

DAYLENGTH RESPONSES OF SOME FOREST TREES

BY

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(received October 5th, 1955)

INTRODUCTION AND LITERATURE

Daylength effects in herbaceous plants have mostly been referred to flowering.

In woody species, however, effects on vegetative development have been especially studied. This may be due to the fact that flowering only occurs at advanced age in these plants, while also the magnitude of these forms prevents regular experiments with full-grown specimens. It has been recognized that, for the vegetative growth, species of lower latitude are preferentially of short day type, whereas those of higher latitude are preferably long day forms. The same often holds for races of one single species.

LANGLET (1944) summarizes the following special properties of high-latitude forms of *Pinus*, as compared with low-latitude ones: 1) better hibernation capacity, 2) higher resistance against diseases, 3) earlier spring growth and earlier winter rest, 4) smaller annual increment, 5) straighter stems, 6) fewer, shorter and weaker twigs, 7) shorter, broader and thicker needles, 8) more sugar, fat, etc., but less water and chlorophyll in winter, more decoloration of the needles in winter, 9) photoperiodic behaviour more of the long day type. He considers that species mostly show the best growth and development with respect to photoperiodicity under the conditions prevailing at the natural habitat.

WAREING (1951) studied daylength effects in *Pinus silvestris* and reviewed the literature for woody species.

According to GARNER and ALLARD (1923), and KRAMER (1936), *Liriodendron* continues growth during winter at a daily illumination of 16 hours, and renews growth if long days are given in September.

As early as 1914, KLEBS observed that in *Fagus* restbreak in September, and continuous growth during winter could be achieved by continuous illumination. According to KLEBS, only high light intensities produce this effect; he considers the amount of energy applied as the decisive factor.

KRAMER (1936) on the contrary, has concluded that in *Fagus* daylength determines shoot development in spring. In many other cases, however, temperature at this time is the decisive factor, whereas often low temperature during winter is also required. The latter may be compensated by increased day length in spring.

We will terminate these brief notes by quoting the principal types of vegetative reactions to photoperiod in trees as given by WAREING (1948), in accordance with KLEBS (1914) and BURGER (1926).

1) Species continuing growth until September or October. In these species

summer daylength exceeds much the critical daylength for stopping growth or entering winter rest. Examples: several lianes, shrubs, e.g. *Salix* species, and juvenile stages of various species.

2) Species finishing growth in July or August. Also in these species the midsummer daylength exceeds the critical one. Growth is terminated because the number of leaves present at that moment is characteristic for the daylength then occurring. Examples: Fullgrown stages of *Liriodendron*, *Betula*, *Picea*, *Larix*, *Pseudotsuga*, *Robinia*.

3) Species finishing growth already in May or June. These only expand the initials present in the bud. The number of internodes has been determined by conditions during the previous year, or, eventually, two years ago (*Pinus*). Examples: Fullgrown stages of *Fagus*, *Pinus*, *Quercus*, *Juglans*, *Fraxinus*, *Acer*, etc.

GREENHOUSE EXPERIMENTS WITH LIRIODENDRON AND FAGUS

a. Experimental procedure

Two similar experiments have been made. The first one started early in September 1950 in a greenhouse attached to the northern wall of the laboratory, receiving very little direct sunlight. Temperature was kept above 10° C. Temperature data are collected in Table 1. One year's seedlings were used, with which a short day series

TABLE 1

Fagus-Liriodendron first experiment. Air temperatures in ° C in greenhouse at North exposition.

		Min.	Min.	Max.	Max.	Mean	Mean
		9 a.m.	17.30p.m.	9 a.m.	17.30p.m.	9 a.m.	17.30p.m.
13 Sept.-							
Oct. 50	ld	12.5	13.4	16.8	17.8	14.7	15.6
	sd	12.3	13.3	16.5	17.6	14.4	15.5
Dec. 1950 . .	ld	12.9	13.1	15.7	15.6	14.3	14.3
March 1951 .	ld	11.7	12.6	17.3	17.5	14.5	15.1
	sd	11.4	12.6	16.5	17.2	14.5	14.9
June 1951 . .	ld	15.3	19.-	25.5	25.5	20.4	20.2
(other thermometer)							
Oct. 1951 . .	ld	11.3	12.4	15.8	16.4	13.5	14.4
Febr. 1952 . .	ld	13.-	13.3	17.3	17.5	15.2	15.4
Aug. 1952 . .	ld	15.1	17.8	25.1	23.4	20.1	20.6

and a long day series were run. The *Liriodendron* experiment had 12 and 14 plants in the short day and long day series respectively, the *Fagus* experiment had 16 plants in both series. Short day was natural day in winter; in the summer season the plants were placed under a dark cover from 5 p.m. to 7 a.m. daily, so as to reduce day length to 10 hours. Long day was produced by artificial illumination with four 40 W. daylight fluorescent tubes, so as to produce a minimum daylength of 16 h., in summer up to 18 h. (Light was supplied from 7 a.m. onward in the morning if required, and in the evening up to 11 p.m. in winter, and 10 p.m. in summer respectively. The lights were at 60 cm (later 80 cm) above the plants. They were not removed during daytime.

The second experiment started July 1, 1951 in a well illuminated and ventilated, but unheated small greenhouse in the experimental grounds of the laboratory. It received full sunlight. In winter it was kept frostfree by heating a coal stove if required. Temperature data are collected in fig. 1, and Table 2. The daylength provisions were much the same as in the previous experiment. There was an additional series under natural conditions, in pots also, but outside the greenhouse, just for

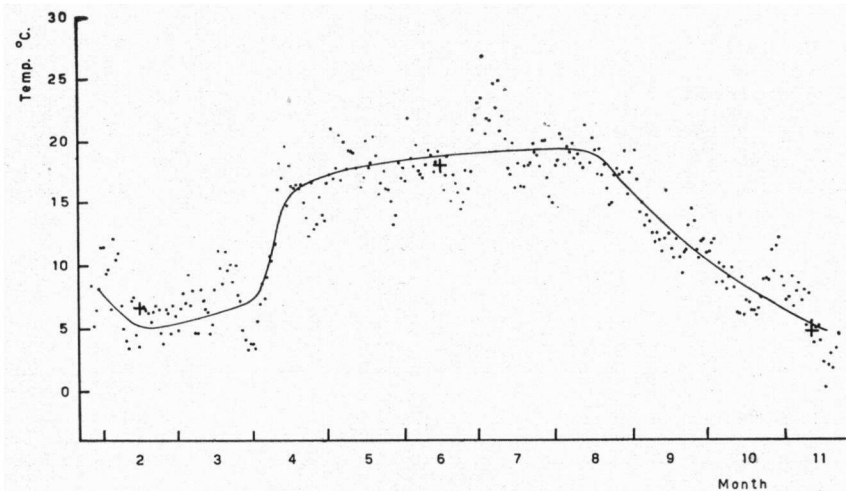


Fig. 1. Air temperature in the short day series at 8 a.m. Outer greenhouse, second experiment with *Liriodendron* and *Fagus*. The sign + = average temperature of a month.

comparing the two experimental series with natural growth and development. Each series consisted of 10 plants which were chosen in such a way that each time (for plants number 1, 2, etc. in each series) three very similar plants were selected from the lot and divided over the three series.

It should be remarked that the experiment is not a laboratory experiment, so that conditions have been rather variable throughout. It has been attempted, however, to have parallel short day and long day series differ only with respect to daylength, keeping all other conditions as equal as possible. The equipment described by WASSINK and STOLWIJK (9), especially designed for field experiments on photoperiodism, was not yet available when these experiments were made.

TABLE 2

Fagus-Liriodendron, second experiment. Some data on temperature in fully exposed greenhouse.

	Air temperature in °C.		Soil temperature in °C.	
	sd	ld	sd	ld
Febr.				
8 a.m.	6.6	6.2	7.5	6.5
17 p.m.	8.7	8.6	9.1	8.9
mean	7.6	7.4	8.3	7.7
June				
7.30 a.m.	17.9	16.5	16.9	16.1
17 p.m.	20.7	20.6	19.9	19.6
mean	19.3	18.5	18.4	17.8
Nov. 1—21				
8(7.30) a.m.	5.3	4.7	6.9	7.1
17 p.m.	7.3	7.2	9.2	9.3
mean	6.3	5.9	8.1	8.2

b. Results and discussion of the data

α . First experiment. In *Liriodendron* (Table 3) the main shoot shows a much greater length after long day treatment than after short day treatment. Side shoots are few and short in long days, but more numerous in short days so that the apical dominance is decreased.

TABLE 3

Shootlength, and some other data for *Liriodendron tulipifera*, as influenced by long and short days. Greenhouse at North exposition. First experiment, 1950-'52. Data for shoots produced in the 1951 and the 1952 season respectively, average values per plant.

Year	Items considered	Long day	Short day	difference	Significance of difference *	Ratio $\frac{ld}{sd}$
1951	Number of plants averaged	14	12			
	Total shootlength (per plant) . . .	19.7 \pm 2.68	11.8 \pm 1.26	7.9 \pm 2.96	2.7*	1.67
	Longest shoot . .	16.9 \pm 1.94	7.5 \pm 0.54	9.4 \pm 2.01	4.7***	2.25
	Other shoots . .	2.8	4.3	-1.5		0.65 = 1: 1.54
	Number of shoots (per plant) . . .	1.6 \pm 0.17	2.5 \pm 0.40	-0.9 \pm 0.43	2.1(*)	0.64 = 1: 1.56
1952	Mean number of leaves (entire plant)	13.2	9.3			1.42
	Longest shoot . .	26.2 \pm 5.58	9.4 \pm 1.21	16.8 \pm 5.71	2.94(**)	2.79
	Fresh weight (entire plant) . .	31.1	26.-			1.20
	Dry weight (entire plant) . .	14.27	7.57			1.89

* Ratio difference/standard deviation of difference, as a measure for significance. One point means: probability of difference being real is more than 95 %, two points, more than 99 %, three points, more than 99.9 %.

In *Fagus* (Table 4) apical dominance is not apparent, but all shoots show a similar effect of long day treatment as the main shoot does in *Liriodendron*.

In both species fresh weight and dry weight at the end of the experiment were highest in long days. Some roots that had grown through the pot were not collected entirely; this happened most in the long day series so that the eventual uncertainty introduced hereby is in favour of the mentioned result.

The larger shoot length in long days results from both a larger number of internodes and a greater length of each internode. In *Liriodendron* the number of leaves is increased in long day. In *Fagus* this has not been determined.

TABLE 4

Shootlength, fresh and dry weight for *Fagus silvatica* as influenced by long and short days. Greenhouse at North exposition. First experiment. 1950-'52. Data for shoots produced in the 1951 and the 1952 season respectively, average values per plant.

Year	Items considered	Long day	Short day	difference	Significance of difference *
	Number of plants averaged	16	16		
1951	Total shootlength per plant	69.4 ± 9.84	42.6 ± 3.56	26.8 ± 10.46	2.6·
	Longest shoot	10.3 ± 2.12	5.2 ± 0.76	5.1 ± 2.25	2.27·
1952	Longest shoot	32.2 ± 6.13	7.9 ± 1.74	24.3 ± 6.37	3.80··
	Fresh weight (entire plant).	45.9	22.1		
	Dry weight (entire plant).	22.9	11.9		

* See under table 3.

β. Second experiment. This experiment started July 1, 1951. *Liriodendron*, at the end of the 1951 season in long days showed already a marked increase in shoot length over that found in short days (Table 5). In this experiment apical dominance in the long day series was less pronounced than in the first experiment. This may be due to the fact that by July 1, all buds had already elongated, so that all growing shoots have been equally influenced by long days. It is seen

TABLE 5

Shoot length, fresh and dry weight for *Liriodendron tulipifera*, as influenced by long and short days. Fully exposed greenhouse. Second experiment, 1951-'52. Data for shoot produced in the 1951 and the 1952 season respectively, average values per plant. Data worked up in pairs.

Year	Items considered	Long day	Short day	Normal day	Diff. of long and short day	Significance of diff. *
	Number of plants averaged	10	10	10		
1951	Total shootlength (per plant)	51.4	21.1	25.1	30.3 ± 3.9	t = 7.77...
	Longest shoot	28.2	7.2	11.5	21.0 ± 2.4	t' = 8.75...
	Other shoots	23.2	13.9	13.6		
1952	Longest shoot	37.0	12.2	40.4	24.8 ± 6.57	t' = 3.77..
	Fresh weight (entire plant)	115.3	74.0	136.2		
	Dry weight	40.0	24.8	53.7		

* See under table 3.

from Table 5 that the difference between long and short day treatment is similar in main shoots and side shoots, be it less pronounced in the latter.

The experiment was continued during 1952. At the end of the 1952 season only the main shoots have been measured, and fresh and dry weights of the plants have been determined. The main shoots were again much longer in the long day series than in the short day series. Also the weights are higher.

The effect of the "natural day" is not very clear. In 1951 it approaches most that of the short day, in 1952 that of the long day. It should be emphasized, that the conditions for this series were not strictly comparable to those of the long and short day series since the "natural day" plants were kept outside, while the two others were in a greenhouse. Moreover, in the long day and in natural day, the roots had outgrown the pots and reached a much richer soil in the case of the natural day plants.

In *Liriodendron*, autumnal rest starts 1.5–2 months earlier in short days (fig. 2); it is also broken somewhat earlier, so that the rest period is lengthened and displaced. Also here, the "natural day" (outdoor) plants are not under comparable conditions. It is seen that *Liriodendron* in the 16 hours day is still far from continuing growth during winter, as GARNER and ALLARD (1923), and KRAMER (1936) observed.

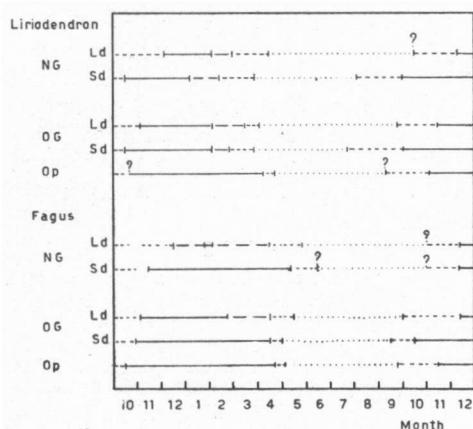


Fig. 2. Winterrest and growth period in *Liriodendron* and *Fagus* in long days (Ld) and in short days (Sd). NG = North greenhouse; OG = outer (fully exposed) greenhouse; Op = open air; — winter rest, --- winter rest, except in 1 or 2 plants or branches, transition period, - growth period.

The latitude of provenance may, eventually, be important for explaining the difference. In North Carolina (Kramer) maximum summer daylength is only $14\frac{1}{3}$ hours.

Kramer also found that in spring the buds developed earlier in long days than in short days, which is another difference with our results. Part of an explanation might be suggested by the fact that Kramer's experiments started when plants were already at rest, so that the entrance into the rest had been at the same time for the long and the short day series of plants.

In the greenhouse some of our plants or some branches in spring developed much earlier than the others. It was found that such plants or branches occupied a favourable position with respect to the light, but also different reaction to temperature may be important.

In *Fagus*, the various treatments failed to show significant difference in shoot length between the 3 series by the end of the 1951 season (Table 6). The continuation in 1952, however, brought about a significantly greater length of the longest shoot (there is no real "main shoot") in long days as compared with short days. There was no significant difference in fresh and dry weights at the end of the season. As to the (outdoor) natural day series the same remarks may be made as for *Liriodendron*.

TABLE 6

Shootlength, fresh and dry weight for *Fagus silvatica*, as influenced by long and short days. Fully exposed greenhouse. Second experiment, 1951-'52. Data for shoots, produced in the 1951 and the 1952 season respectively, average values per plant. Data worked up in pairs.

Year	Items considered	Long day	Short day	Normal day	Difference of long and short day	Significance of diff.*
	Number of plants averaged	10	10	10		
1951	Total shootlength (per plant) . . .	174.3	150.6	140.8	23.8 ± 16.55	$t = 1.44$
	Longest shoot . .	11.5	11.8	11.0		
1952	Longest shoot . .	34.0	7.1	8.2	26.9 ± 4.83	$t' = 5.56$
	Fresh weight (entire plant) . .	118.3	116.3	137.5		
	Dry weight (entire plant) . .	55.0	49.5	61.9		

* See under table 3.

The growth period in *Fagus* in long days is longer than in short days (fig. 2).

In spring 1952, plants in short days (and in natural days) developed much faster than those in long days. An explanation herefor cannot be given. Also in *Fagus*, in the greenhouse, some branches developed exceptionally early in spring, but only in long days; some branches stayed green in autumn considerably longer than others. The impression was gained also here that these exceptions were connected with a favourable position of the branches with respect to the light.

EXPERIMENTS WITH SEEDLINGS OF *PINUS SILVESTRIS* FROM DIFFERENT ORIGIN

a. Experimental procedure

The experiment with *Pinus silvestris* of northern and southern provenance was designed to see if these plants would show hereditary differences in reaction to daylength under controlled conditions.

The Swedish seed originated from Hietaniemi, Annusjärvi, near the Torneälf, at 50–100 m above sea-level and at a latitude of more than 66°; the French seed from the "Massif central" at 45° 30'. So the difference in latitude of origin is over 20°.

The seed was sown on May 20, 1952, in paraffin-coated wooden boxes and put under the light on June 4.

The French seed had germinated somewhat better. From each origin 2 boxes were put under long day, and 2 under short day conditions.

The lots of long and short day plants were each illuminated with four 40-watt day light fluorescent tubes between which 2 incandescent lamps of 20 watt were mounted.

Long day consisted of 12 hours light from the fluorescent tubes, followed by 12 hours illumination from the 2 incandescent lamps only. Short day plants received both illuminations simultaneously during 12 hours followed by 12 hours of darkness. In this way the total energy supply and the quality of the light were the same for long and short day illuminations.

The illumination intensity at the level of the seedlings was less than 100 to 240 lux for the incandescent lamps, and 2300 to 3000 lux for the fluorescent tubes. The temperature-course is indicated in Table 7. The difference in temperature between long and short day at day-time was for air-temperature within + 1.6° and – 1.1° C, and for soil-temperature within + 0.9° and – 0.3° C, so that illumination and temperature are controlled within narrow ranges.

TABLE 7

Pinus silvestris. Experiment on daylength influence under laboratory conditions. Some data on temperature during the experiment (° C).

	June		Sept.		Dec.	
	air temp.	soil temp.	air temp.	soil temp.	air temp.	soil temp.
9 a.m.						
ld	22.5	20.8	20.5	18.5	21.–	18.5
sd	21.3	19.9	20.–	18.2	19.4	17.6
12.– or 13.30 p.m.						
ld	24.7	21.6	21.8	18.7	22.2	18.5
sd	24.6	21.5	22.9	18.8	21.7	18.–
17.– p.m.						
ld	23.9	22.4	22.3	18.8	22.4	18.8
sd	24.7	22.2	23.1	19.1	22.5	18.3

Important is also that the plants were under the same day-length conditions from germination onwards. Not in direct connection with these experiments, the same provenances have also been sown under a daylength of 18 hours and in the open.

b. Results and their discussion

Obviously the Swedish provenance was below its subsistence minimum in a twelve hours day under the conditions described. Many

plants died, while others grew badly. The other series grew reasonably well, notwithstanding the fairly low light intensity (see plate I). In the open air, and also even at a daylength of 18 hours in the laboratory, the Swedish provenance showed bad growth. In the French provenance under short days (to be denoted as F.sd.) one plant showed a pair of large and one of small dwarf shoot needles on September 30. In the other lots (F.ld. [French provenance in long day], S.sd [Swedish provenance in short day] and S.ld [id. in long day]) the greater part of the larger plants had dwarf-shoot-needles, while smaller and suppressed specimens were still in the plantule state.

By the end of November, the situation was as indicated in Table 8:

TABLE 8
Formation of dwarf shoots (end of November) in *Pinus silvestris*.

	France		Sweden	
	sd	ld	sd	ld
> 4 fully developed dwarf shoots per plant	—	67,8	1,7	51,2
< 4 fully developed dwarf shoots per plant	18,4	18,2	62,1	22,4
formation of dwarf shoots just started .	3,4	3,8	6,—	4,—
no dwarf shoots	78,2	10,2	30,2	22,4

According to WAREING, (1951) *Pinus silvestris* will form dwarf shoots prematurely in the first season already, if grown under daylengths of more than 20 hours. Here is proved, that there is also something else, that influences premature forming of dwarf shoots. It looks, as if temperature, that was constantly rather high, will have been of importance. In our experiments premature formation of dwarf shoots was not observed in plants sown in the open air, whereas the day was considerably longer than 12 hours there.

Table 9 summarizes data, determined in December.

Some of these data have been determined on 6 well grown plants of each series (3 from each box), viz, a large one, a middlesized one, and a small one, (a predominant, dominant, and codominant plant). Some other data have been determined on a small number of fairly equivalent plants. Most data have been obtained from 25 plants, taken at random from one of the two boxes in each series. Root and shoot fresh and dry weight have also been determined from all plants of the second box, but these data are not presented in this Table (see, e.g., fig. 3, 4).

Special attention may be drawn to the following results shown in Table 9.

Shoot and root weight are very low in Swedish short day plants, demonstrating their bad development. The weights are lower in Swedish long day plants than in French short and long day plants, except for the six indicated specimens, what means, that in Swedish long day plants there is much more difference in growth. The large plants are larger than those of French origin, but there are relatively more small plants.

TABLE 9

Pinus silvestris, provenances N. Sweden and S. France. Various features of growth in relation to daylength under laboratory conditions.

	Number of plants averaged:	F.sd ¹⁾ (12h)	F.ld ²⁾ (24h)	S.sd ³⁾ (12h)	S.ld ⁴⁾ (24h)
1. Mean shoot weight (mg) .	25	417.-	524.9	58.9	300.5
2. Id. dry weight	25	119.6	154.-	21.2	107.2
3. Ratio dry weight: fresh weight of shoot, per cent.	25	29.7	21.7	36.1	35.7
4. Mean root weight (mg) .	25	89.5	82.-	19.2	60.2
5. Id. dry weight	25	35.6	33.6	8.4	29.2
6. Ratio dry weight: fresh weight of root, per cent. .	25	40.6	41.-	43.8	48.3
7. Total dry weight (mg) .	25	155.2	187.6	29.6	136.4
8. Id. (well grown plants) .	6	205.-	210.-	65.-	221.7
9. Ratio shoot weight: root weight	25	1.49 4.88 ± 0.242 7.28 ± 0.413		1.69 3.15 ± 0.115 5.31 ± 0.196	
10. Id. dry weight	25	3.36 4.58		2.52 3.67	
11. As 10, conversion to F.sd = 4.88	25	4.88 6.64		3.65 5.32	
12. Length of hypocotyl (cm)	25	1.11 3.48 ± 0.083 3.86 ± 0.069		1.08 3.04 ± 0.061 3.29 ± 0.093	
13. Id. (well grown plants) .	6	1.03 4.13 4.25		1.02 3.62 3.70	
14. Distance cotyledons to top (cm)	25	3.79 ± 0.198 4.28 ± 0.185		0.65 ± 0.62 4.08 ± 0.256	
15. Id. (well grown plants) .	6	4.48 4.93		1.08 5.18	
16. Total shoot length (cm) .	25	7.27 8.14		3.69 7.37	
17. Id. (well grown plants) .	6	8.61 9.18		4.70 8.88	
18. Root length (main root, cm)	25	1.05 21.92 23.12		1.28 11.92 15.20	
19. Internode length (mm) .	4	0.47 1.06		0.47 1.14	
20. Diam. C. 2 mm under cotyledons (mm)	25	1.25 ± 0.046 1.11 ± 0.047		0.64 ± 0.013 1.- ± 0.045	
21. Number of cotyledons . .	25	6.4 ± 0.16 6.4 ± 0.14		5.4 ± 0.14 5.6 ± 0.13	
22. Number of primary leaves	4	110.5 53.3		28.8 50.3	
23. Total length of prim. leaves (cm)	2	345.1 134.7		50.4 129.8	
24. Mean length of prim. leaves (cm)	2	3.20 2.30		1.55 2.38	

¹⁾ F.sd = French provenance, short-day conditions

²⁾ F.ld = French provenance, long-day conditions

³⁾ S.sd = Swedish provenance, short-day conditions

⁴⁾ S.ld = Swedish provenance, long-day conditions

In the French provenance the long day plants have a much greater shootweight, but a smaller rootweight than short day plants, so that the shootweight rootweight ratio is much higher in long day than in short day. Dry matter content is very low in F.ld, the diameter just under the cotyledons is larger in F.sd. Also the number of primary leaves and their average length is larger in F.sd.

Daylength has only little influence on the length of the hypocotyl, and in the French provenance also on the shoot length above the cotyledons. In the Swedish provenance the shoot has developed extremely badly in short days. Internode length is determined by day length only, and seems to be the same for a certain daylength in all provenances of *Pinus silvestris*. This should be investigated further, also for related species. The number of internodes nearly compensates the short internodelength in French short day plants, but in Swedish short day plants this number is also very low.

The mean length of the primary leaves shows the same tendency as the number of primary leaves, so that the total length of primary leaves is extremely large in the French short day plants and very low in Swedish short day plants. Rootlength is much higher in the French plants than in the Swedish. The before mentioned six Swedish plants could not be taken from the soil in such a way that roots were not destroyed, so that it is not known, whether their relative length was as great as that of the shoot, as compared with the French plants.

The unfavorable development of plants of Swedish provenance probably may be ascribed to extreme adaptation to long days, much more than plants from French provenance are adapted to short days. Data from literature suggest that, in pushing to the North, many genes have been lost, while in the South a large scale of genes is present, so that no very strict adaptation to the prevailing conditions obtains (LANGLET, 1944). On the average, F.ld even had grown better

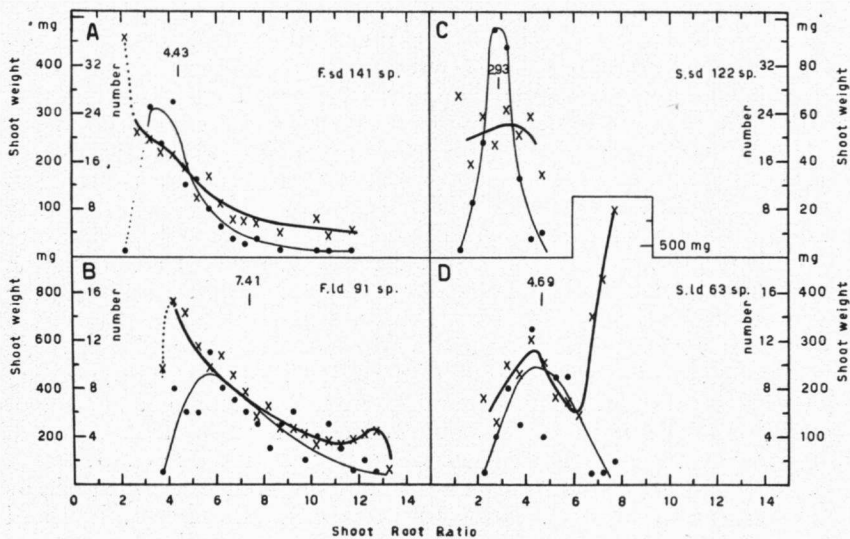


Fig. 3, A-D. Distribution curves (in numbers of plants) of shoot weight-root weight ratio (classes from $n-0.5$ to $n+0.5$), and relation of this ratio to the average shoot weight per class, in *Pinus silvestris*. Thin lines: number, heavy lines: shoot weight; S.sd = Swedish plants, short days, S.ld = idem, long days; F.sd. = French plants, short days. F.ld = idem, long days; 4.43 etc., average shoot weight root weight ratio's ;141 sp. etc., number of plants.

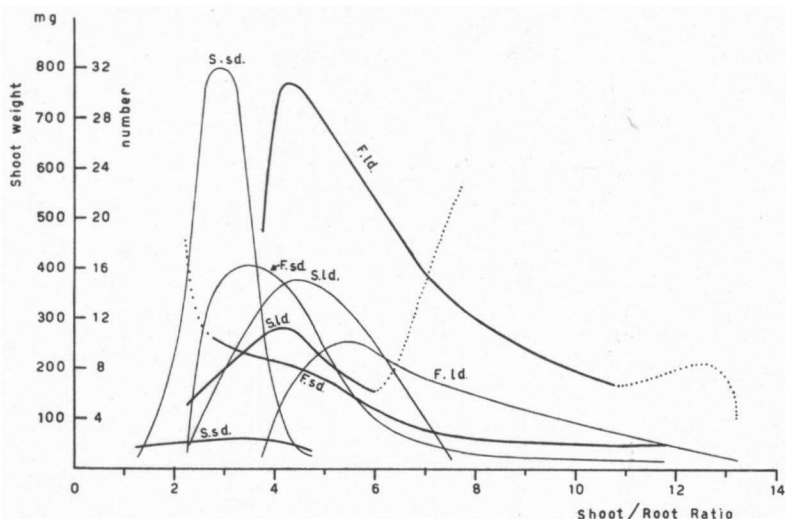


Fig. 4. *Pinus silvestris*, same curves as figure 3, A-D, with the distribution curves (thin lines) calculated per 100 plants, and the shoot weight curves (heavy lines) all at the same scale. Further symbols as in figure 3.

than F.sd, yet data suggest that, in the long run, short day conditions might be more favorable.

In many data, the effects of daylength and ecotype are mixed. Daylength has hardly any influence on the number of cotyledons. The ecotype, or perhaps the preceding conditions of the trees from which the seed originates, has a definite effect.

Internode-length is strongly influenced by daylength independent of the ecotype. It would be interesting to extend these observations with measurements of plants from other provenances and species.

The distribution curve of shoot weight over root weight is high and narrow in S.sd., low and wide in F.ld (figure 3). The relation of these values to shoot weight is shown in figure 3, in figure 4 these data are assembled on a percentage basis. In the French provenance the distribution curves show a tail towards the high ratio's, while in the Swedish provenance they are nearly symmetrical under short day conditions, and somewhat extended to the high ratio's under long days. In French plants the highest weight is found at the lowest shoot weight/root weight ratio; in Swedish plants weight is maximal near a shoot weight/root weight ratio of about 4. In both cases the maxima of number and shoot weight curves are nearly at the same ratio.

Under long day conditions some relatively well developed plants show an extremely high ratio. In these cases the relatively small root-system seems to be very active. Perhaps especially these plants already had a well-developed mycorrhiza, whereas the other plants had not. Mycorrhiza was observed in some of the seedlings; unfortunately, however, no special attention has been given to it. Its formation seems to be promoted by long days, which calls for further investigation.

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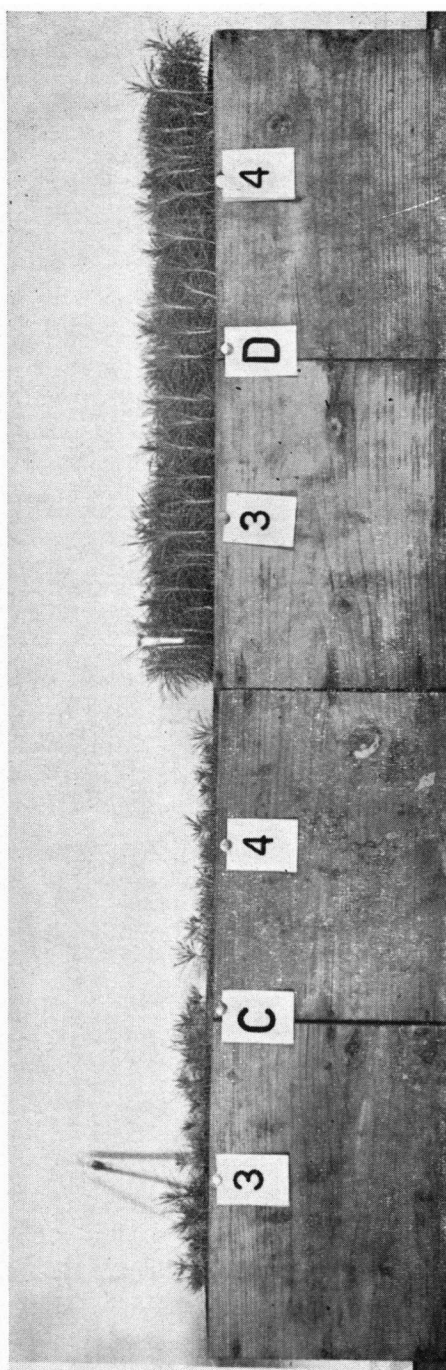
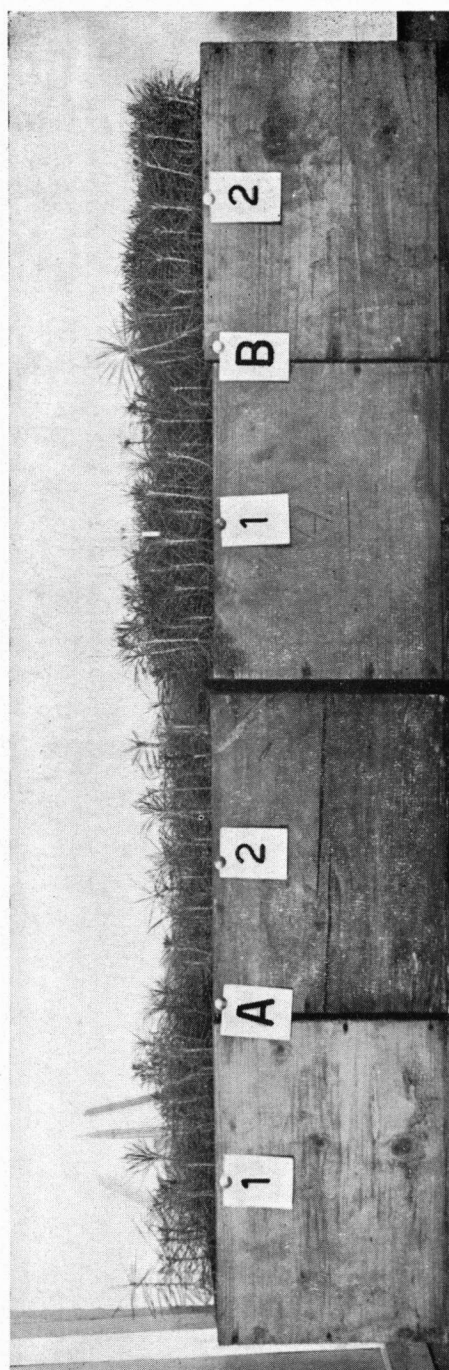


PLATE I. *Pinus silvestris*, from French and Swedish origin in long and short days. Artificial light only, see text. A = Swedish plants, long days; B = French plants, long days; C = Swedish plants, short days; D = French plants, short days. Photographs made August 28, 1952.

According to HUXLEY (1932) the differential growth coefficient is a better characteristic for the relative growth of shoot and root than the ratio shoot weight/root weight (3). For many plant species Huxley found a linear relation between the logarithm of shoot and root weights:

$$S = cR^k, \text{ or } \log S = k \log R + c,$$

in which S = shoot weight, R = root weight, k = differential growth coefficient, c = a constant.

WAREING (1951) gives a graph which shows 2 lines, representing Huxley's relation for seedlings of *Pinus silvestris* in different stages of development grown under long (15h) and short day (10h) conditions. According to Wareing the lines don't show a significant difference in direction (or in k) except for a deviation towards the abscis at the end of the vegetation period in short days, representing a continuation of root growth, whereas shoot growth has already ceased.

In our experiment, this relation was not followed during the season, yet we have plotted graphs according to Huxley's relation for plants of both provenances and treatments.

In figure 5, the curve for long day treatment seems to have the same direction (or k) as that for short days, but is displaced upward over a distance of nearly 0.26 so that, virtually, the log of shoot weight is increased by 0.26. A deviation towards the abscis for short day plants as in the case of Wareing might have the same result. For the Swedish provenance the graph for long day plants cannot be derived from that for short day treatment by vertical displacement only, but has also proceeded along the developmental line. Perhaps a shorter vegetation-period (which has not been determined) has stopped growth

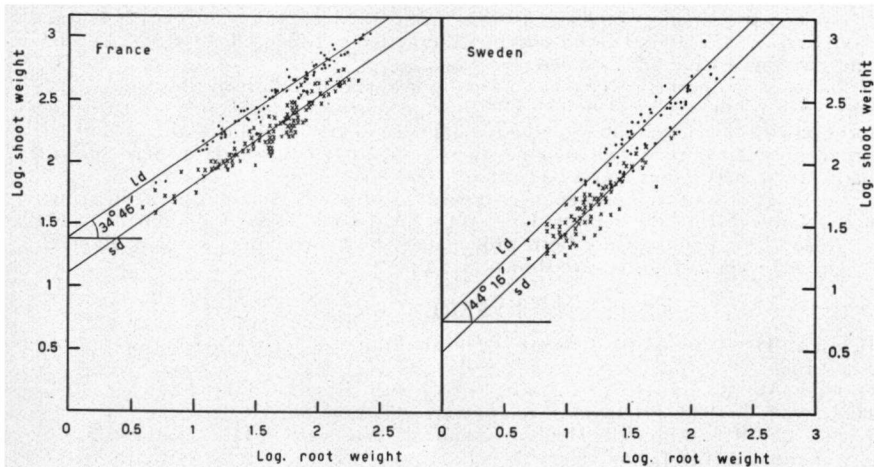


Fig. 5. Relation between log shoot weight and log root weight in *Pinus silvestris* as influenced by provenance and daylength. Not all points could be presented.

France: ld: $K_1 = 0.69, C_1 = 1.38$

sd: $K_2 = 0.69, C_2 = 1.11$

$$C_1 - C_2 = 0.27$$

Sweden: ld: $K_1' = 0.97, C_1' = 0.72$

sd: $K_2' = 0.98, C_2' = 0.47$

$$C_1' - C_2' = 0.25$$

in S.sd. *Pinus silvestris* is known to conclude its vegetation in the open under influence of decreasing day length. As to the declination of the line and the value of K, Wareing's curve is situated between those for French and Swedish plants, suggesting a gradual increase of the declination of the curve with increasing geographical latitude. See table no. 10. Here too, further investigation is needed.

TABLE 10

"Differential growth coefficient" for *Pinus silvestris* seedlings of various provenances.

	Declination	k	latitude
France	34° 46'	0,694	45° 30'
England (from Wareing's graph) . . .	39° 45'	0,831	± 51° 30'
Sweden	44° 16'	0,975	± 66°

SUMMARY

The influence of daylength has been investigated on some aspects of vegetative growth in tree seedlings. With *Liriodendron* and *Fagus* greenhouse experiments were carried out. Natural daylight was used for the basic illumination period of 10 hours, extended by light of fluorescent tubes to a daylength of 16 hours, when necessary.

In both species long day brings about a lengthening of branches, in *Liriodendron* especially of the main shoot, and a higher fresh and dry weight.

A daylength of 16 hours did not cause continuous growth during winter under the conditions of our experiments and with the provenances we used, as is found by GARNER and ALLARD (1923) and KRAMER (1936). Yet it brought about a lengthening of the growth period in both species, as compared with a daylength of 10 hours. Winterrest begins much later and ends somewhat earlier under long day treatment.

For two provenances of *Pinus silvestris*, from Sweden (more than 66° N.L.) and from France (45° 30' N.L.) the possible interaction between effects of racial variety and daylength have been studied.

Plants of southern provenance, normally growing in relatively short days, grew very well in long days (24 hours) as well as in short days (12 hours), in both cases forming well-developed shoots and having a normal green colour. Plants of northern provenance grew very well in long days but badly in short days, here showing badly developed shoots and a bad colour.

Seedlings of southern provenance showed a positive correlation between growth and relative size of the root system, except in special cases (development of mycorrhiza?), for plants of northern provenance such correlation was not observed.

The main data collected are shown in Table 9.

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