Some Effects of Inter- and Intraspecific Grafting on Growth and Flowering of some Five-Needle Pines

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Introduction

Grafting of fruit trees has been practiced extensively for many years, and the effects of grafting on growth, hardiness, yield, and quality of fruit are well known. Grafting of conifers has recently come into increasing use in seed orchard work, and there is evidence that grafting may also affect growth and fruiting of these forest species. Age of stock and scion, grafting methods, clonal variations, species, and soil fertility may affect results. Clonal differences in growth, survival, and cone production were reported in grafts of 5-needle pines on Pinus resinosa Ait. and P. strobus L. stocks (1). In most cases, survival, growth, and staminate and pistillate conelet production of interspecific grafts on Pinus strobus stocks were better than those on P. resinosa. Decreases of various elements in both scion and stock in interspecific grafts of Pinus cembra L. on *P. sylvestris* L. have been reported (6). Successful interspecific grafts of *Pinus sibirica* Mayr (7), *P. cembra* (6), *P. peuce* Griseb. (5), *P. mugo* Turra (5), *P. koraiensis* Sieb & Zucc. (5), P. nigra var. cebennensis (7), and P. resinosa (3) on P. *sylvestris* stocks have also been reported. Those intergeneric grafts reported have not been successful (2).

This study, aimed at the development of techniques useful in seed orchard work with pines (4), investigated the survival, growth, and conelet production of inter- and intraspecific 5-needle pine grafts. The work was done at the Quetico-Superior Wilderness Research Center, located on Basswood Lake, northeastern Minnesota, and financed by the Wilderness Research Foundation. Additional support was obtained from a grant from the Hill Family Foundation.

Materials and Methods

Two to four-year-old seedlings of *Pinus strobus*, *P. resinosa*, *P. banksiana* Lamb., *P. sylvestris*, *P. montana* Mill., and *Abies balsamea* (L.) Mill. were planted on cleared land. Three or more growing seasons after planting, side

Table 1. — *Seventeen year summary of compatibility of pine grafts. Age is based on number of growing seasons. Incompatible grafts are those on which 1 year of growth after union is formed, but growth does not continue the second year. Semi-incompatible grafts have 1 to 5 years of growth, but graft is not healthy and dies in 2 to 5 years or is very much wcakened. Up to 20 percent may survive longer. Semi-compatible grafts are healthy for 5 or more years, gradually weakening between the 5th and 17th year. Compatible grafts have survived for 7 to 17 years. This table includes both terminal and lateral grafts, as well as young grafts not included in table 4.*

Scion species	*Stock species*	*Compatibility*	*Grafts number*	Age of graft *years*	Surv. *pct.*
P. strobus	*P. strobus*	*compatible*	1230	17	74
P. peuce	*P. strobus*	*compatible*	48	17	62
P. koraiensis	*P. strobus*	*compatible*	42	17	67
P. cembra	*P. strobus*	*compatible*	53	17	53
P. griffithii	*P. strobus*	*semi-compatible*	15	6	0
P. strobus	*P. resinosa*	*semi-incompatible*	120	17	8
P. peuce	*P. resinosa*	*semi-compatible*	88	17	19
P. koraiensis	*P. resinosa*	*semi-incompatible*	72	17	7
P. cembra	*P. resinosa*	*semi-compatible*	81	17	25
P. griffithii	*P. resinosa*	*semi-incompatible*	15	4	0
P. strobus	*P. banksiana*	*semi-incompatible*	22	9	9
P. peuce	*P. banksiana*	*semi-incompatible*	15	6	13
P. cembra	*P. banksiana*	*semi-incompatible*	15	8	20
P. koraiensis	*P. banksiana*	*semi-incompatible*	15	6	0
P. griffithii	*P. banksiana*	*semi-incompatible*	15	3	0
P. strobus	*P. sylvestris*	*semi-compatible*	22	9	9
P. peuce	*P. sylvestris*	*semi-incompatible*	15	6	13
P. cembra	*P. sylvestris*	*semi-compatible*	20	8	25
P. koraiensis	*P. sylvestris*	*semi-incompatible*	15	7	7
P. griffithii	*P. sylvestris*	*incompatible*	15	2	0
P. strobus	*P. montana*	*compatible*	51	9	45
P. peuce	*P. montana*	*compatible*	40	6	20
P. cembra	*P. montana*	*compatible*	37	8	87
P. koraiensis	*P. montana*	*compatible*	62	7	67
P. griffithii	*P. montana*	*compatible*	122	7	27
P. strobus	*Abies balsamea*	*semi-incompatible*	22	4	0
P. peuce	*Abies balsamea*	*incompatible*	15	2	0
P. cembra	*Abies balsamea*	*semi-incompatible*	15	8	27
P. koraiensis	*Abies balsamea*	*incompatible*	15	3	0
P. griffithii	*Abies balsamea*	*incompatible*	15	2	0

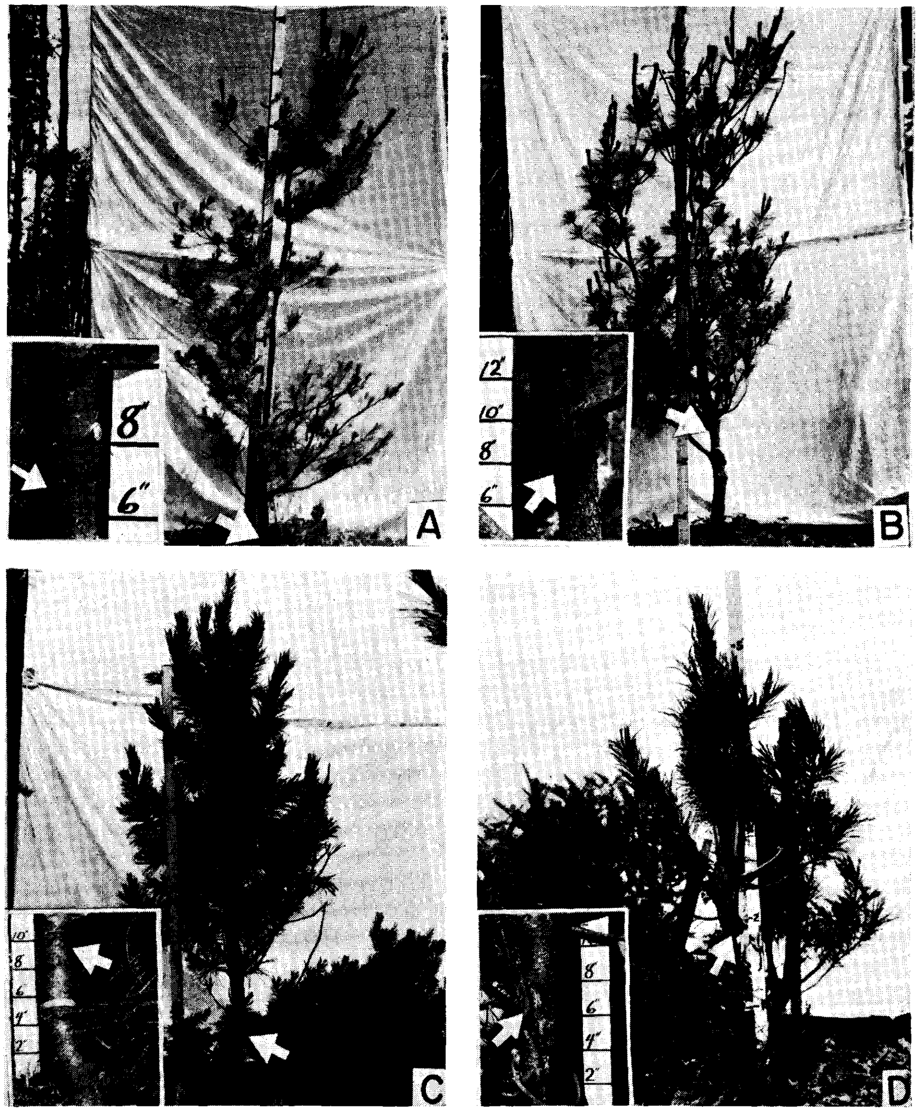

Figure 1. — Examples of 9 year old grafts. Insets are close views of graft unions. Graft unions indicated by arrows. — A. *Pinus strobus* scion on *P. strobus* stock, compatible combination. — B. *Pinus strobus* on *P. banksiana*, semi-incompatible combination. — C. *Pinus cembra* on *P. montana* stock, compatible combination. — D. *P. cembra* on *Abies balsamea*, semi-incompatible combination.

slit grafts were made on main terminal branches. Most grafts were made before onset of bud activity in early spring, although a few intraspecific *Pinus strobus* grafts were made in October with limited success. Scions of *Pinus strobus, P. cembra,* and *P. griffithii* McClelland came from mature, cone-bearing trees. Scions of *P. koraiensis* and *P. peuce,* however, came from 18—20 year old trees which were only approaching maturity. About half of the scions came from the upper, cone-bearing portions of the crown, the remainder from lower in the crown. In the early work, some homeoplastic grafts on lateral branches were also made to determine success of grafting technique. Terminal buds of stocks were removed during grafting. Grafts were bound with rubber budding strips and enclosed in glassene bags to reduce water loss. These were enclosed in white kraft bags. The glassene bags were removed after 6 weeks and the kraft bags after about 8 weeks. Most grafts were made one to three feet above ground. On the slow-growing *Pinus montana* stocks, grafts were occasionally made close to the ground near the root collar. In subsequent years, stock growth was pruned to eliminate competition until the scion had developed good terminal dominance. Included in this study are the 17-year results of grafts of 5-needle pines on 4- to 17-year-old *Pinus resinosa* and *P. strobus* stocks (1), as well as 2- to 9-year results of more recent grafting.

Staminate and pistillate conelets produced on the grafts were used in controlled pollination work. Pollen viability was determined microscopically after pollen had incubated at room temperature in 5 percent sucrose for 48 hours. A phenological record of reproductive activity was maintained annually throughout the study. Height growth and needle length were measured for two consecutive years, 1968 and 1969.

Results

Survival and Compatibility: Graft survival varied among the species combinations from zero to 87 percent *(Table 1)*. Highest survival was found on *Pinus strobus* and *P. montana* stocks. The low survival of grafts of *Pinus griffithii*

Table 2. — Mean annual height growth of scion species on different stock species. Data were obtained from 10 trees of each combination, except in those cases where number of surviving trees was smaller (see *table 4*).

Scion	Stock *P. strobus*	*P. resinosa*	*P. montana*	*P. sylvestris*	*P. banksiana*	*Abies balsamea*
P. cembra	0.8 ft.	0.8 ft.	0.7 ft.	0.7 ft.	0.8 ft.	0.3 ft.
P. peuce	0.7	0.4	0.5	0.4	0.4	—
P. strobus	1.0	0.3	0.6	1.4	0.9	—
P. koraiensis	1.2	0.2	0.9	1.2	—	—

scions on *P. strobus* and *P. montana* can be attributed in part to a protective mulch of straw applied in the late fall of 1967, prior to unseasonably warm weather. The trees became active and both scions and stocks were badly damaged because of unsatisfactory hardening off.

There were obvious differences in scion-stock compatibility among the species combinations *(Fig. 1)*. For example, all scion species were compatible with *Pinus strobus* stocks, while only *P. cembra* scions showed good compatibility with *P. sylvestris* stocks. In the compatible combinations, smooth unions usually formed with no abnormal swelling, and secondary growth of both scions and stocks was uniform.

Semi-compatible species combinations characteristically formed good graft unions and grew vigorously for 5 or more years but showed signs of gradual weakening and swelling of the unions between the 5th and 17th years. These grafts often produced large quantities of pollen, suggesting that slight incompatibility may stimulate reproduction.

Semi-incompatible graft unions were usually weak with noticeable swelling, and the grafts survived for 2 to 5 years or were very much weakened beyond that. Semi-incompatibility was characteristic of grafts on *Pinus banksiana* stocks, on which the scions sometimes could not compete with the vigorous growth of the stock. Mortality was found even among the most compatible combinations, and an occasional graft remained healthy, even among the less compatible.

It is interesting to note that *Pinus griffithii*, which is not hardy in northern Minnesota, can survive when grafted on certain hardy stocks. Although some grafts of this species were protected with straw mulch, others survived without it.

Height Growth: Growth in height varied among the various scion-stock combinations *(Table 2)*, and few generalizations can be made. However, *Pinus strobus* stocks were frequently associated with rapid scion growth, and *P. resinosa* with slow scion growth. Among the younger grafts, those on *Pinus sylvestris* stocks usually exhibited rapid growth, and those on *P. montana* and *P. banksiana* stocks

Table 3. — Mean needle length of scion species on different stocks, determined in tenths of centimeters from 25 needles on each tree, taken from the last two years of growth.

Scion	Stock *P. strobus*	*P. resinosa*	*P. montana*	*P. sylvestris*	*P. banksiana*	*Abies balsamea*
P. cembra	9.1	9.9	9.1	10.5	10.7	7.7
P. peuce	7.9	8.1	6.8	9.0	9.3	—
P. strobus	8.2	7.0	8.1	10.3	8.6	—
P. koraiensis	9.4	5.6	8.3	10.4	—	—

Table 4. — Staminate and pistillate conelet production by various scion-stock species combinations. Only main terminal grafts 9 to 17 years old are included.

Scion	Stock	Graft age range during observation period yrs.	No. living grafts during past 5 yrs.	Average proportion live grafts within any 1 yr. with ♀ %	♂ %	Cones per flowering tree
P. strobus	*P. strobus*	2 to 17	123	14	17	4
P. strobus	*P. resinosa*	2 to 14	10	1	10	2
P. strobus	*P. banksiana*	2 to 9	3	12	4	4
P. strobus	*P. sylvestris*	2 to 9	2	11	2	3
P. strobus	*P. montana*	2 to 9	10	1	6	1
P. peuce	*P. strobus*	2 to 17	21	13	12	3
P. peuce	*P. resinosa*	2 to 17	7	5	8	3
P. peuce	*P. banksiana*	2 to 9	2	19	3	7
P. peuce	*P. sylvestris*	2 to 9	3	10	0	2
P. peuce	*P. montana*	2 to 9	3	0	0	0
P. cembra	*P. strobus*	2 to 17	17	1	12	1
P. cembra	*P. resinosa*	2 to 17	8	9	14	2
P. cembra	*P. banksiana*	2 to 9	4	10	8	1
P. cembra	*P. sylvestris*	2 to 9	8	15	9	2
P. cembra	*P. montana*	2 to 9	13	3	5	2
P. koraiensis	*P. strobus*	2 to 17	22	4	25	2
P. koraiensis	*P. resinosa*	2 to 17	2	0	24	0
P. koraiensis	*P. banksiana*	2 to 9	3	0	26	0
P. koraiensis	*P. sylvestris*	2 to 9	3	0	40	0
P. koraiensis	*P. montana*	2 to 9	11	0	56	0

may be associated with intermediate growth. There was a noticeable difference in compatibility between the two stock species which produced rapid growth: *Pinus strobus* is frequently associated with good compatibility and *P. sylvestris* with relatively poor compatibility.

Pinus montana has a low, slow growing habit which might not be capable of supporting growth of vigorous scions. However, if grafts were made close to the root collar, the *Pinus montana* stocks tended to thicken and grow in pace with the scions *(Figure 1, C)*. Thus, a firm base developed which would support the rapidly growing scion for some time. The effect of rootstock age on scion growth was not investigated here, since age differences among the stocks were not great. Previous study (1) indicated no effect of stock age on scion growth.

Needle Length: Scion needle length varied among the combinations *(Table 3)*. The greatest scion needle length was found on *Pinus sylvestris* and *P. banksiana* stocks, both of which have relatively short needles. There is no consistent relationship between needle length and either rate of growth or compatibility.

Conelet Production: There were differences in staminate and pistillate conelet production among the various scion-stock combinations *(Table 4)*. Among *Pinus strobus* scions, the proportion of staminates was higher on *P. resinosa* stocks, and the proportion of pistillates was higher on *P. strobus* stocks. For *Pinus cembra* scions the reverse was true; the proportion of pistillates was higher on *P. resinosa*. *Pinus koraiensis* scions produced pistillate conelets only on *P. strobus* stocks.

As previously mentioned, not all scions came from completely mature, cone-bearing trees. Both *Pinus peuce* and *P. koraiensis* scions were from trees just approaching maturity. Furthermore, not all scions were from the upper, cone-bearing portion of the crown. For *Pinus strobus,* especially, approximately half of the scions were from lower in the crown. In many cases in which the *P. strobus* scions came from the upper portion of the crown, conelet production was noticeably abundant, ranging up to 90 cones per 10 year old graft.

Although frequency and abundance varied, viable pollen and pistillate conelets capable of setting seed were produced on all scion/stock species combinations.

There was no correlation between conelet production and either compatibility or growth in height. However, pistillate conelet production was most abundant on those scion-stock combinations which also produced longest needles *(Pinus strobus, P. cembra,* and *P. peuce* scions on *P. sylvestris* and *P. banksiana* stocks).

There was a tendency for intraspecific *Pinus strobus* grafts to produce conelets more abundantly at ages 7 to 10 years and again between ages 15 and 16 years, suggesting the development of a 5-year reproductive periodicity. Similar periodicity may be developing in *Pinus peuce* and *P. koraiensis* on *P. strobus* stocks and *P. cembra* on *P. sylvestris* stocks.

Although many *Pinus griffithii* scions did not survive well because of overheated mulch described above, and are not included in *Table 4*, the surviving grafts formed some staminate and pistillate conelets on *P. strobus* and *P. montana* stocks two years after grafting and have continued. Grafts on *Abies balsamea* are also omitted from *Table 4* because very few survived. However, *Pinus cembra* scions on *Abies balsamea* stocks formed both staminate and pistillate conelets for several years.

Pollen viability was not affected by scion-stock combinations, except on *Pinus banksiana* stocks, on which all pollen except that of *P. griffithii* frequently aborted and was less viable. *Pinus peuce* pollen had a relatively low viability of 43 percent on all stock species, while others ranged from 65 to 85 percent.

Phenology: Stock species had no influence on the onset of bud activity in any combinations. However, time of pollen production was influenced by stock. *Pinus cembra* produced pollen first each year on *P. resinosa* stocks, followed by *P. cembra* on *P. sylvestris,* then on *P. montana,* finally on *P. strobus.* Such a sequence of pollen shed was not as evident among other combinations. Frosts during early June in 1965 and 1967 severely reduced conelet production and pollen viability.

Discussion and Summary

Field grafting techniques are practical for propagation of clones to be used in breeding work with pines in northeastern Minnesota. Successful grafts have continued to reproduce over a period of 17 years. Of the various stock species used, *Pinus strobus* was the most successful; its use in seed orchard work is practical. Although cones per tree on *P. strobus* stocks was somewhat low, this number could be increased by using only scions from the upper, cone bearing portions of the tree.

Grafting techniques also bring cone-bearing wood near the ground and accessible to the worker on foot or step ladder, making work quicker, safer, and more precise. Use of *Pinus montana* stocks may be promising in this respect with some scion species. Grafts on this species remain low for a number of years after development of conelets begins, and the presence of numerous terminals makes several grafts possible on one stock. While conelet production reported here was low on this stock species, grafts are young and samples are small. Further investigation is continuing.

Pinus banksiana was the least promising stock species; other species are of experimental interest because of differences in scion response. Some success was achieved with all combinations, even intergeneric grafts of pine on *Abies balsamea (Figure 1, D)*. Compatibility and growth rate varied among the scion-stock combinations but were not related to frequency with which grafts produced staminate and pistillate cones. Increased conelet production appeared to be associated with those scion-stock combinations which also produced long needles. This may be the result of increased photosynthate in the branches.

Zusammenfassung

Bei Untersuchungen über die Möglichkeiten von Freilandpfropfungen im Rahmen der Kiefernzüchtung war *Pinus strobus* die erfolgreichste Art. Die Zapfenzahl je Baum konnte erhöht werden, wenn die Reiser aus den oberen Kronenteilen geschnitten worden waren. — Pfropfungen auf *Pinus montana* bleiben lange Jahre niedrig, auch dann noch, wenn bereits das Fruktifizieren beginnt. — *Pinus banksiana* eignete sich am wenigsten als Unterlage. — Einige erfolgreiche Pfropfungen gelangen mit Kiefern auf *Abies balsamea*.

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Genetic Variability in Juvenile Height-Growth of Douglas-Fir

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Introduction

In the Douglas-fir region of western North America, planting methods for establishing stands and cultural practices for maintaining them are in a state of evolution. Some seedlings are planted in areas so clean they approximate agricultural fields; others in jungles of slash and brush. In some Douglas-fir plantations, seedling growth is impeded for years by overtopping brush or by browsing of deer and hare. Because seedlings with rapid juvenile height-growth pass through the vulnerable stage more quickly, nursery and outplanting practices which increase seedling growth are being developed. Innovative practices are now undergoing extensive testing: the planting of seedlings grown in paper or plastic containers, machine planting on terraced slopes, and fertilizing, irrigating, or mulching of planted seedlings. Some of these practices are expensive and genetic improvement of juvenile growth rate has been suggested as an alternative. The suggestion is worth pursuing as long as negative correlations with mature growth, or other detrimental side effects, are not found.

As a first step, this paper examines genetic variability in seedling height increment of Douglas-fir. It reports estimates of additive genetic variances, dominance effects, and family-location interaction variances based on a sib analysis of 54 families grown in two plantations. An example of genetic gain from mass selection is used to illustrate effects of interaction on heritability and gain.

Materials and Methods

Families came from crosses made according to the Design I crossing scheme of Comstock and Robinson (1952). The 63 parents, nine used as females, 54 as males — six crossed to each female — were chosen randomly from reproductive trees in a small, naturally regenerated stand in Pack Demonstration Forest near LaGrande, Washington (elevation 335 meters). Stratified seed of each cross were planted in four randomized blocks using procedures closely approximating those of forest nurseries in the Pacific Northwest. In February 1966, seedlings, then 2—0, were outplanted at two locations near Centralia, Washington. Location 1 is on a relatively fertile soil (Salkum series) having a clay-loam subsurface texture and a clay subsoil. Location 2 is on a droughty site, the soil (Spanaway series — gravelly, sandy loam) being excessively drained and of medium fertility. Locations are 25 kilometers apart and both are at low elevations (less than 200 meters).

At each location, 60 seedlings from each of the 54 families were planted in February 1966 in a randomized block design of 15 replications of 4-tree family plots. Both sites were cultivated prior to planting. After planting, location 1 was watered once, while location 2 was watered several times in the 1966 and 1967 growing seasons and kept essentially weed free.

Height increments from 1966 and 1967 growing seasons were measured and analyzed separately for effects due to location, replication, females, males, and their interactions, all effects being considered random. Because of differential mortality, between- and within-plot variances were analyzed in two steps: (1) an analysis of plot means ignoring differences in their reliabilities, and (2) an analysis of within-plot variability, estimated from random plots in each replication and location, then pooled (Kempthorne 1957). Components of variance were estimated by equating mean squares to expectations *(Table 1).* Assuming the absence of effects due to inbreeding, epistasis, linkage, and maternal environment, variance among females estimates one quarter of the additive genetic variance. Variance among males in females estimates one quarter of the additive genetic variance plus one quarter of the dominance variance (Comstock and Robinson 1948). See Campbell and Rediske (1966) for a discussion of the likelihood of violations of assumptions in this material.

Genetic gain (R) from mass selection is estimated by

$R = i\,h^2\,\sigma_{ph}$ where:

i = the selection differential expressed in phenotypic standard deviations (For this example, the assumption is that 1 percent of seedlings are selected as parents, so in large samples from a normally distributed population, $i = 2.67$.)

$$h^2 = \frac{4\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + \hat{\sigma}_{s(f)}^2 + \hat{\sigma}_e^2 + \hat{\sigma}_w^2} \text{ for within-plantation, and}$$

$$= \frac{4\,\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + \hat{\sigma}_{s(f)}^2 + \hat{\sigma}_{pf}^2 + \hat{\sigma}_{ps(f)}^2 + \hat{\sigma}_e^2 + \hat{\sigma}_w^2} \text{ for combined}$$

plantations (See *Table 1* for description of symbols.)

σ_{ph} = phenotypic standard deviation from the denominator

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