering between the treatments were not significant in any of the years. The treatments had no statistically significant effect on male or female flowering in orchard N:o 301 (Fig. 7).

In orchard N:o 249 the effects of the treatments on female flowering were almost significant in 1987 in the case of clones P 3209 (p = 9 %) and P 3576 (p = 6 %), and on male flowering in clone P 124 (p = 9 %). The greatest number of female flowers occurred on clone P 3209 with the N_2PKgh treatment and on clone P 3576 with the Ngh treatment, and the greatest number of male flowers on clone P124 with the NKgh treatment. However, the results of the individual treatments for each clone are based on the flowering of only three grafts.

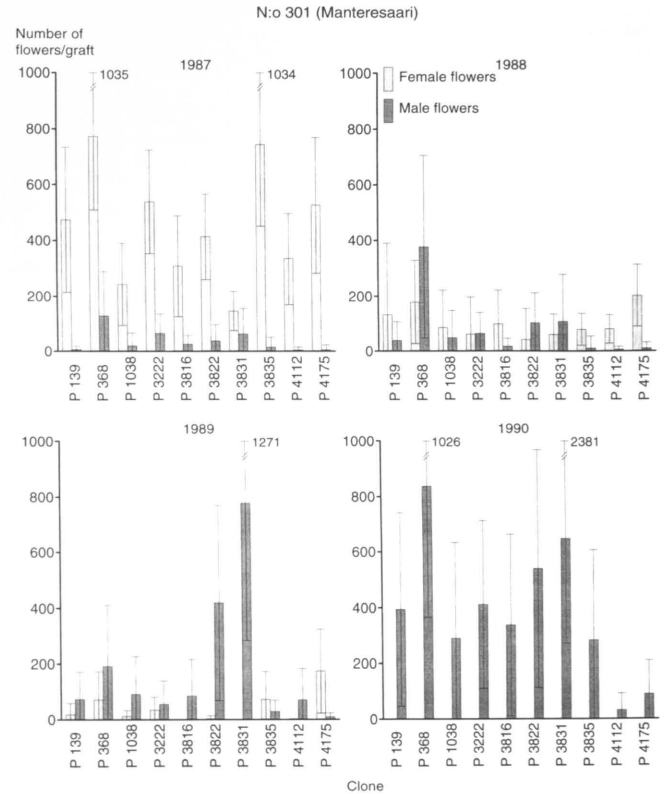


Fig. 5. Abundance of female and male flowering on the different clones in seed orchard N:o 301 during 1987–1990.

3.2 Cone and Seed Crops

3.2.1 Annual and Inter-Clonal Variation in the Cone and Seed Crops

The cone and seed crop varied considerably between years (Fig. 8). The cone and seed crops in orchard N:o 249 were greater, except in 1987, than in orchard N:o 301.

Genetic factors had a clear effect on the size of the cone and seed crops. The differences between the clones in the cone and seed crops were statistically highly significant in all years in both

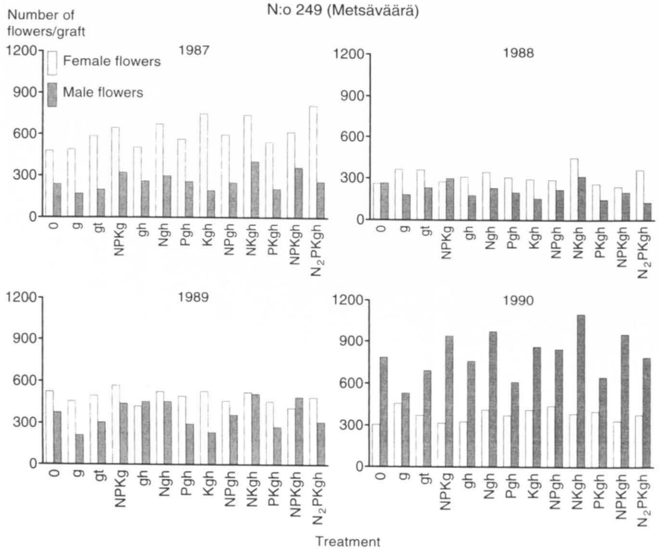


Fig. 6. Abundance of female and male flowering in the different treatments in seed orchard N:o 249 during 1987–1990. See Table 1 for explanation of treatments.

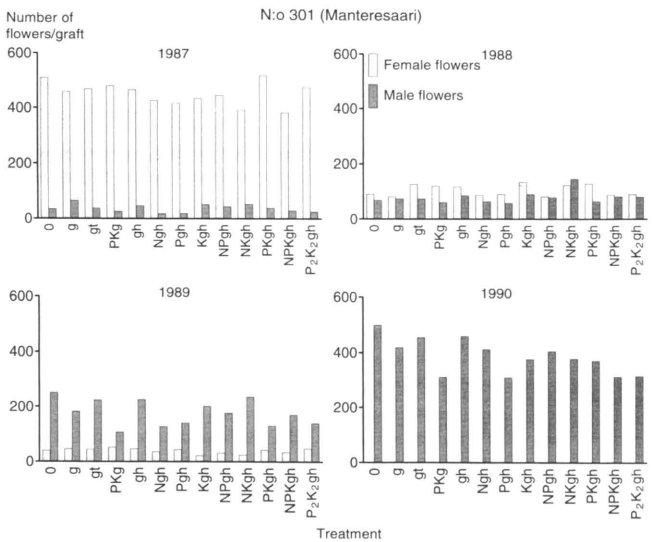


Fig. 7. Abundance of female and male flowering in the different treatments in seed orchard N:o 301 during 1987–1990. See Table 1 for explanation of treatments.

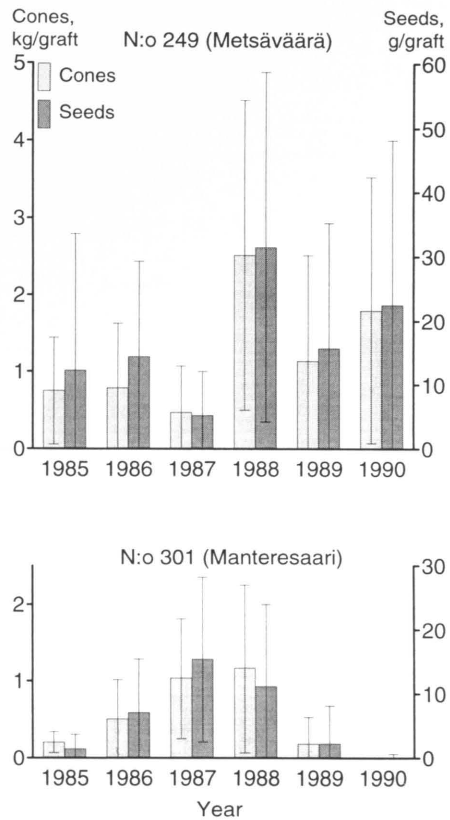


Fig. 8. Mean annual cone crop (fresh weight) and seed crop (dry weight) during 1985–90.

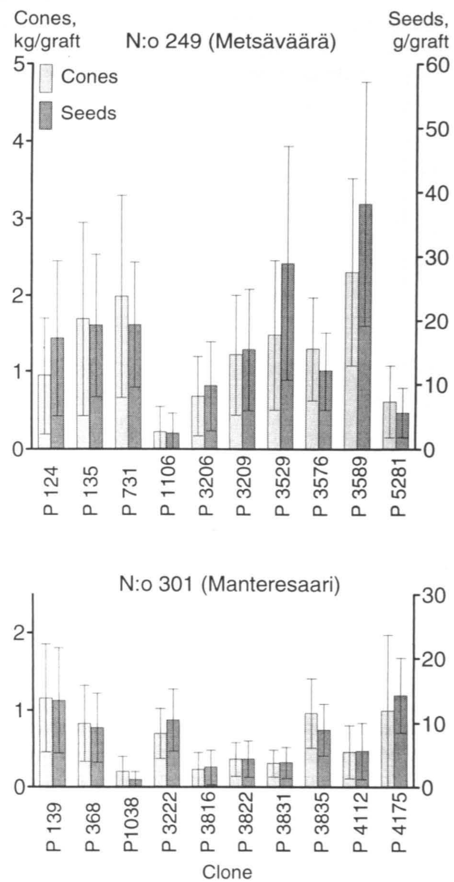


Fig. 9. Mean seed crop (dry weight) during 1985–1990 on the different clones.

orchards. Some clones almost always produced a good crop, while others did not produce cones at all (Fig. 9). Those clones in which the majority of the grafts did not produce a crop at all can hide the effects of the treatments in the other clones. Clones P 1106 and P 5281 in orchard N:o 249 and clone P 1038 in orchard N:o 301 were therefore omitted when studying the effects of different treatments on the size of the seed crop.

3.2.2 *Effect of the Treatments on the Size of the Seed Crop*

In 1985 the cone crop was collected before fertilization and grass control. The treatments probably had no effect in 1986 and 1987 because the cones had developed from flower primordia formed before fertilization. The mean crop during 1985–87 was used as a covariant to correct

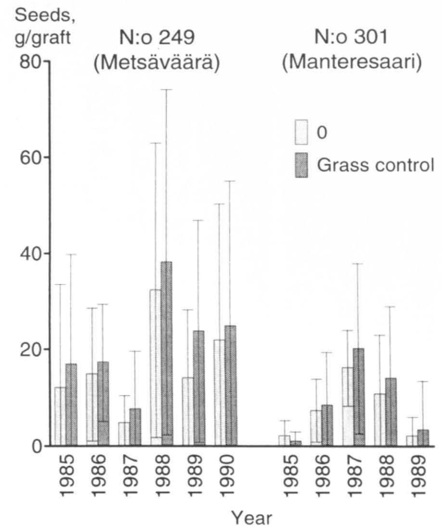


Fig. 10. Mean seed crop (dry weight) on the grass control and control plots during 1985–1990. All clones except P 1106 and P 5281 in seed orchard N:o 249, and P 1038 in seed orchard N:o 301.

the level of subsequent crops to the same starting level when analysing the effects of grass control and fertilization. The flower primordia producing the 1988 crop had been formed in 1986 at the time when the fertilizer was applied (cf. Kramer and Kozlowski 1979, p. 133), and hence the fertilizers would probably have had an effect. The analysis concerning the effects of grass control and fertilization was restricted to the seed crop only.

Because grass control was included in all the fertilizer treatments, its effect alone could only be determined using the treatment pair - control (0) and grass control (g).

The seed crop in orchard N:o 249 was slightly greater on the grass-controlled plots throughout the study period (Fig. 10). However, grass control had no statistically significant effect on the seed crop. The effect of grass control was accentuated in those cases where the seed crop was otherwise high. Grass control on the clone with the highest crop (P 3589) increased the seed crop almost significantly in 1988 (p = 6 %) and in

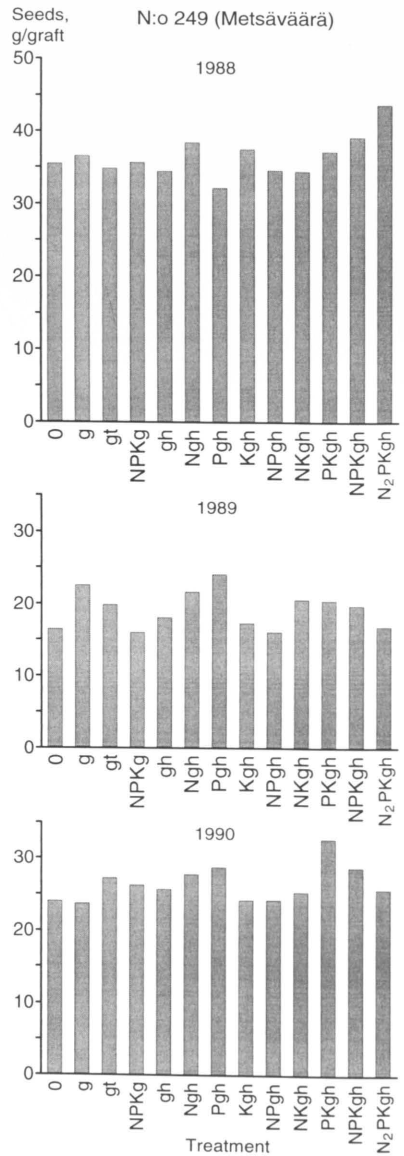


Fig. 11. Seed crop (dry weight) in different treatments in seed orchard N:o 249 in 1988, 1989 and 1990. Mean of the 1985, 1986 and 1987 seed crops used as a covariant. All clones except P 1106 and P 5281. See Table 1 for explanation of treatments.

1989 (p = 9 %).

The ground vegetation in orchard N:o 301 was clearly more luxuriant than that in orchard N:o 249. The seed crops were slightly larger in those treatments including grass control than on the control (Fig. 10). Owing to the small size of the crop and the high inter-clonal variation the differences were not, however, statistically significant.

The seed crops obtained with different treatments during 1988–90 are presented in Figs. 11 and 12. Separate analyses were carried out on the wood ash (g-gt), micronutrients (N:o 249 treatment pairs: g-gh and NPKg-NPKgh and N:o 301: g-gh and PKg-PKgh), different combinations of N, P and K fertilizers (Ngh, Pgh, Kgh, NPgh, NKgh, PKgh, NPKgh), nitrogen dose (N:o 249: PKgh-NPKgh-N_2PKgh) and the phosphorus and potassium doses (N:o 301: gh-PKgh-P_2K_2gh). See Table 1 for explanation of treatments mentioned above.

Neither wood ash nor micronutrients, alone or with macronutrients, had any significant effect on the size of the seed crop.

Different combinations of N, P and K fertilizers in orchard N:o 249, or the size of the nitrogen dose, had no significant effect on the size of the seed crop. However, nitrogen, phosphorus and potassium given together (NPK) somewhat reduced the seed crop (p = 6 %) in the clone with the highest seed production (P 3589) in 1988.

In orchard N:o 301 different combinations of N, P and K fertilizers had no significant effect on the size of the seed crop in 1988. The following year NP fertilization significantly increased the seed crop (p = 3 %). However, the crop in 1989 was so small that the difference can hardly be of any practical significance. The amount of potassium or phosphorus dose had no effect on the seed crop.

When calculating the factorial effects of the fertilizer nutrients, the seed crops for 1988, 1989 and 1990 were corrected in order to balance out the natural variation by means of covariance correction (cf. Lipas 1981). The increases in seed crop produced by the different nutrient combinations were calculated from the factorial effects (Table 6) (cf. Lipas 1981).

The greatest crop increment in orchard N:o 249 was obtained with NPK and NK fertilization

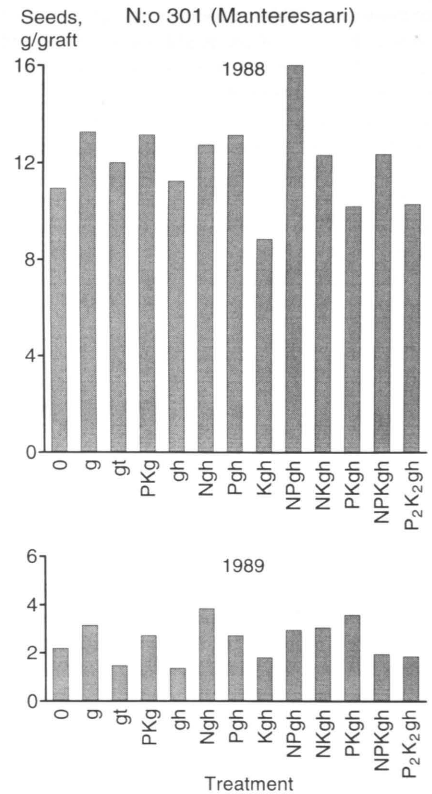


Fig. 12. Seed crop (dry weight) in different treatments in seed orchard N:o 301 in 1988 and 1989. Mean of the 1985, 1986 and 1987 seed crops used as a covariant. All clones except P 1038. See Table 1 for explanation of treatments

during the good seed year of 1988. In 1989 the factorial effects of the fertilizer nutrients were small. The largest crop increase in 1990 was obtained with NPK and PK fertilization. The double nitrogen dose almost doubled the increment in the seed crops in 1988, which was a year when the crop was otherwise abundant. As has already earlier been mentioned, none of the effects were statistically significant. The effect of double nitrogen dose on the subsequent crops was almost negligible. The best seed crop in

Table 6. Change in seed crop obtained with different nutrient combinations. g = grass control, h = micronutrient fertilization.

Fertilization + gh	Crop increase g/graft N:o 249 (Metsäväärä) 1988	1989	1990	N:o 301 (Manteresaari) 1988	1989	Replications/ crop increase[1)]
N	1.4	–0.4	–1.3	2.5	0.6	12
P	–0.4	0.7	2.9	1.7	0.3	12
K	2.2	–0.4	1.2	–2.3	–0.1	12
NP	1.0	0.3	1.6	4.2	0.9	6
NK	3.6	–0.8	–0.1	0.2	0.5	6
PK	1.8	0.3	4.1	–0.7	0.2	6
NPK	4.9	1.8	3.1	1.1	0.6	3
N2PK	9.4	–1.3	0.0	–1.0	0.5	3
The average crop	36.0	19.7	27.2	12.1	2.7	27

[1)] Number of sample plot pairs.

orchard N:o 301 occurred with NP fertilization in 1988. The following year, when the crop was small, the effects of fertilization were non existent.

3.3 Seed Quality

3.3.1 1000-Seed Weight

There were statistically significant differences between the 1000-seed weight of the clones already before fertilization, and the genetical differences in seed weight continued from year to year (Table 7).

According to the results for treatments included in the factorial part of the experiment (Table 1), fertilization had no effect at all on the 1000-seed weight in orchard N:o 301 (Table 7). In orchard N:o 249 the only significant effects were found in 1986, when the seeds of clone P 3589 were smaller in the gh treatment than those in the Pgh ($p = 5$ %), NPKgh ($p = 1$ %) and N_2PKgh ($p = 10$ %) treatments. There were no differences between the 1000-seed weight of the other clones.

When the additional treatments (cf. Table 1) were included in the examination, the number of cases of statistically significant differences increased somewhat. However, the seeds of only a few clones reacted to fertilization. In all the significant or almost significant cases, the seeds of the control (0) were smaller than those of other treatments. No individual fertilizer treatment proved to be superior to any of the other treatments; in contrast the treatment which produced the heaviest seeds differed nonsystematically in different years and in different clones.

Because one very cool and a number of clearly warmer growing seasons occurred during the course of the study, the effect of the mean temperature during May–August on 1000-seed weight was also investigated. Only the unfertilized grafts were included in the calculations. There was positive correlation between 1000-seed weight and the mean temperature during May–August. However, the mean temperature during these months explained only 15 % (N:o 249) and 6 % (N:o 301) of the variation in 1000-seed weight.

3.3.2 Germination

The seed from the cones collected in October germinated well, apart from the seed which had

Table 7. Maximum, minimum and average 1000-seed weight (g) of all grafts in the seed maturation year and result of the 2-way Brown-Forsythe test on the effect of clone and fertilization on 1000-seed weight. Only treatments in the factorial experiment included.

Year	$\bar{x}$	Max	Min	$F_{(clones)}$	$F_{(treatments)}$
N:o 249 (Metsäväärä)					
1985	6.0	8.3	4.4	41.5***	
1986	6.3	8.0	4.9	39.8***	3.8**
1987	5.9	9.6	4.3	58.9***	
1988	6.2	7.6	4.7	52.7***	
1989	6.3	7.4	4.0	17.6***	
1990	5.3	6.8	4.4	37.0***	
N:o 301 (Manteresaari)					
1985	5.7	7.7	3.1	30.4***	
1986	6.1	8.1	4.1	36.4***	
1987	5.5	7.3	3.0	121.2***	
1988	6.2	7.9	4.4	78.5***	
1989	5.6	8.2	3.9	34.7***	

Statistical significance of difference between treatments:
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

matured in 1987. The germination of the seed in orchard N:o 249 was on the average over 95 %, and in some years almost 99 %. The seed in orchard N:o 301 did not germinate quite as well, but even in this orchard the germination was on the average over 90 %.

The germination of seed collected in October only is examined in this report. For this reason the effect of clone and treatment on germination had to be tested separately using one-way analysis of variance, and it was not possible to determine interactions between the clones and fertilization treatments.

Although the seeds generally matured well and their germination was high, there were differences between the clones. However, there were no differences between the treatments. The differences between the clones in a number of years were highly significant even though the variation range was very small. For instance, the mean germination of the different clones in orchard N:o 249 varied between 98–99.7 % in 1988 but, despite this, the differences between the clones were significant ($p = 0.3$ %). The differences between the clones became even more accentuated during the cool growing season of 1987, when the germination in orchard N:o 249 varied from 22.0 to 95.7 % (mean 66.5 %), and in orchard N:o 301 from 59.7 to 96.1 % (mean 87.4 %). The differences between the grafts of the same clone became more strongly evident, as was seen from the increase in the standard deviation.

4 Discussion

Nutrient Status of the Seed Orchards

Fertilization has become an established practice in seed orchards. The nutrient requirements have usually been estimated primarily on the basis of soil analyses. However, no general comparison values have so far been presented for soil analysis results. In this study the mean soil nutrient concentrations indicate that the nutrient status was sufficient. The clones in both orchards clearly explained more of the variation in the first seed crop (1985) than soil parameters. Correspondingly, the first seed crop explained much more of the variation in the second seed crop than the soil parameters. The dependence of the seed crop on the soil parameters was random.

Strong growth of the grafts in seed orchards is not desirable after the juvenile stage because collection of the cones becomes difficult as the grafts increase in height. The increase in growth of the grafts of some clones in orchard N:o 249 given by potassium indicates that the nutrient status of the mineral soil is perhaps unbalanced. Mineral soils generally contain sufficient potassium compared to nitrogen and phosphorus. The small growth reaction or its absence shows that the nutrient supply has been sufficient for the grafts in the orchard. There was no correlation between the growth and cone or seed crops of the grafts.

The needle dry weight in seed orchards is usually large, and the variation in needle dry weight between the grafts greater than that of the needle nutrient concentrations (Danusjavitshjus 1982, Rosvall and Untinen 1982). This was also the case in this study. In contrast to the results obtained in the study of Rosvall and Untinen (1982), however, there was no correlation between the needle dry weight and the needle nitrogen concentration.

Needle nitrogen, phosphorus and potassium concentrations are usually high in seed orchards (Beloborodov et al. 1983, Danusjavitshjus 1982). The corresponding needle concentrations were also higher in the study in hand than the average values for young or middle-aged, thinned pine stands in Finland (Mälkönen 1991), and clearly higher than the lower limit for the class "optimum" presented for Scots pine stands by Jukka (1988, p. 156). The nutrient ratios corresponded to those of young or middle-aged, thinned pine stands in Finland (Mälkönen 1991), except for the N/Mg ratio which was low. In fact the needle Mg concentrations in both orchards remained low throughout the course of the study, despite the fact that there was sufficient Mg in the soil. According to Jukka (1988), the needle Mg concentration on peat soil sites should be above 1 g/kg. On the other hand, the large variation in needle nutrient concentrations shows that estimates of the nutrient status should not be based solely on the results obtained from individual trees, but on average values from a number of sample trees representative of the site in question.

The effect of fertilization on needle nutrient concentrations was only small, probably because the concentrations had been high already before fertilization. It is also possible that the effect of fertilization had already dissipated within three years. Beloborodov (1983) also found that different combinations of N, P and K fertilizers had no effect on needle nutrient concentrations in pine seed orchards in the chernozem soil region in Russia. In contrast, Rosvall (1983) reported that the needle nitrogen concentrations in pine seed orchards increased, irrespective of whether the needle nitrogen concentrations before fertilization were high or low, as a result of N fertilization (60–200 kg N/ha).

The effect of the treatments was most strongly evident as an increase in needle boron concentrations on those plots treated with the micronutrient fertilizer in both orchards. However, it is significant that neither N nor K fertilization at doses of 300 kg N/ha and 400 kg K/ha had any effect on the needle nutrient concentrations.

There was no correlation between needle nutrient concentrations and the cone or seed crops. In contrast, it has been reported that needle nitrogen and potassium concentrations in spruce explain about 40 % of the variation in the seed crop between trees in good seed years (Mälkönen 1971).

Flowering and the Seed Crop

At the time of fertilization in 1986 fifteen years had elapsed since establishment of orchard N:o 249 and 13 years for orchard N:o 301. In 1986 the average height of the grafts was 5 m and 4 m, respectively. The orchards were in the so-called juvenile stage and their flowering was just developing. Female flowering in grafts of this age and size can sometimes be fairly abundant, but male flowering is usually just beginning and rather a large number of grafts often do not produce any male flowers at all (Bhumibhamon 1978). The mean proportion of non male-flowering grafts in orchard N:o 249 in 1987 was 18 %, and in orchard N:o 301 40 %. In 1990 the corresponding proportions were 8 and 12 %. Part of the variation in the female flowering of the grafts may be due to the fact that there are genetical differences in the duration of the juvenile stage. The ability of the individual grafts to react to fertilization may therefore have been different, thus making interpretation of the fertilization reaction difficult. The effects of fertilization in more mature orchards would perhaps have been clearer.

There is large between-year variation in flowering in pine, although smaller than that in spruce. Part of the variation is due to weather factors. Warm and dry weather stimulates the formation of flower primordia, and cool weather during the previous summer increases the abundance of female flowering (Pukkala 1987). These preconditions were fullfilled in 1989 and abundant flowering was to be expected. However this was not the case; female flowering in orchard N:o 301 was especially poor in 1989, and the following year there were no female flowers at all. The reason for the lack of flowers in 1990 was the frost that occurred during flowering that destroyed the delicate female flowers. In Finland the seed crops in pine seed orchards were generally poor or at the best moderate at the end of the 1980's.

The effects of grass control and fertilization on flowering and the seed crop were small in this study. The high annual variation, as well as the high variation between the clones, was many times greater than any possible differences caused by the treatments. In addition, the nutrient status of the soil in both orchards was good already before fertilization. According to Werner and Hellström (1984), too, fertilization on fertile soil did not affect female flowering in pine and the differences in flowering between the clones were significant. Similarly, Beloborodov et al. (1983) and Danusjavitshjus (1982) reported that fertilization on a fertile site had either no effect or only a slight one on the seed crop.

Nitrogen fertilizer applied on sandy soil in a pine stand of the *Vaccinium* site type has increased seed weight, and phosphorus decreased cone shedding; the seed crop obtained with NPK fertilizer was 20–25 % greater compared to the control (Kozubov 1971). In Kozubov's study it was also found that it would be necessary to apply N, P and K at a dose of 120 kg/ha in order to increase the seed crop of pine, and on coarse soils regular fertilization is essential owing to leaching losses. In a Swedish study in which the average annual seed crop was, without fertilization, of the same order of magnitude as that given by the most productive clone P 3589 (N:o 249) in this study, NPK and micronutrients increased the seed crop by 13 % (Hadders 1984).

Grass control must be carried out in conjunction with fertilization in order to prevent the ground vegetation from utilizing all the nutrients added in fertilization. In contrast to results obtained earlier (Rosvall 1983, Mikola 1987), grass control had no significant effect on the seed crop. However, the grass control did have an effect when the seed crop was large.

1000-Seed Weight and Germination

According to Heikinheimo (1937), the mean 1000-seed weight in Scots pine stands in the part of Finland lying to the south of Rovaniemi (66°29'N, 25°40'E) is 4.2 g. The 1000-seed weight in both seed orchards was considerably higher than this already before fertilization: on the average 6.0 g (N:o 249) and 5.7 g (N:o 301). The higher 1000-seed weight compared to seed from natural stands may be due to the fact that the grafts are growing in areas which are climatically more favourable and on rather fertile sites. According to Simak and Gustafsson (1954), too, grafts produce larger cones than their corresponding mother trees in natural stands.

The greater size of the seed from seed orchards compared to that collected from natural stands is generally considered to be an important physiological advantage in seedling production and forest regeneration because seed size is positively correlated with the initial development of pine transplants. However, these effects decline rapidly after seed germination and often disappear completely in later years (e.g. Hadders 1963, Mikola 1980).

There are large differences between the 1000-seed weight of different clones (von Weissenberg 1981, Lindgren 1982). In fact the seed weight of pine has been shown to be a strongly inheritable property (Lindgren 1982). There were also clear differences in the 1000-seed weight between the clones in the study in hand. Fertilization had only a slight effect on 1000-seed weight. Some treatments temporarily increased the 1000-seed weight of few clones. These clones included the most productive ones, i.e. P 3589 (N:o 249) and P 139 (N:o 301).

According to Nygren (1990), the summer temperature in the year when the seed matures has an effect on the seed weight in pine: somewhat lighter seeds are obtained when the summer is warmer than average. However, the mean summer temperature must exceed 11.5 °C because, according to Kujala (1927), this is the threshold value for the normal development of pine seeds. The results obtained in the study in hand do not support the results presented by Nygren. The 1000-seed weight of the unfertilized grafts was the greater, the higher the mean temperature during May–August.

The weather conditions during the growing season preceding seed shedding is of decisive importance for the germination of pine seed. The dependence between the temperature during the summer when the seed matures and the development of the embryo has been known for a long time already (Hagem 1917, Heikinheimo 1921, Kujala 1927, Wibeck 1928). Sarvas (1970) linked the accumulation of the temperature sum to the maturation of pine seed. If the temperature during the summer of maturation is low, then the embryo does not have time to fully occupy the embryonic cavity. The germination of incompletely developed seed remains, correspondingly, poor.

Except for one orchard, all the Finnish pine seed orchards have been established in southern and central Finland. Thus the orchards producing seed for northern Finland are located considerably to the south of the area where the seed is to be used. One of the aims of performing transfers to the south has been to ensure regular maturation of the seed. Orchards established using seed of northern origin usually produce seed that germinates well. Orchards N:o 249 and 301, which are located about 300 d.d. units to the south of their seed origin, produced seed that germinated extremely well, apart from during the exceptionally cool summer of 1987.

There were differences between the clones in seed germination. The differences became evident during the cool growing season of 1987 when maturation was seriously interrupted in some of the clones. Ryynänen (1982) has also reported that there can be considerable differences between the trees in the same stand as regards seed maturation. Some trees are able to produce germinating seed even during cool growing seasons.

Site fertility does not appear to have any effect on the maturation of pine seed and, through this, on germination (Ryynänen 1982). For instance, rather well germinating seed has been obtained from stunted pines growing on oligotrophic peatlands (Lukkala 1936). In this study, too, the addition of nutrients had no effect on seed maturation and germination.

Conclusions

The seed orchards investigated in this study were young and their flowering and seed production just starting. The nutrient status of the soil in the orchards was good already before fertilization. For this reason, as well as the unfavourable weather conditions in orchard N:o 301 during flowering in 1989 and 1990 the treatments had only a minimal effect or none at all on the growth of the grafts, needle nutrient concentrations, flowering, seed crop, seed germination and 1000-seed weight in both orchards. Because magnesium fertilizer was not included in the treatments, except indirectly in the wood ash and as an additional constituent in ammonium nitrate with lime, it was not possible to determine whether a shortage of magnesium had reduced the size of the seed crop. The results show that soil and needle analyses can be a useful tool when planning the fertilization of seed orchards. Fertilization is unnecessary if the analyses indicate that the nutrient reserves are sufficient.

The importance of heritability became apparent in the growth, flowering and cone and seed crops of the grafts, in the germination of the seeds and in the 1000-seed weight. If the aim is only to increase the seed crop, the selection of abundant cropping clones in the seed orchards is a much more certain way of influencing the size of the crop than fertilization. Fertilization does not convert low-yield clones into high-yield ones, neither does it even out the considerable annual variation in the size of the crop. If the aim is to get low-yield clones to flower, or if the orchards are also to produce seed during naturally unfavourable seed years, then other methods of flower induction will have to be resorted to. Hormone treatments have proved to be extremely effective, but many other factors restrict their use in large-scale seed orchard production (e.g. Bonnet-Masimbert 1987, Philipson and Fletcher 1990).

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References

Beloborodov V.M., Efimov, Ju.P. & Stebakova V.N. 1983. Urozhaj shishek sosny obyknovennoj na udobrennyh semennyh plantacijah. Lesovedenie 3: 18–26.

Bhumibhamon, S. 1978. Studies on Scots pine seed orchards in Finland with special emphasis on the genetic composition of the seed. Communicationes Instituti Forestalis Fenniae 94(4). 118 p.

BMDP statistical software. 1985. University of California Press. 734 p.

Bonnet-Masimbert, M. 1987. Floral induction in conifers: A review of available techniques. Forest Ecology and Management 19: 135–146.

Danusjavitshjus, Ju.A. 1982. Rol' ydobrenij v stimulirovanii semenonoshenija. Lesnoe hozjajstvo 11: 32–35.

Eriksson, G. 1980. Är lokalisering A och O för granens och tallens sexliv. Summary: The importance of the correct location of seed orchards. Sveriges Skogsvårdsförbunds Tidskrift 78(1–2): 65–71.

Hadders, G. 1963. Some causes of variation in the initial development of Scots pine (Pinus sylvestris L.). World Consultation on Forest Genetics and Tree Improvement, Stockholm, 23 to 30 August 1963. FAO/FORGEN 63/–2a/8. 10 p.

— 1984. Gödslingseffekt i en tallplantage. Institutet för Skogsförbättring. Information, Skogsträdsförädling 1984/85 (5). 3 p.

Hagem, O. 1917. Furuens og granens frosætning i Norge. Meddelelse fra Vestlandets Forstlige Forsoksstation 2. 188 p.

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. Metsäntutkimuslaitoksen tiedonantoja 121. 28 p.

Heikinheimo, O. 1921. Suomen metsärajametsät ja niiden vastainen käyttö. Referat: Die Waldgrenzwälder Finnlands und ihre kunftige Nutzung. Communicationes Instituti Forestalis Fenniae 4. 71 p.

— 1937. Metsäpuiden siementämiskyvystä. II. Referat: Über die Besamungsfähigkeit der Waldbäume. II. Communicationes Instituti Forestalis Fenniae 24(4). 67 p.

Huurre, L. 1983. Siemenviljelysten ravinneanalyysit. [Nutrient analyses in seed orchards]. Metsähallituksen Etelä-Suomen piirikonttorin kirje n:o 10561 (7.7.1983).

Jukka, L. (ed.). 1988. Metsänterveysopas. [Forest Health Guide]. Metsätuhot ja niiden torjunta. [Forest damaging agents and their control]. Samerka Oy, Helsinki. 168 p.

Koski, V. 1975. Natural pollination in seed orchards with special reference to pines. In: Faulkner, R. (ed.). Seed orchards. Forestry Commission Bulletin 54: 83–91.

Kozubov, G.M. 1971. Vlijanie mineral'nyh udobrenij na reproduktivnuju dejatel'nost' sosny. Udobrenija i gerbicidy v lesnom hozjajstve evropejskogo severa SSSR. AN SSSR Karel'skij filial, Institut lesa. Izd. Nauka, Leningrad. p. 36–44.

Kramer, P.J. & Kozlowski, T.T. 1979. Physiology of woody plants. Academic Press, New York. 611 p.

Kujala, V. 1927. Untersuchungen über den Bau und die Keimfähigkeit von Kiefern- und Fichtensamen in Finnland. Communicationes ex Instituto Quaestionum Forestalium Finlandiae Editae 12. 106 p.

Leikola, M., Raulo, J. & Pukkala, T. 1982. Männyn ja kuusen siemensadon vaihtelujen ennustaminen. Summary: Prediction of the variations of the seed crop of Scots pine and Norway spruce. Folia Forestalia 537. 43 p.

Lindgren, D. 1982. Fractionation of seed orchard seeds by weight does have genetic implications. Silva Fennica 16(2): 156–160.

Lipas, E. 1981. Faktoriaalisen lannoituskokeen tulosten tulkinta. Summary: Interpretation of the results from the factorial fertilization experiments. Folia Forestalia 482. 15 p.

— 1986. Maan ravinnetila siemenviljelyksillä. Abstract: Soil-fertility levels in Finnish seed orchards. Folia Forestalia 667. 19 p.

Lukkala, O.J. 1936. Rämemäntyjen siemenen laadusta. Referat: Über die Beschaffenheit der Moorkiefernsamen. Communicationes Instituti Forestalis Fenniae 22(3). 45 p.

Mälkönen, E. 1971. Fertilizer treatment and seed crop of Picea abies. Communicationes Instituti Forestalis Fenniae. 73(4). 16 p.

— 1991. Neulas- ja maa-analyysien käyttökelpoisuus metsänhoitotoimenpiteiden suunnittelussa. [The role of needle and soil analysis in the planning of silvicultural treatments]. In: Mäkkeli, P. & Hotanen, J.-P. (eds.). Metsänkasvatuksen perusteet turve- ja kivennäismailla. Metsäntutkimuspäivä Joensuussa 1991. Metsäntutkimuslaitoksen tiedonantoja 383: 52–61.

Metsäpuiden siementen käsittely- ja analyysiohjeisto. [Forest tree seed handling and analysis instructions]. 1980. Mimeograph. Metsähallitus, siemen- ja taimituotanto. 19 p.

Mikola, J. 1980. The effect of seed size and duration of growth on the height of Scots pine (Pinus sylvestris L.) and Norway spruce (Picea abies (L.) Karst.) provenances and progenies at the nursery stage. Silva Fennica 14(1): 84–94.

— 1987. Effects of fertilizer and herbicide application on the growth and cone production of Scots pine seed orchards in Finland. Forest Ecology and Management 19: 183–188.

Nikkanen, T. & Velling, P. 1987. Correlations between flowering and some vegetative characteristics of grafts of Pinus sylvestris. Forest Ecology and Management 19: 35–40.

Nygren, M. 1990. Männyn ja kuusen siementen massan vaihtelusta. Abstract: Variation in the seed mass of Scots pine and Norway spruce. Silva Fennica 24(1): 77–81.

Pajamäki, J. & Karvinen, K. 1993. Suomen metsänjalostuksen yleistilastoa 1.1.1993. General statistics on forest tree breeding in Finland. Metsäntutkimuslaitoksen tiedonantoja 466. 27 p.

Philipson, J.J. & Fletcher, A.M. 1990. Implications of cone induction techniques for breeding strategies and the production of improved seed. Forest Tree Improvement 23: 69–80.

Pukkala, T. 1987. Kuusen ja männyn siemensadon ennustemalli. Abstract: Effects of seed production on the annual growth of Picea abies and Pinus sylvestris. Silva Fennica 21(2): 135–144.

Rosvall, O. 1983. Uppföljning av fröplantagernas näringstatus. Institutet för Skogsförbättring. Interim Rapport 1983-05-30. 16 p.

— & Untinen, P. 1982. Fröplantagernas näringstatus. Institutet för Skogsförbättring, Information, Skogsträdsförädling 1981/82(4). 8 p.

Ryynänen, M. 1982. Individual variation in seed maturation in marginal populations of Scots pine. Silva Fennica 16(2): 185-187.

Sarvas, R. 1953. Siemenviljelys. Metsätaloudellinen aikakauslehti 70(16): 73–76.

— 1970. Establishment and registration of seed orchards. Folia Forestalia 89. 24 p.

Savtshuk, R.I. 1981. Vlijanie mineral'nyh ydobrenij na semenonoshenie sosny obyknovennoj. Lesnoe hozjajstvo 6: 31–33.

Simak, M. & Gustafsson, Å. 1954. Fröbeskaffenheten hos moderträd och ympar av tall. Summary: Seed properties in mother trees and grafs of Scots pine. Meddelanden från Statens Skogsforskningsinstitut 44 (2): 1–73.

Weissenberg, K. von. 1981. Taimikasvatuksen ja -lajittelun vaikutukset metsien geneettisiin ominaisuuksiin. Metsäntutkimuslaitoksen tiedonantoja 34: 15–40.

Werner, M. 1975. Location, establishment and management of seed orchards. In: Faulkner, R. (ed.). Seed orchards. Forestry Commission Bulletin 54: 49–57.

— & Hellström, C. 1984. Gödlingsförsök i en sydsvensk tallfröplantage. Institutet för Skogsförbättring, Information, Skogsträdsförädling 1983/84(5). 3 p.

Wibeck, E. 1928. Det norrländska tallfröets grobarhet och anatomiska beskaffenhet. Norrlands Skogsvårdsförbunds Tidskrift 1. 35 p.

Total of 44 references