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Growth differences within full-sib families of *Picea abies* (L.) Karst.

Tillväxtskillnader inom helsyskonfamiljer av gran Picea abies *(L.) Karst*

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Abstract

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In the present paper the reasons for differences in plant height within full-sib families of Norway spruce are discussed. In many cases it was shown that the duration of the growth period to some extent was responsible for the differences in plant height. If the total plant height is plotted against the percentage growth 4 or 5 weeks before growth termination, clones with good growth rhythm characteristics could conveniently be identified. Therefore this technique is recommended for selection of ortets in nurseries.

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1 Introduction

The different growth capacity of provenances of *Picea abies* originating from varying countries has long been known (e.g. Langlet, 1964, Kiellander, 1970, Krutzsch, 1975). These dissimilarities between provenances can, at least to a certain extent, be attributed to different photoperiodic responses of the provenances tested (cf. Sylvén, 1940, Dormling, 1973). Similar results for provenances of *Picea sitchensis* (Burley, 1966) and *Pinus taeda* (Perry et al. 1966) as well as for clones of *Salix alba/fragilis* (Lattke, 1973) were reported. This means that budset and growth cessation take place following exposure to dark periods of different length in different provenances. Such differences are not limited to the provenance level. Thus Hagner (1970) demonstrated a great variation within provenances of *Pinus sylvestris* as regards the annual rhythm. Similar observations have been noted by Schütt (1962) for *Pinus sylvestris* and by Kozlowski and Peterson (1962) for *Pinus resinosa*. The tallest trees became tallest because they terminated their growth later than the others.

It is also evident that there are differences in growth capacity within full-sib families. Therefore, the question might be raised as to whether these differences can also be attributed to varying photoperiodic responses of the individual plants or whether they are due to some other physiological reasons, such as photosynthetic capacity.

The purpose of the present investigation was to throw some light on the question "Why do some plants from a particular full-sib family grow better than their full-sibs?" The benefits derived from the present investigation might be twofold:

1. To guide the physiologists in undertaking more detailed investigations concerning the reasons for the variation of growth capacity within a full-sib family.
2. To guide the geneticists in their work of selecting ortets which should be used as starting material for commercial production of cuttings.

2 Material and methods

In an investigation studying the inheritance of the critical night length for budset (CN) in *Picea abies* (Dormling et al. 1974) the plant height was measured once a week. These data were used in the present investigation. Three types of full-sib families were included in the study:

short CN × short CN
short CN × long CN
long CN × long CN

The short CN was represented by clones from northern Sweden and the long CN was represented by clones from France. Further details as regards the clones are presented below (Table 1) and in a paper by Dormling et al. (1974). All plants, irrespective of type of the progeny, were grown under continuous light for 11 weeks. From then on the plants were grown under different light regimes (0—8 hours of

Table 1. The correlation and regression coefficients for the relationship between the date for reaching 90 per cent of the total plant height and the total plant height.

		Number of dark hours	Exp. No.	r	b
French × French					
1	O 1005 × O 1009	7	1	0.558*	4.53
2	O 1006 × O 1008	7	1	0.401	2.59
3	O 1006 × O 1009	7	1	0.393	4.29
4	O 1007 × O 1006	7	1	0.398	4.24
16	O 1007 × O 1008	7.5	2	−0.193	−1.02
17	O 1008 × O 1009	7.5	2	0.765*	2.24
Swedish × Swedish					
5	Z 3008 × AC 1008	5	1	0.552*	3.78
6	Z 3008 × AC 1009	5	1	0.220	2.56
6	Z 3008 × AC 1009	4.5	2	0.719**	2.97
7	Z 3008 × AC 1014	5	1	0.705**	8.96
8	AC 1002 × AC 1009	5	1	0.250	1.70
18	AC 1002 × AC 1008	6	2	0.584*	3.55
19	BD 2006 × AC 2003	4.5	2	0.670**	4.12
French × Swedish					
9	O 1006 × AC 2003	7	1	0.426	4.43
10	O 1007 × AC 2003	7	1	0.755***	8.60
10	O 1007 × AC 2003	6	2	0.474	2.54
11	O 1008 × AC 1008	7	1	0.360	2.56
12	Z 3008 × Neufchateaux	7	1	−0.253	−3.11
20	O 1006 × BD 2006	6	2	0.572*	2.41
21	O 1007 × BD 2006	6	2	0.484	3.55

darkness) for six weeks. So far six progenies from each type of combination have been studied. The experiment was partitioned in such a way that 12 of the progenies were studied at one time whereas the other six were tested in a later experiment in which two progenies from the first experiment were included a second time, thus constituting a reference between the two experiments (cf. Table 1). Moreover, it may be mentioned that each progeny was represented by 16 plants growing in four-plant plots. The two French×French combinations were represented by fewer plants in the second experiment. To get reliable information on the response of plants to a certain photoperiod it was necessary to study the progenies which at the termination of the experiment showed 100 per cent growth cessation.

3 Results and discussion

In Figure 1 plants belonging to progeny 8 (Swedish × Swedish) are illustrated. The two most extreme plants are shown, as well as some intermediate plants. It is obvious from this photograph that there is a great variation within a full-sib family as regards the plant height.

Before entering upon the discussion of the growth pattern within full-sib families, the general pattern of growth in the three categories of progeny will be commented. In Figures 2—3 the percentage of growth of the individual progenies are illustrated. From these figures it may be seen that there is a slight difference between the French × French progenies on the one hand and the French × Swedish and the Swedish × Swedish ones on the other hand. Thus none of the French × French progenies had reached their 90 percentage growth four weeks before the termination of the experiment, whereas all French × Swedish and Swedish × Swedish progenies reached their 90 percentage growth before that point of time. This observation is promising since it indicates the possibility of using those particular provenance hybrids in practical forestry.

3.1 The point of time for 90 percentage growth

To test whether or not the variation in final plant height within a full-sib family could be attributed to differences in the duration of the growing period, the final plant height was plotted against the point of time for reaching of 90 percentage of the total growth (cf. Figures 4—9). This method will be referred to as method I. This percentage was preferred to the date for complete cessation of growth. At the 90 per cent level the growth curves have not yet reached their insensitive parts where they start to flatten.

The correlation and regression coefficients for the relationship between the point of time for reaching 90 per cent growth and the total plant height were calculated. The coefficients are listed in Table 1. From this table it may be seen that the correlation coefficients 18 times out of 20 were positive and nine of these cases were significant. The progenies which show a negative correlation are all weak. However, they are interesting from a breeding point of view as will be discussed below. The large differences as regards the correlation and regression coefficients from progeny 10 in the two experiments may partly be explained by the difference in photoperiodic conditions. These plants may respond faster to a longer dark period than to a shorter. Anyhow, this observation indicates the necessity of testing the plant response under outdoor conditions. The regression coefficients indicate that the duration of growth is to some extent responsible for the observed difference in plant height. The longer the growing period the taller the plant. This in turn means that there is a variation of the photoperiodic response even within a full-sib family.

For each type of progeny the two extremes as regards the regression coefficient were selected for an illustration of the relationships discussed above. Progenies 16—17 contained fewer plants as pointed out above and were therefore excluded from the diagrammatic illustrations. Figures 4—9 reveal that there is a great variation within each type of progeny. The strength of the photoperiodic response seems to be less pronounced in the French × French progenies.

These diagrams should be used as a starting point for a discussion of the selection of ortets for cutting propagation. It is probable that reforestation in future would

Figure 1. Photograph of plants belonging to progeny 8, AC 1002×AC 1009. The biggest and smallest plants are illustrated as well as some intermediate plants.

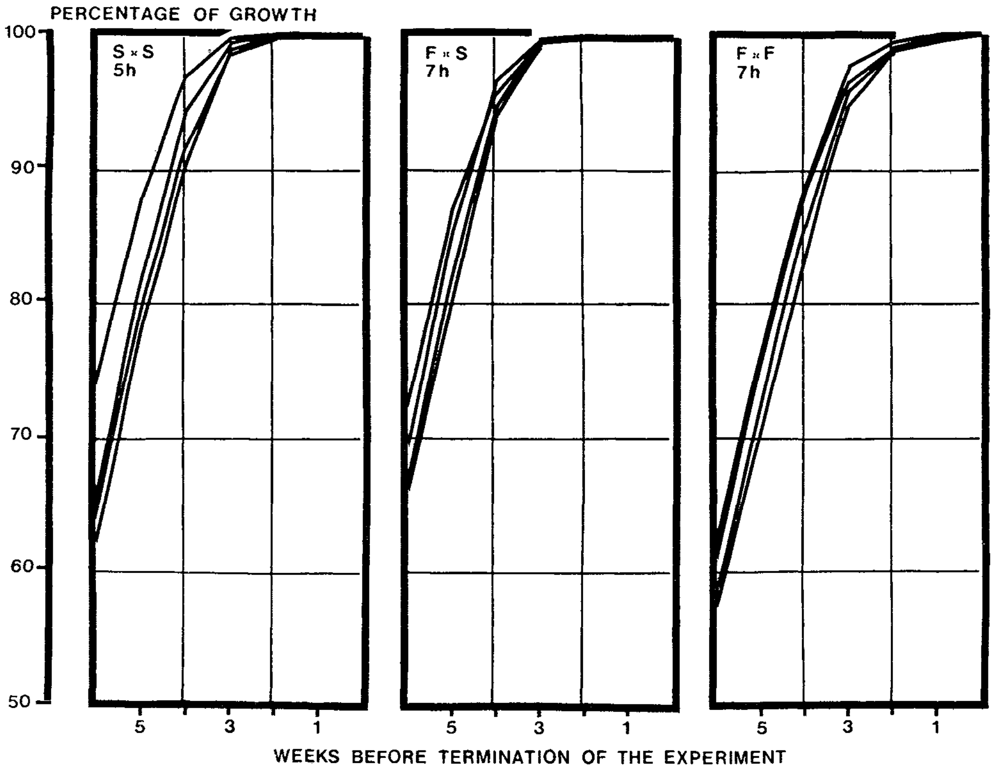

Figure 2. The relationship between the percentage growth and time for different types of progenies in experiment 1. F = French; S = Swedish.

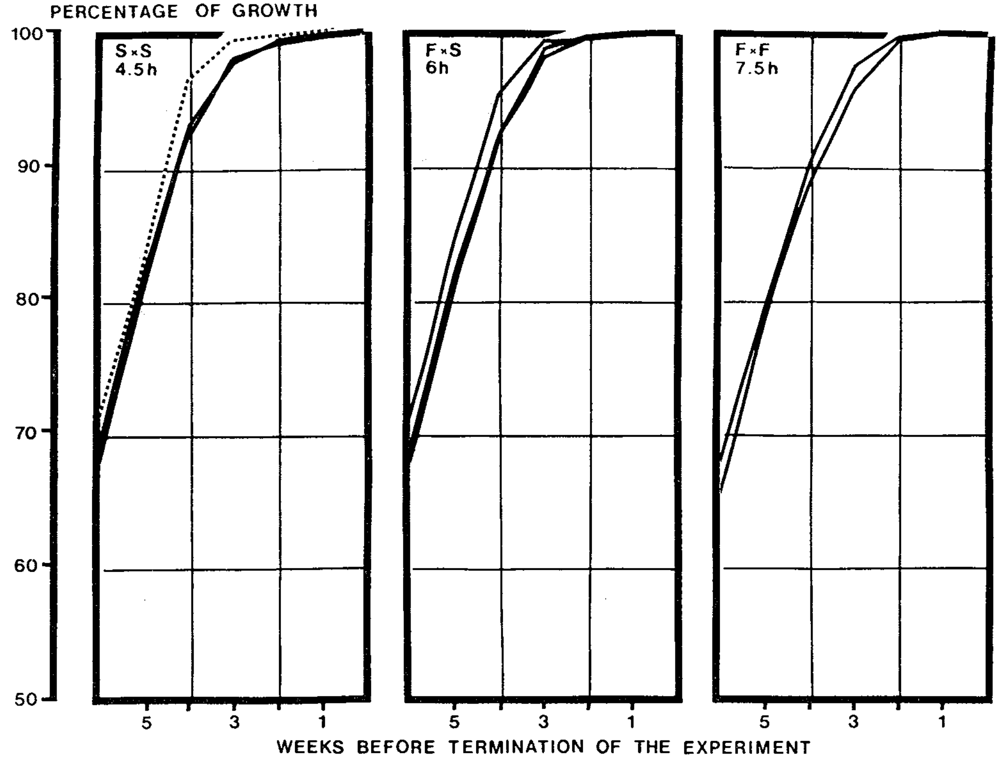

Figure 3. The relationship between the percentage growth and time for different types of progenies in experiment 2. F = French; S = Swedish. The dotted line refers to progeny 18 which had to be studied at 6 hours of darkness since 4.5 hours of darkness did not cause a 100 percentage growth cessation.

gain from using cuttings. This is particularly pronounced for Norway spruce (cf. Kleinschmit 1974). To avoid late spring and early autumn frost damages in Norway spruce plants it is necessary that the plants show an annual rythm that avoids the risks for such damages. Therefore, the bud flushing should not take place too early, whereas the bud set and growth cessation as well as the lignification should not take place too late (cf.—e.g. Krutzsch 1975). Therefore, it seems advantageous to select ortets among plants which show a good growth capacity although they terminate their growth early. If the plants in progeny 10 are investigated, hardly any plant would fulfil this criterium for selection. The situation is reverse among the plants of progeny 12, in which the tallest plant was also the first one to reach 90 percentage growth (cf. Figure 9). The overall poor growth of progeny 12 must therefore be regretted. In progeny 2 (Figure 5) one plant is marked. This plant possesses a good growth capacity and terminates its growth comparatively early. Such plants should be searched for in the selection of ortets for cutting propagation.

The growth curves for two extreme plants from progeny 10 are illustrated in Figure 10.

The variation in photoperiodic response as studied in the present investigation is summarised in Figure 11. This figure reveals that the photoperiodic response is on an average considerable, amounting to ten or more days. The absolute minimum of 4.4 days was noted for progeny 12, while the maximum was 22.6 (progeny 9). This great variation is promising for the forest tree breeder but of less advantage for the forester in his search for a hardy material showing limited variation.

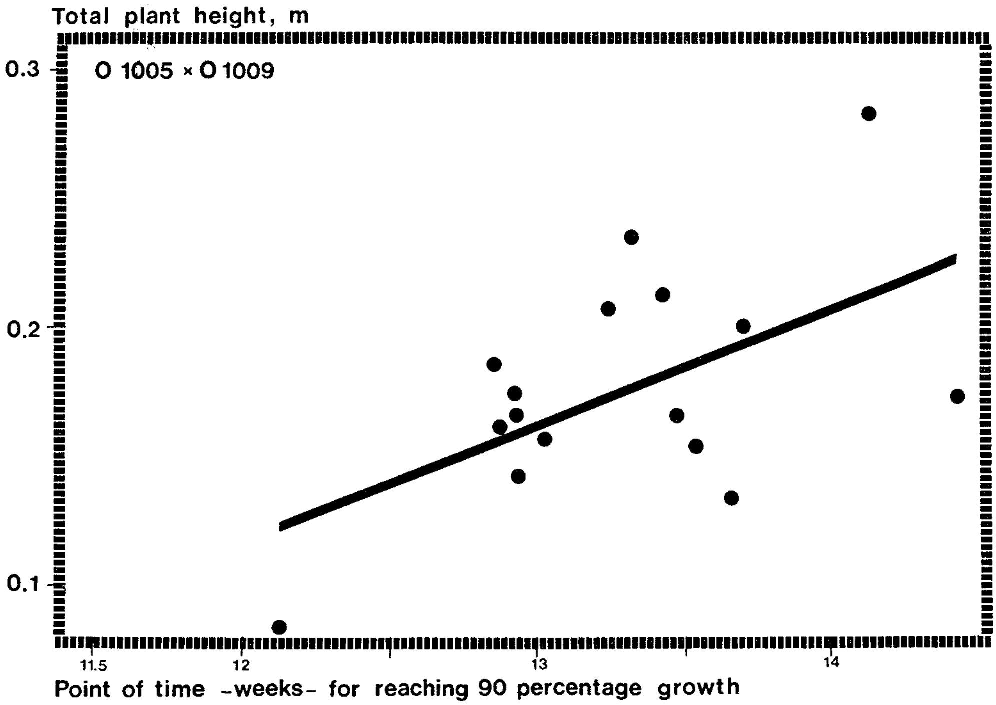

Figure 4. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 1 (French × French).

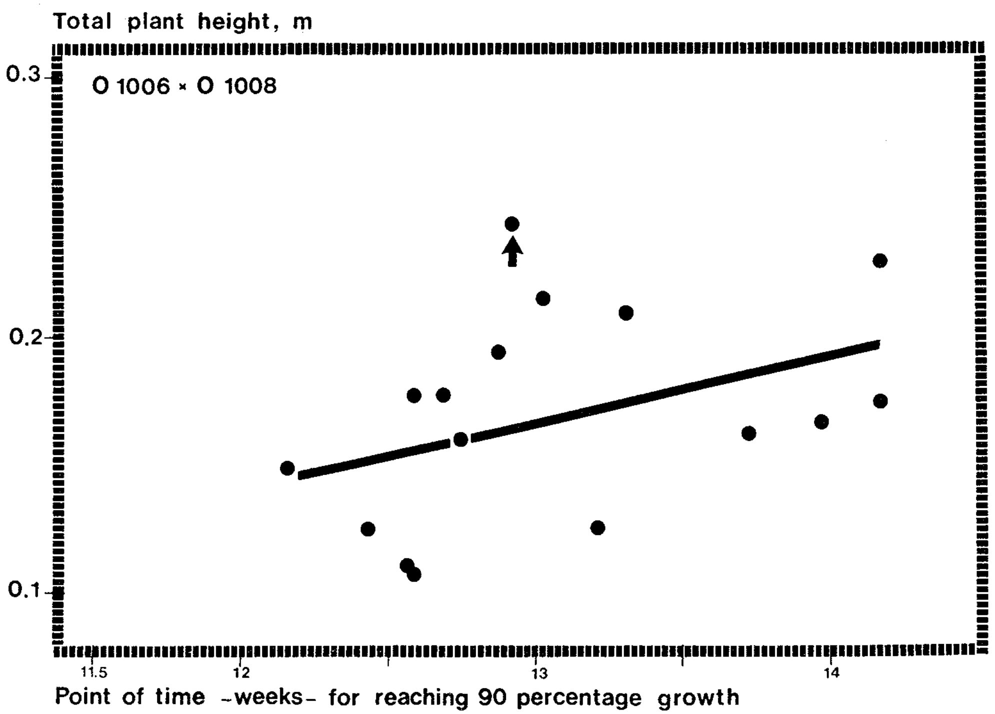

Figure 5. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 2 (French × French).

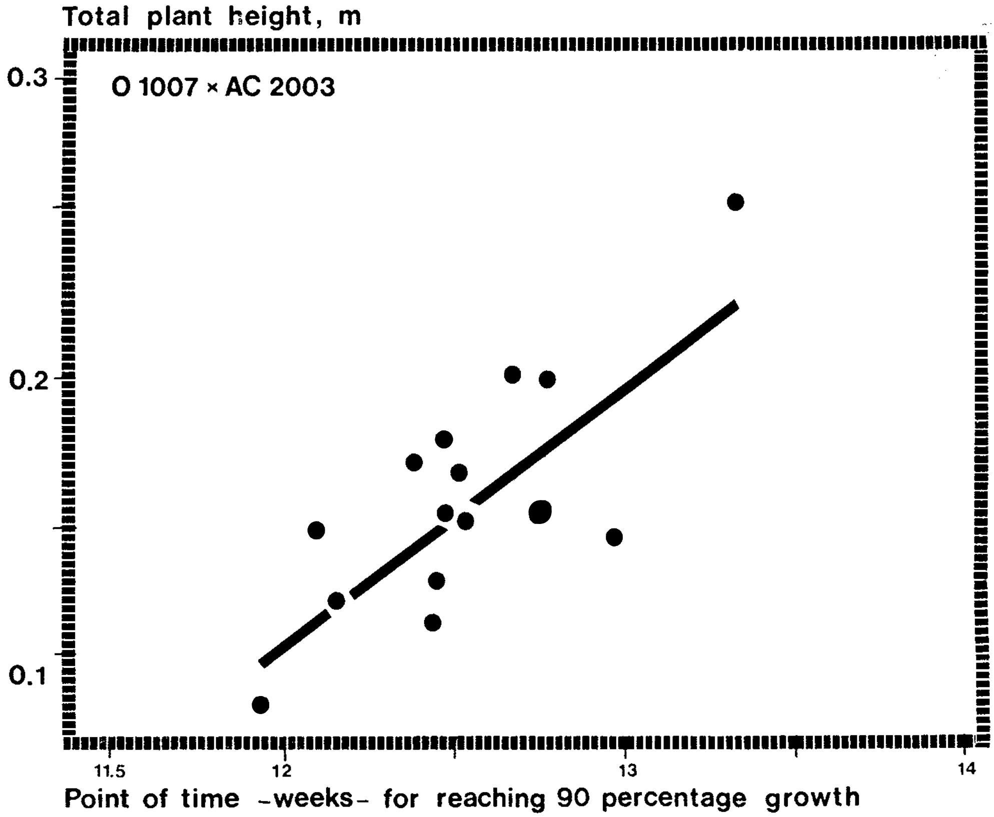

Figure 6. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 10 (French × Swedish).

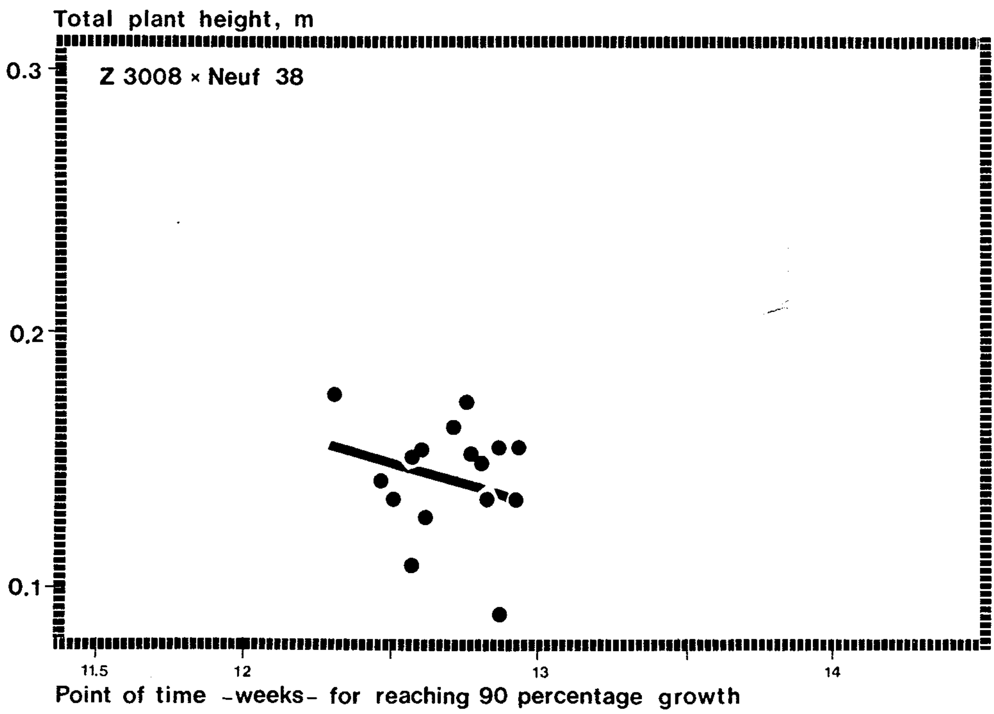

Figure 7. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 12 (French × Swedish).

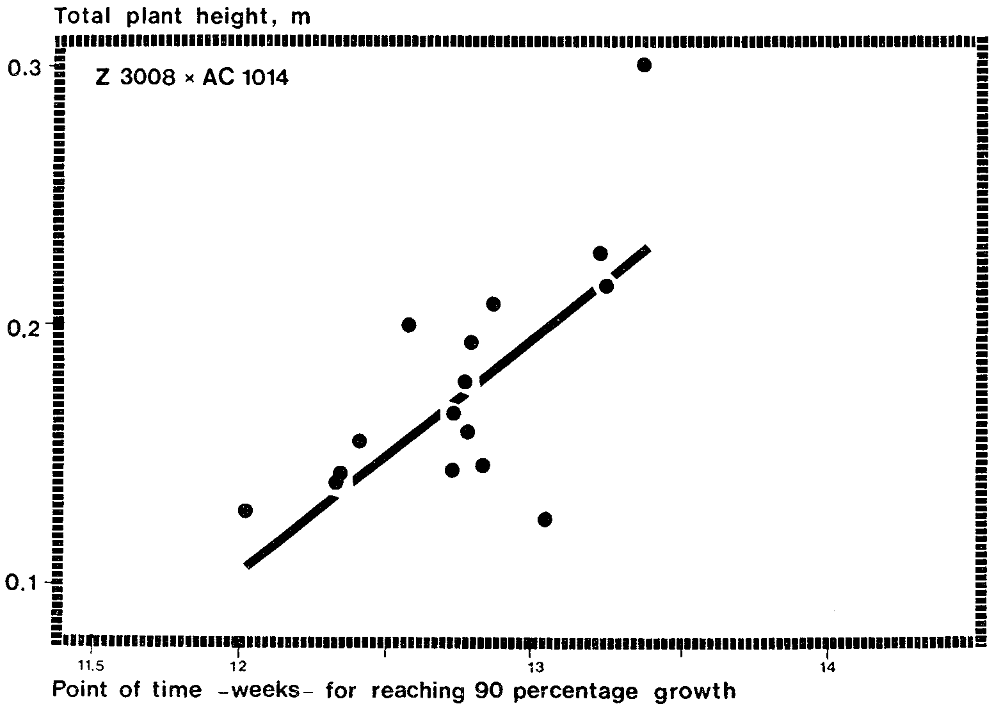

Figure 8. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 7 (Swedish×Swedish).

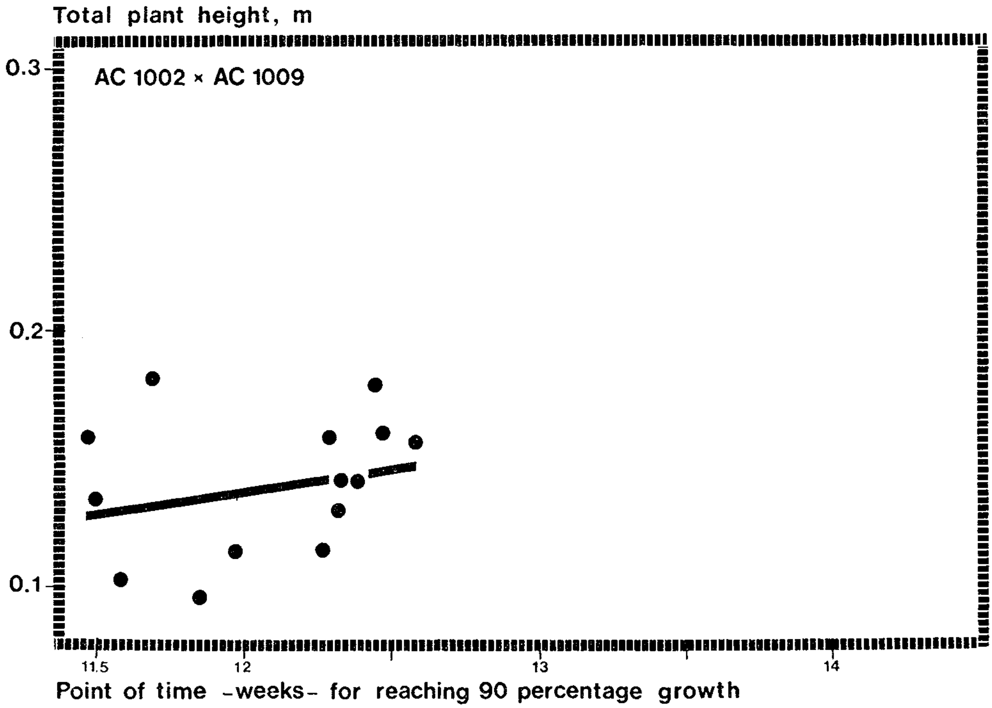

Figure 9. The relationship between the total plant height and the date for reaching 90 percentage growth of individual plants of progeny 8 (Swedish×Swedish).

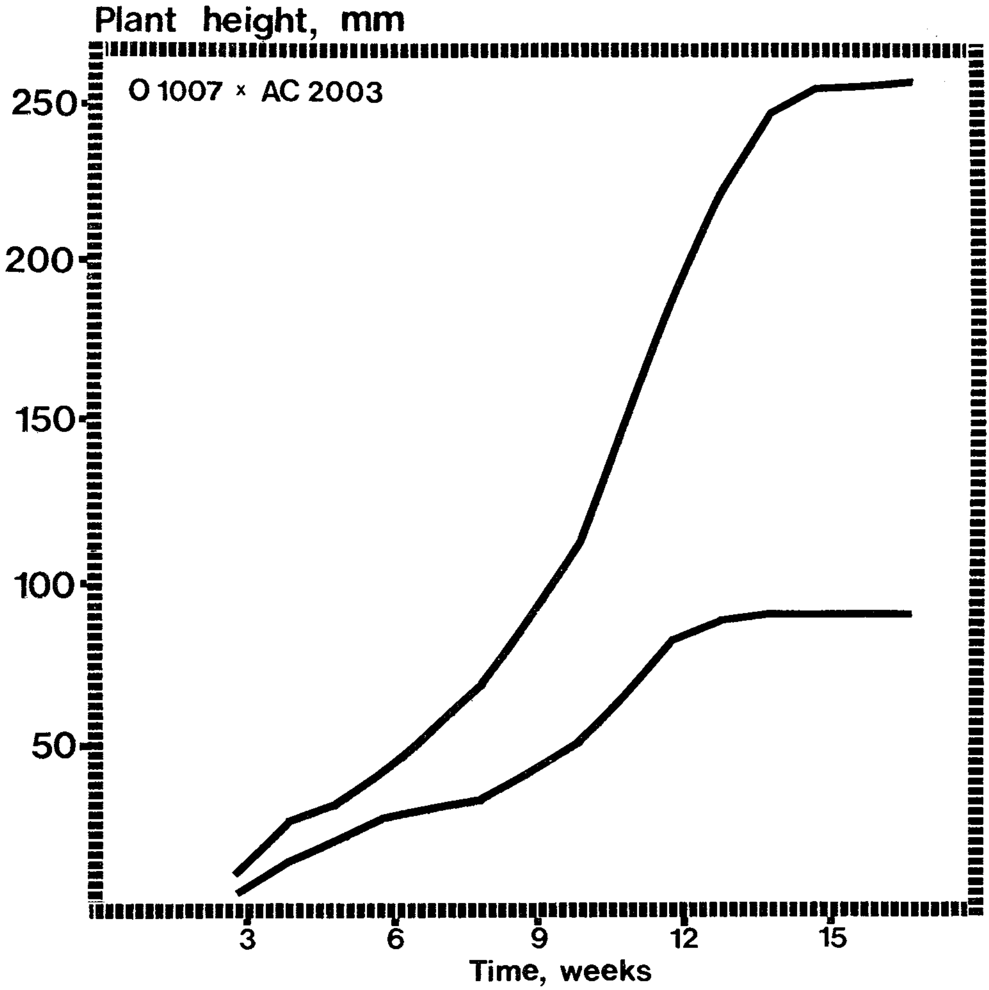

Figure 10. The growth pattern of the two most extreme plants in progeny 10 (French × Swedish).

Whether or not this great variation is due to the cultivation technique—11 weeks of continuous light and then six weeks of 5—7 hours of darkness per day—must be tested in separate experiments. If this cultivation technique brings about a greater diversity of the material it means that the selection would be facilitated.

3.2 Growth at certain intervals before growth cessation

The way of studying the photoperiodic response of plants as presented above is, of course, a laborious way, with the regular measurements once a week during the growing season. Therefore, it cannot be applied in investigations comprising large materials. To connect the method used above and one which might be possible to handle on a large scale, the photoperiodic response was also studied by relating the total plant height to the percentage growth at certain time intervals before the termination of the experiment (referred to as method II below). From Figures 2—3 it may be seen that 4—5 weeks before the termination of the experiment most closely corresponds to the 90 percentage growth level. Therefore, the relationship between

Table 2. The correlation and regression coefficients for the relationship between total plant height and the percentage growth six, five, and four weeks before the termination of experiment 1.

Progeny No.	Numbers of dark hours	Number of weeks before the termination of the experiment 6 r	b	5 r	b	4 r	b
Swedish × Swedish							
5	5	−0.3555n.s.	−1.5930	−0.5021*	−2.4433	−0.5372*	−4.1064
6	5	−0.1741n.s.	−1.1229	−0.3117n.s.	−2.5904	−0.2335n.s.	−3.0366
7	5	−0.7451**	−5.4962	−0.8036***	−6.6713	−0.7062**	−8.3847
8	5	−0.5197*	−2.2033	−0.5707*	−3.2540	−0.4242n.s.	−7.3947
French × Swedish							
9	7	−0.3409n.s.	−2.2078	−0.4128n.s.	−3.3534	−0.4961n.s.	−11.5728
10	7	−0.6714**	−5.5288	−0.6705**	−5.5007	−0.6526**	−8.2144
11	7	−0.3207n.s.	−2.1935	−0.3229n.s.	−2.0673	−0.3372n.s.	−3.6222
12	7	−0.2097n.s.	1.3371	0.3111n.s.	2.1498	0.2024	2.2506
French × French							
1	7	−0.546*	−3.189	−0.4626n.s.	−2.6405	−0.4186n.s.	−3.0695
2	7	−0.4878	−3.1650	−0.3806n.s.	−1.8565	−0.4019n.s.	−2.1922
3	7	−0.5939**	−4.4757	−0.2368n.s.	−2.0128	−0.4018n.s.	−3.4428
4	7	−0.3321	−2.2304	−0.2509n.s.	−1.7708	−0.2307n.s.	−2.3199

Table 3. The correlation and regression coefficients for the relationship between total plant height and the percentage growth six, five, and four weeks before the termination of experiment 2.

Progeny No.	Numbers of dark hours	Number of weeks before the termination of the experiment 6 r	b	5 r	b	4 r	b
Swedish × Swedish							
6	4.5	−0.6944	−2.0249	−0.7927***	−2.6765	−0.6244**	−4.6412
18	4.5	−0.7903***	−3.3709	−0.7891***	−3.0139	−0.7816***	−3.0770
19	4.5	−0.3894	−1.8016	−0.5667*	−2.7675	−0.6743**	−4.5952
French × Swedish							
10	6	−0.4676*	−1.7273	−0.4495	−1.9804	−0.4979*	−4.4388
20	6	−0.5595*	−1.6555	−0.5311*	−1.9406	−0.4729	−3.5027
21	6	−0.4959*	−2.7041	−0.5074*	−3.1395	−0.4261	−4.1269
French × French							
16	7.5	0.2926	0.9382	0.1467	0.4386	0.1721	0.8536
17	7.5	−0.6100	−1.5878	−0.7089*	−2.1774	−0.7092*	−2.7433

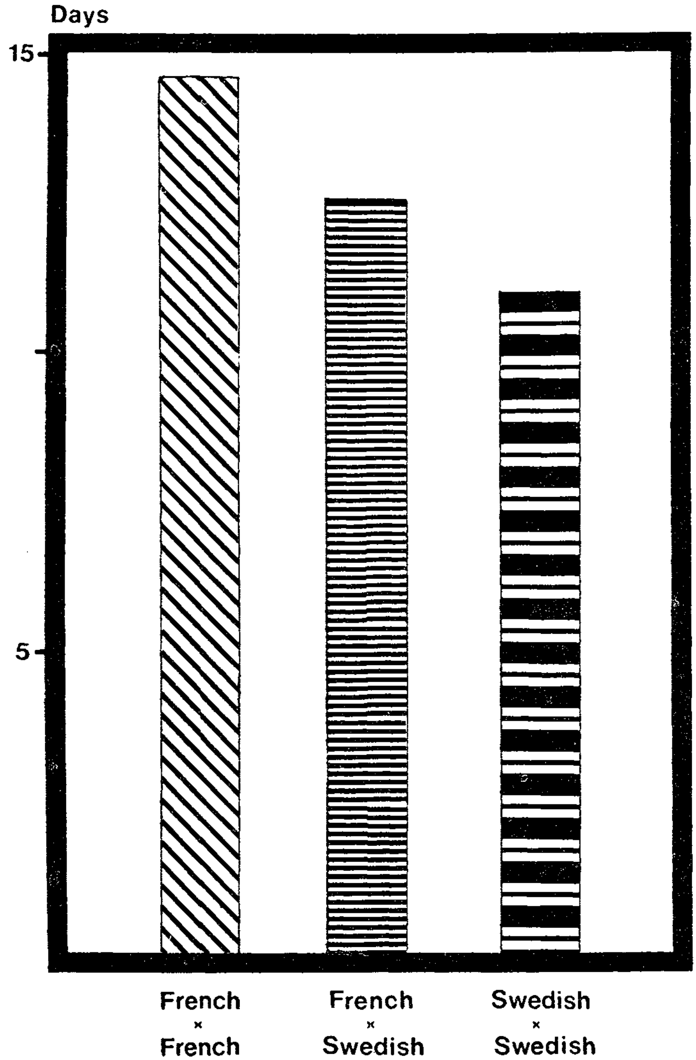

Figure 11. The average difference in days between the first and the last plant within a full-sib family reaching 90 percentage growth. The averages refer to the three types of progenies studied.

the total growth and percentage growth four or five weeks before the termination of the experiment was studied. In addition, the data from six weeks before the end of the experiment were used. The same progenies that were shown in Figures 4—9 are also illustrated by making use of method II (cf. Figures 12—17). A pairwise comparison of Figures 4—9 and 12—17 reveals that they more or less constitute a reflected image of each other. The strong agreement between the results of the two methods is further supported by an analysis of the relationship between the correlation and regression coefficients of the two methods as shown below:

Relationship		Comparison between: correlation coeff.	regression coeff.
method I—method II	4 weeks	$r = -0.926^{***}$	$r = -0.729^{***}$
method I—method II	5 weeks	$r = -0.961^{***}$	$r = -0.926^{***}$

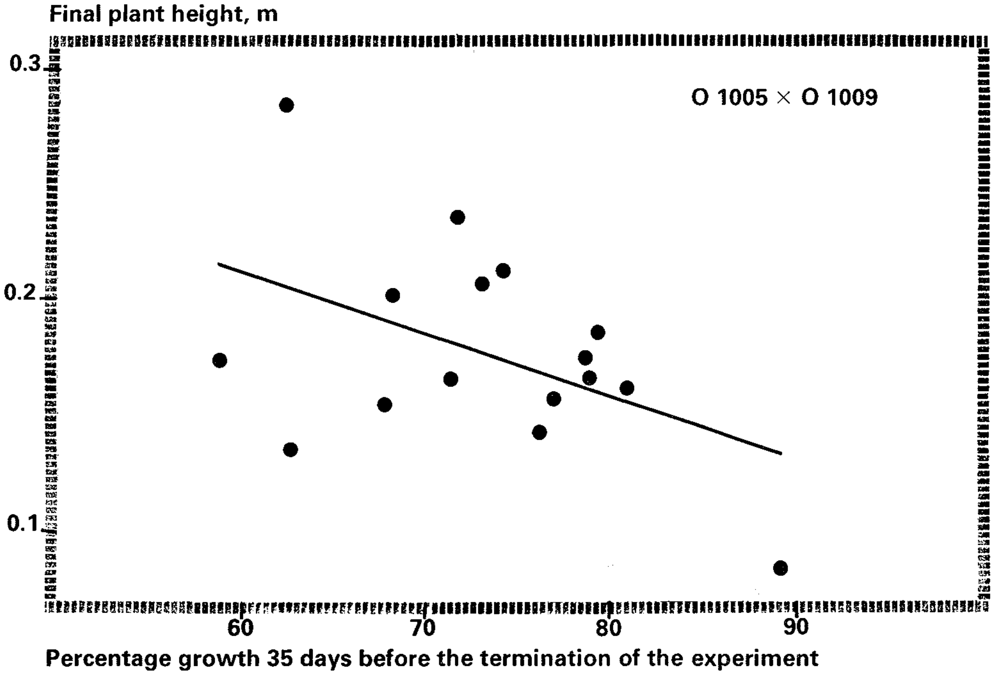

Figure 12. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 1 (French × French).

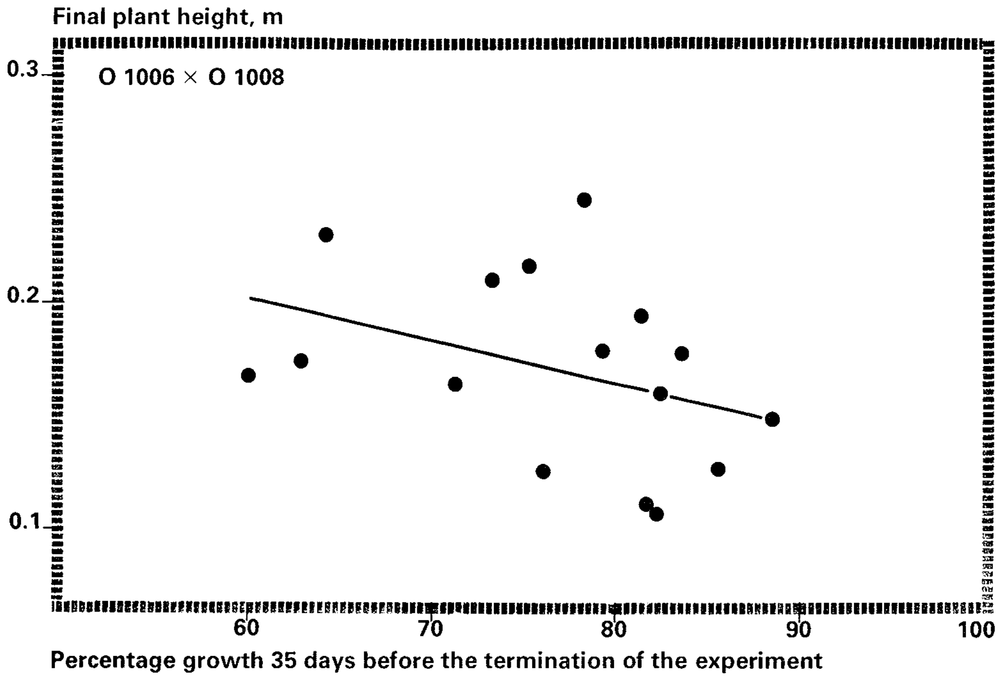

Figure 13. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 2 (French × French).

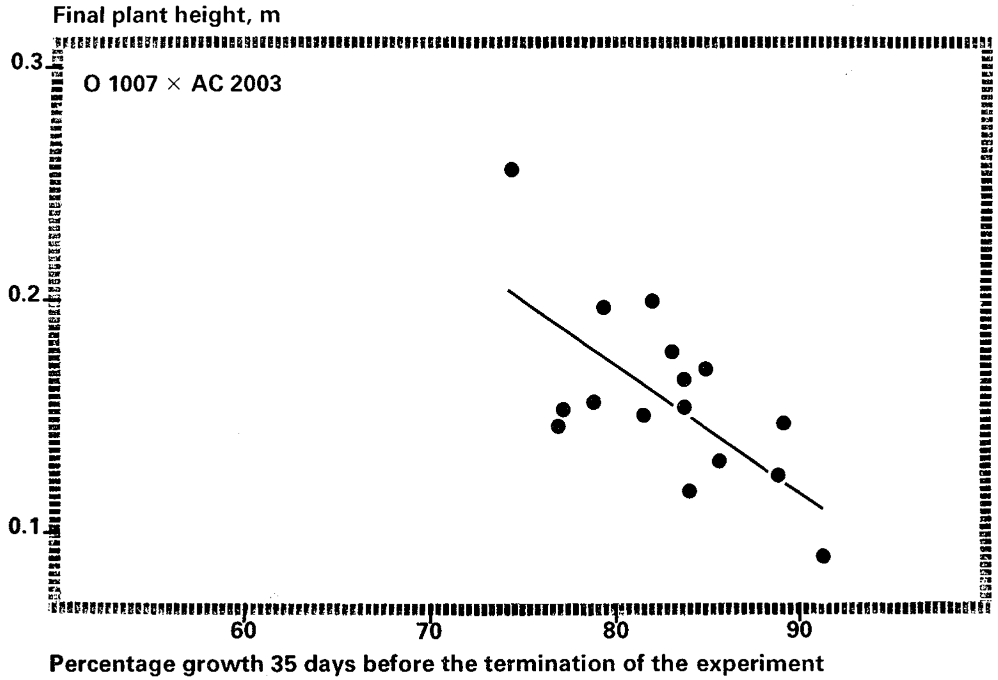

Figure 14. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 10 (French × Swedish).

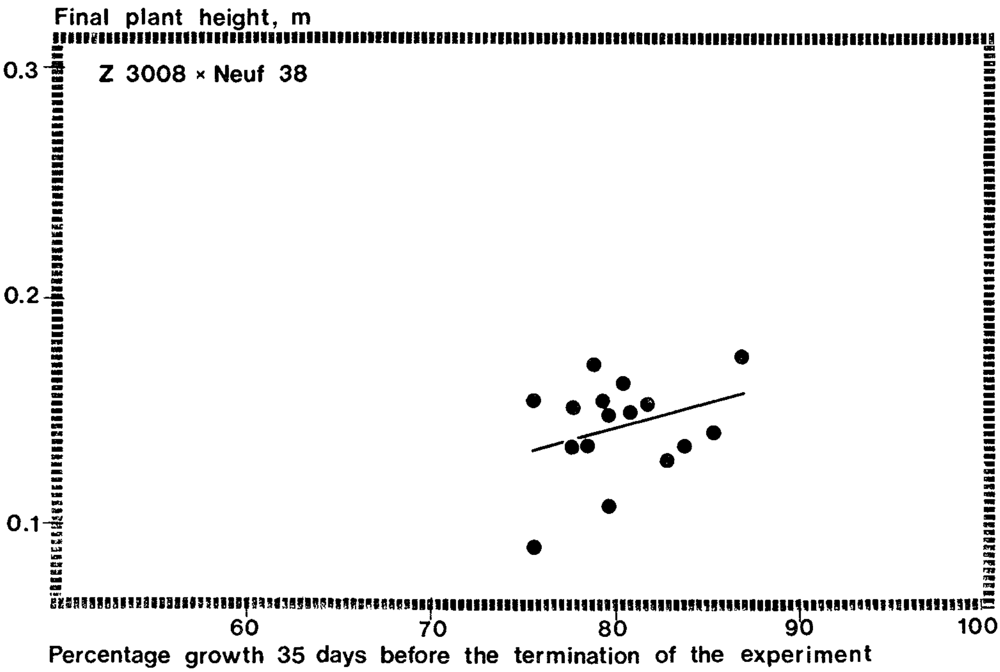

Figure 15. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 12 (French × Swedish).

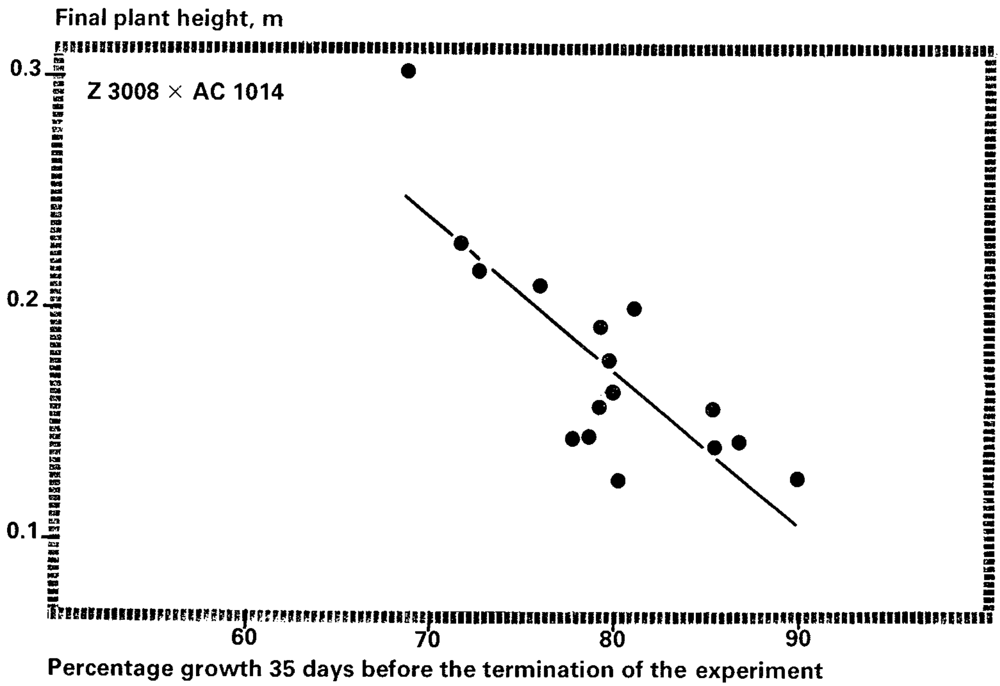

Figure 16. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 7 (Swedish × Swedish).

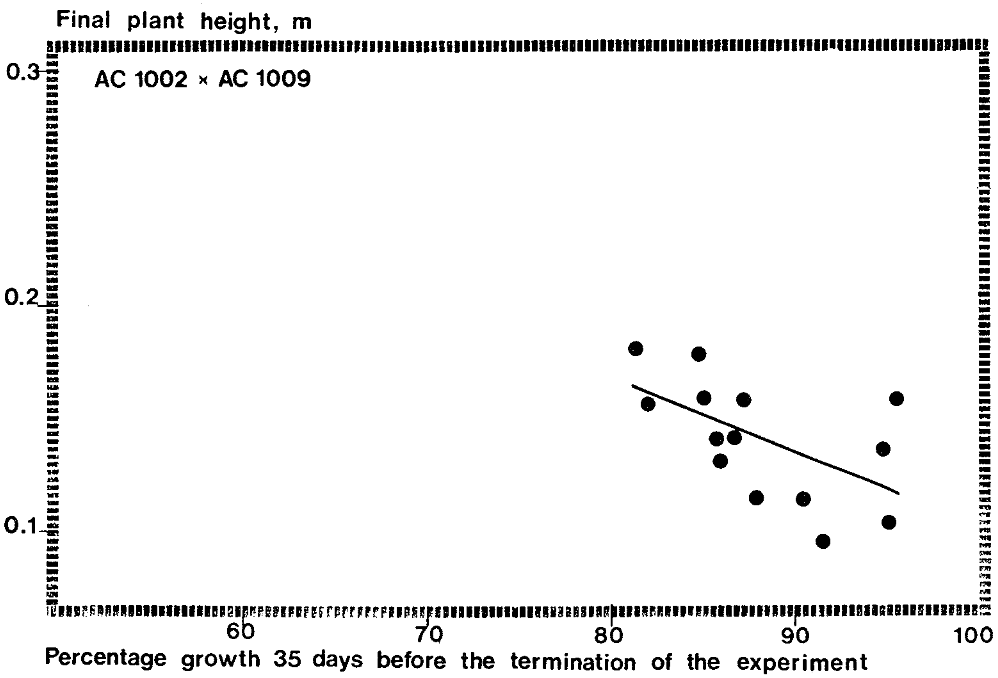

Figure 17. The relationship between the total plant height and the percentage growth at five weeks before the termination of the experiment. Progeny 8 (Swedish × Swedish).

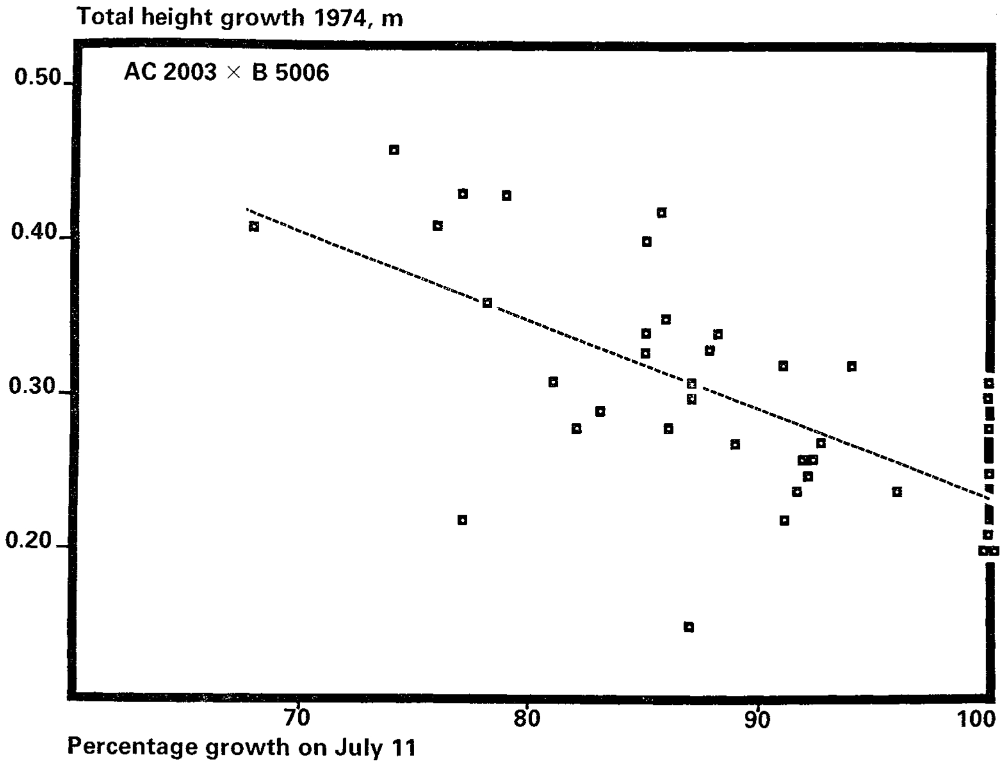

Figure 18. The relationship between the total growth and the percentage growth on July 11, 1974 in a progeny from a cross between a north Swedish clone and a clone originating from the provenace Dolina, Soviet union. The data refer to the fifth growing season.

This analysis seems to support the idea that the less laborious method II could be used when investigations on a large scale have to be carried out. A prerequisite is, of course, that the measurement during the growth period is carried out at an appropriate time.

The method II technique was applied to some intra- and interprovenance hybrids growing in a nursery at Bogesund (9 kilometers northeast of Stockholm). The plants were measured every 14 days during their active growth. The relationship between the total growth and the percentage growth on June 27 and July 7 respectively, was studied. Also in this material a negative relationship predominated. However, the correlation coefficients were in most cases non-significant. One example from this study is shown in Figure 18. Based on the percentages of growth on those two dates it seems that a measurement made at an intermediate date would have been more profitable for a study of the present type. Detailed analysis of the growth pattern under outdoor conditions have to be carried out to permit a general use of method II in selection work. It would be advantageous if such a test could be performed at localities with different light regimes.

3.3 **Total plant height—total branch length**

It might be speculated as to whether or not the growth capacity could be attributed to a large extent to the size of the "photosynthetic apparatus". A very rough estimate of the size of this characteristic would be to measure the length of the branches.

Therefore, such a measurement was carried out at the termination of experiment II. The relationship between the values obtained and the total plant height was investigated. The data obtained are compiled in Table 4. As seen from this table the regression coefficients were positive with the exception of those for progeny O 1006 × BD 2006. However, no very far-reaching conclusions could be drawn from such a limited material but it suggests that such measurements are worthwhile in future experiments.

Table 4. The correlation and regression coefficients for the relationship between total plant height and total branch length.

Type of progeny	Correlation coefficient	Regression coefficient
Swedish × Swedish		
Z 3008 × AC 1009	0.674**	0.192
AC 1002 × AC 1008	0.726**	0.264
BD 2006 × AC 2003	0.611*	0.143
French × Swedish		
O 1007 × AC 2003	0.293	0.043
O 1006 × BD 2006	−0.149	−0.040
O 1007 × BD 2006	0.843***	0.268
French × French		
O 1007 × O 1008	0.943**	0.362
O 1008 × O 1009	0.649	0.160

4 Acknowledgement

The present investigation was supported by a grant from the Knut and Alice Wallenberg foundation, which is gratefully acknowledged. One of us, Velichko Gagov, visited Sweden as a stipendiate of the Swedish Institute for Cultural Relations with foreign countries, which is acknowledged. We wish to express our thanks to professor Enar Andersson, Stockholm for reading the manuscript. Finally we wish to thank Mr Kjell Lännerholm for drawing the diagrams in this paper.

5 Summary

The present investigation showed that the variation in height growth within a full-sib family in many cases could be attributed to different photoperiodic responses of the individual plants. The range of variation was in many cases considerable (cf. Figure 12). Since the plants for the first eleven weeks were exposed to continuous light and then exposed to different night regimes, the range of variation may have been influenced. Therefore, the studies have to be continued on material grown under outdoor conditions.

In the paper a method is presented that permits a selection in large plant materials. In this method the total plant height (or growth during a certain season) is plotted against the percentage growth at a certain time before growth cessation. Thereby it is possible to distinguish plants which combine early growth cessation with a good total height growth capacity.

6 Sammanfattning

Syftet med den föreliggande undersökningen var att klarlägga frågan ”Varför växer vissa granplantor inom en helsyskonfamilj bättre än andra?” Ett klarläggande har betydelse

1. för att vägleda fysiologerna beträffande mera sofistikerade undersökningar över skillnader i tillväxtkapacitet hos olika plantor.

2. för att vägleda skogsträdsförädlare beträffande urval för sticklingsförökning.

I många av helsyskonfamiljerna visade sig tillväxtperiodens längd ha stort inflytande på planthöjden. Skogsträdsförädlaren är mest intresserad av att kunna välja sådana plantor som vuxit bra under en kort vegetationsperiod. Ett sätt att klara detta urval är att tillämpa den teknik som betecknats som metod II i uppsatsen. I denna avsätts den totala planthöjden mot den procentuella tillväxten en viss tid före tillväxtavslutningen. I diagram (figurerna 12—17) kan man sedan lätt välja de plantor som äger de önskade egenskaperna.

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