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The Phytotron in Stockholm

Skogshögskolans fytotronanläggning

by

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The Phytotron in Stockholm[1]

The phytotron at the Royal College of Forestry, Stockholm, was planned, designed, and constructed during the years 1958—1964 by the joint efforts of scientists and engineers. Operation of the versatile climate laboratory for genecological and physiological research on forest trees, agricultural and wild plants was started in January 1965.

The devices for air-conditioning were constructed and supplied by AB Svenska Fläktfabriken (Ing. O. Malmström). The electric and electronic installations were made by ASEA, according to the plans worked out by the engineering firm Bergman and Co. AB (Ing. G. Nilsson). Engineer H. Gille (Hugo Theorell Engineering firm) functioned as chief engineering consultant. The architect, Professor H. Brunnberg from the Royal Academy of Arts, designed the building so that it eminently satisfies all the requirements arising from the technical aspects of the climate laboratories. Engineer H. R. Jung coordinated the final building and installation work, and put the phytotron into operation. The phytotron is operated under the scientific direction of Professors Åke Gustafsson and Erik Hagberg.

The costs of construction amounted to 4.5 million Sw. crowns. The project was financed by donations from the Rockefeller Foundation, the Knut and Alice Wallenberg Foundation, the Foundation for Forest Research, the Cellulose Industry Foundation, the "Norrlandsfond", and the "Malmfond". Some of the technical installations were donated by AB Svenska Fläktfabriken and ASEA.

This paper presents a brief survey of the facilities themselves and of some experiences obtained during the first ten months of operation. A more detailed description of the phytotron will be published elsewhere. For general information on phytotrons and phytotronics — the control of plant growth in deliberately created environments — the reader is referred to WENT, 1957, and EVANS, 1963.

The area for the growth of plants under strict environmental control amounts to 195 m^2, and comprises two air-conditioned greenhouses (32 m^2

[1] Lecture given at the Second Symposium for Industrial Plant Production, Vienna 1965.

each) (Figures 1, 2), six climate rooms with artificial light (8.7 m^2 each) (Figure 3), three air-conditioned dark rooms (8.7 m^2 each), one humidity controlled room with artificial light (12 m^2), two constant temperature rooms (14 m^2 each), and two low temperature rooms (9 m^2 and 4 m^2). The air-conditioning and other machinery, the light sources, the central controls, the service area and the laboratories occupy 1300 m^2.

The central air intake, with a maximum capacity of 20,000 m^3/h, is located in the basement. All air is passed through a preheating radiator, an oil filter, a coal filter, and an absolute filter. From the large central fan, the air is distributed for preparation to the various air-conditioners serving the growing rooms and for general ventilation. All air-conditioners, compressors, and other machinery — with the exception of those for the constant temperature rooms — are located in the basement below the respective growing rooms (cf. Fig. 1). The air prepared as to the required temperature and humidity is introduced through the perforated floors of the rooms with a velocity of 0.2 m/sec. Thereby, 300 air changes per hour take place in the climate rooms. All artificial light sources are separated from the growing rooms by glass roofs and provided with a separate air cooling system. A total of 250 tons of air per hour is moved through the growing rooms and the spaces containing the artificial light sources. To remove the heat from the growing rooms and lamps, a maximum cooling capacity of 400 million calories per hour is provided. An evaporative cooling system with three cooling towers (Figure 1) is used to remove the heat from the lamps and compressors. Otherwise, direct expansion cooling is employed.

Thermoperiods between +40°C and 0°C can be studied and temperatures down to -25°C are available in the low temperature room. Any photoperiod employing light intensities up to 40,000 lux (4,000 fc.) can be automatically run.

In the two air-conditioned greenhouses (Figure 2), with their glass roofs and a glass wall towards the south, temperatures can be regulated between +15°C and +30°C during the daytime and between +10°C and +25°C during the nighttime. The temperatures can be maintained with an accuracy of at least ±0.5°C, while relative humidity is kept constant at 75% at all times. In the air-conditioned greenhouses, artificial light can be used instead of or alternating with daylight (Figures 2 and 5). The glass side wall can be automatically darkened, and the light sources which are mounted on telpher cars can be moved automatically with the aid of timers over the inner greenhouse roof. The darkening device of the side wall and the telpher car with the lamps turned off can also be used to exclude daylight during nyctoperiods.

The nine climate rooms comprise three units with respect to thermoperiods. The temperature and humidity in the two artificial light rooms

(Figure 3) and one darkroom making up each unit are always the same, and are regulated by a single air-conditioner. Different photoperiods can be maintained in the two light rooms. A temperature range between +5°C and +40°C is covered with an accuracy of ±0.2°C. Relative humidity can be regulated between 75 and 95%.

A diagram of the air circulation and air-conditioning system used in some of the climate rooms is given in Figure 6. Air-conditioning is accomplished via the dew point in a spray-chamber. The prepared air is blown by a fan (2) through the floor of the climate rooms (1). The feeler organs for the dry (3) and wet (4) bulb temperature controls are located in the introducing air channel. From the return ducts the air is passed through a water spray-chamber (7) where the desired dew point is established. Part of the air by-passes the spray-chamber through dampers (6) and recombines in the fan with the air which has been treated in the spray-chamber. An afterheating radiator (5) is placed above the fan. The dry bulb temperature control determines the amount of air to by-pass the spray-chamber by regulating the dampers (6) and the amount of afterheating or drying to be done by the afterheating radiator (5). The wet bulb temperature control regulates the temperature of the spray water in the chamber (7). The spray water is warmed by a water heater (8) or cooled in the basin of the spray-chamber by extension coils (9) from a compressor. Ten to twenty percent fresh air is continuously introduced into the system.

The humidity controlled room has a larger air-conditioning capacity than the other rooms, which allows the testing of a large range of humidities on plants at temperatures between 5°C and 40°C.

The control room (Figure 4) contains the central regulating equipment. Here are the timers regulating the photo- and the thermoperiods in the individual climate rooms, and the signal indicators for all motor and light units. A control system using thermocouples, which is entirely separate from the regulating system, records continuously on multipoint recorders the temperature, the humidity, and the light conditions at certain points in all climate rooms. Additional measuring points can be established in any climate room and recorded in the control room. An elaborate alarm system to warn of malfunctions of motors and other equipment has been built into the system. During nights or holidays the alarm can be transferred by a telephone robot to any desired home number.

Facilities are provided to operate the phytotron under sterile conditions. The plants are grown in inert substrates such as gravel, sand, or vermiculite, and are watered with nutrient solutions. Deionized water, compressed air, and a standard nutrient solution are available through pipelines in all growth rooms.

During the first ten months of operation, the performance of the installations was tested and the following plants were grown under long- and short-day conditions.

Trees:	*Betula verrucosa*, northern provenance
	Pinus silvestris, two provenances
	Picea abies, two provenances
	Larix decidua
Agricultural plants:	
	barley, (Bonus, Mari, Pallas)
	pea (Strålärt)
	lettuce (Urania)
	spinach (Nobel II)
	bean (Alabaster)
	soybean (Fiskeby IV)
	Nicotiana tabacum (Samsun, Maryland Mammoth)
Horticultural plants:	
	Impatiens balsamina
	Matthiola incana
	Antirrhinum majus
	Lathyrus odoratus
Wild plants:	*Hyoscyamus niger* $(\frac{an}{an})$
	Hyoscyamus albus

Under suitable photoperiodic and thermoperiodic conditions, many of these plants have been successfully grown from seed to seed within a few weeks. Examples of the appearance of the plants are given in Figures 7 and 8, in which lettuce and spinach plants of the same age grown under long- and short-day conditions are compared. As expected for typical long-day plants, flowering occurred only under long-day conditions.

Three different artificial light sources were tested in the experiments: Power Grooves (PG, General Electric); Very High Output (VHO, Sylvania); and Grolux (GL, Sylvania). The plants were grown under these three commercial lamp types with photoperiods and thermoperiods being kept identical. No major differences in growth or morphology could be detected among plants grown under these three light sources. A comparison of representative individuals of the long-day plant *Hyoscyamus niger* grown under the three light sources in short- and long-day conditions is given in Figure 9. We have now chosen to use only Grolux as the artificial light source in the phytotron.

Pea plants of the variety Strålärt reacted markedly to long- and short-day conditions (Figure 10). After two months extensive flowering and fruiting had occurred under long-day conditions, whereas no flowering had occurred under short-day conditions after four months, in spite of vigorous growth of the plants.

Examples of the habitus of the two short-day plants, *Nicotiana tabacum*, Maryland Mammoth, and *Matthiola incana*, are given in Figures 11 and 12. In the climate room designated as D2, the first and last four hours of the 16 hour dark period were kept at 20°C instead of 15°C as in rooms B, E1, and E. Flowering of *Matthiola* is strongly inhibited by this higher temperature during the dark period, in spite of the short-day conditions. Maryland Mammoth, on the other hand, seems little affected by such a high night temperature treatment. That high temperature during the dark period inhibits flower induction under long-day conditions in long-day plants, such as *Hyoscyamus niger*, is a well known phenomenon (LANG and MELCHERS, 1943). Obviously, some short-day plants are also sensitive to a high night temperature treatment, whereas others are not.

One year old seedlings of *Pinus silvestris* grown in the phytotron for 150 days responded drastically to long- and short-day conditions (Figures 13 and 14). Under long-day conditions extremely long needles developed and there was also a strong diameter growth of the stem. Under short-day conditions the needles are shorter and the diameter growth of the stem falls far behind that obtained in long-day conditions. A very clear-cut difference in growth rates between the provenance from Poland and that from northern Sweden is observed (Figures 13 and 14). Even more pronounced was the difference in the reactions of the two provenances of *Picea abies* under these conditions (Figures 15 and 16). The southern spruce provenance grew extremely rapidly under long-day conditions (Figure 15), but much less so under short-day conditions. The northern Swedish provenance produced only a little initial growth under both photoperiodic conditions. Thereafter, shoot elongation ceased and buds formed which remained dormant during the following months (Figure 16). In Figure 17 is depicted the response of a Slovakian alpine provenance of *Larix decidua* to long- and short-day conditions for 150 days. An extremely vigorous growth was observed under long-day conditions.

These preliminary observations demonstrate that the phytotron will make it possible to determine the various photo- and thermoperiodic systems controlling the growth of different provenances of European conifers. It is quite likely that optimal growth and bud breakage are determined by night temperature in one provenance, by day temperature in others, and by the difference between the day and night temperature in still others as demonstrated by HELLMERS (1962) for different coniferous tree species of North America. Finally, there may be provenances in which thermoperiodic growth control is absent and only photoperiodism operates.

In experiments now under way, the optimal photo- and thermoperiodic requirements for a number of individual genotypes in various species (*Pinus*, *Picea*, *Hordeum*, *Nicotiana*) are being investigated. A set of 30 climates differing with regard to photoperiods and thermoperiods are being used simultaneously in the phytotron for this purpose.

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Sammanfattning

Skogshögskolans fytotronanläggning

En beskrivning lämnas av fytotronanläggningens olika utrymmen och dess utrustning. Sedan redogöres för resultat erhållna i den första försöksserien.

Fytotronen med dess klimatiserade växthus och klimatrum innehåller 195 m² odlingsareal med fullt kontrollerade miljöbetingelser. 1 300 m² upptagas av maskineri till klimatisering, av belysningsanordningar, av kontrollerande och regulerande organ samt av planterings- och laboratorieutrymmen. Termoperioder mellan + 40°C och 0°C kan användas i klimatutrymmena och temperaturer till −25°C kan erhållas i frysrummet. Valfria fotoperioder med lysintensiteter upp till 40 000 lux kan köras automatiskt. Speciellt noggrann fuktighetskontroll kan uppnås i ett av rummen.

Flera skogsträdsarter, jordbruks- och trädgårdsväxter samt vilda växter har odlats framgångsrikt i fytotronen, varvid både kort- och långdagsbetingelser har studerats. Olika lysrörstyper har jämförts under identiska foto- och termoperiodiska betingelser. Tydliga skillnader mellan sydliga och nordliga raser av gran och tall har kunnat fastställas, när dessa odlades under långdags- och kortdagsbetingelser.

Figures

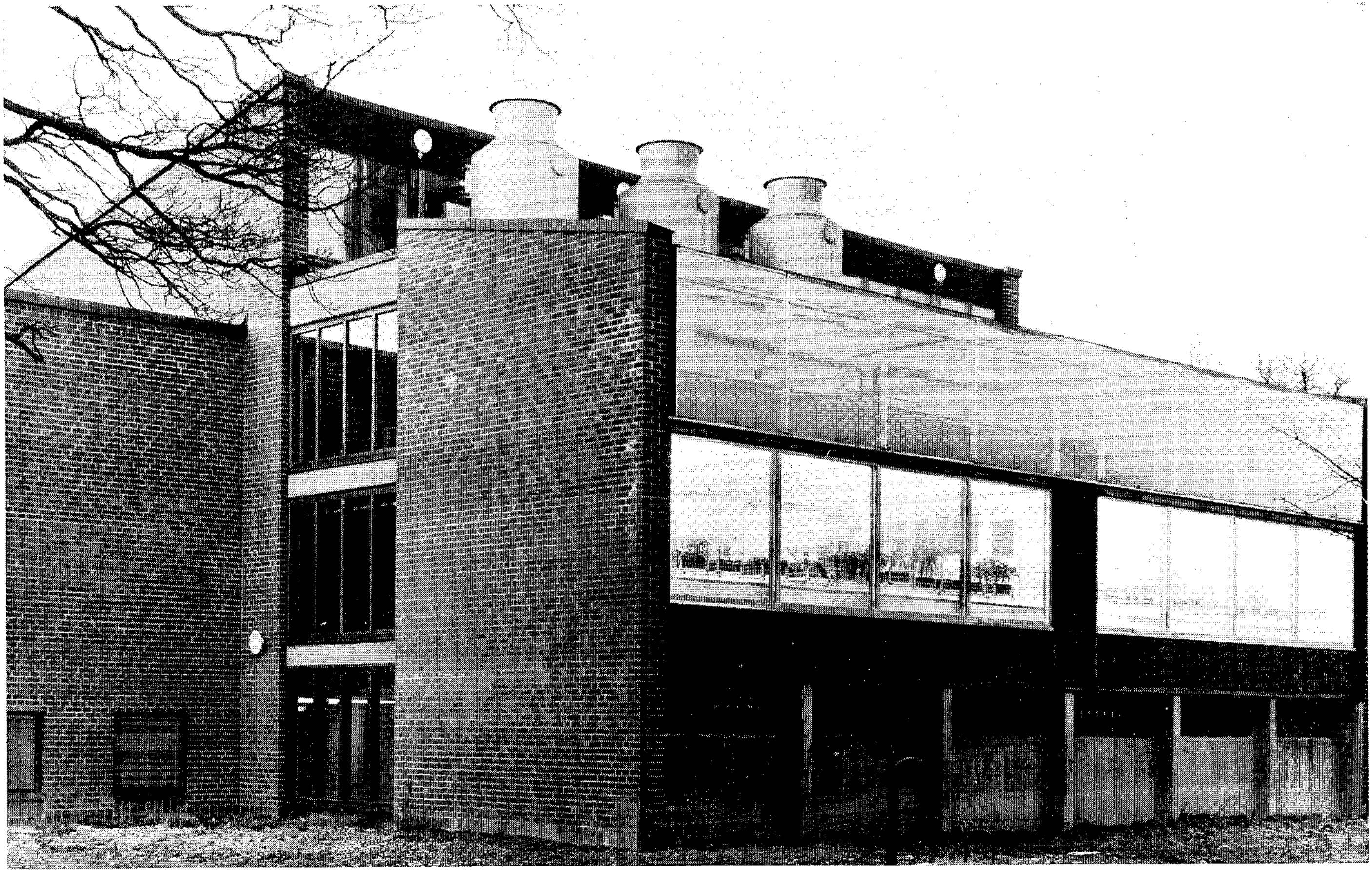

Fig. 1. View of the phytotron with the two air-conditioned greenhouses. Artificial light sources mounted on telpher cars can be moved automatically over the inner greenhouse roof. Three cooling towers are to be seen above.

Fig. 2. Inside view of one air-conditioned greenhouse during use of daylight. The prepared air is blown through the perforated floor.

Fig. 3. Inside view of climate rooms with artificial light sources.

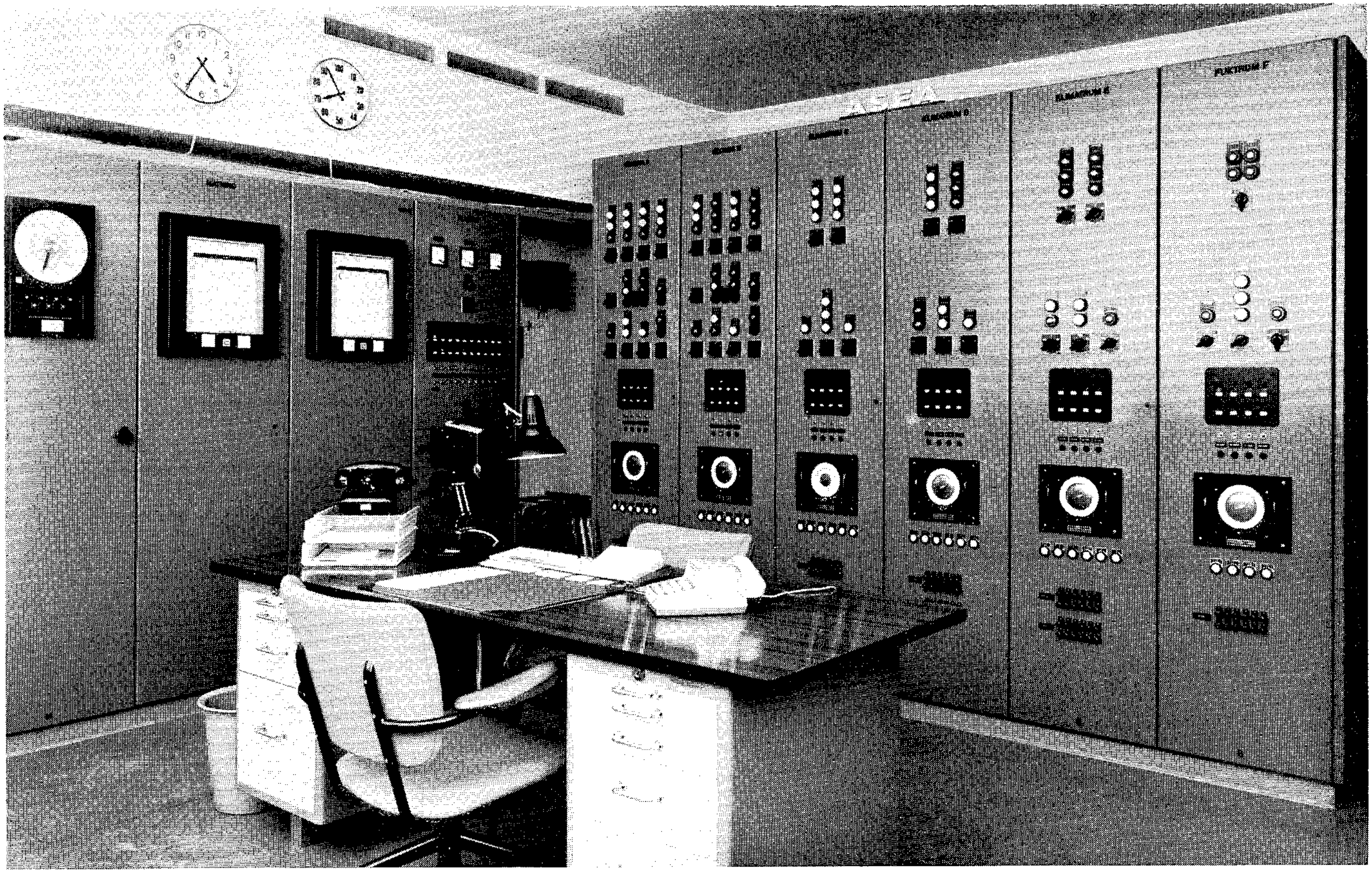

Fig. 4. Control room with the panels containing the electronic air-conditioning controls, timers, and signal indicators for motors and lights. At left, units for recording of temperature and humidity.

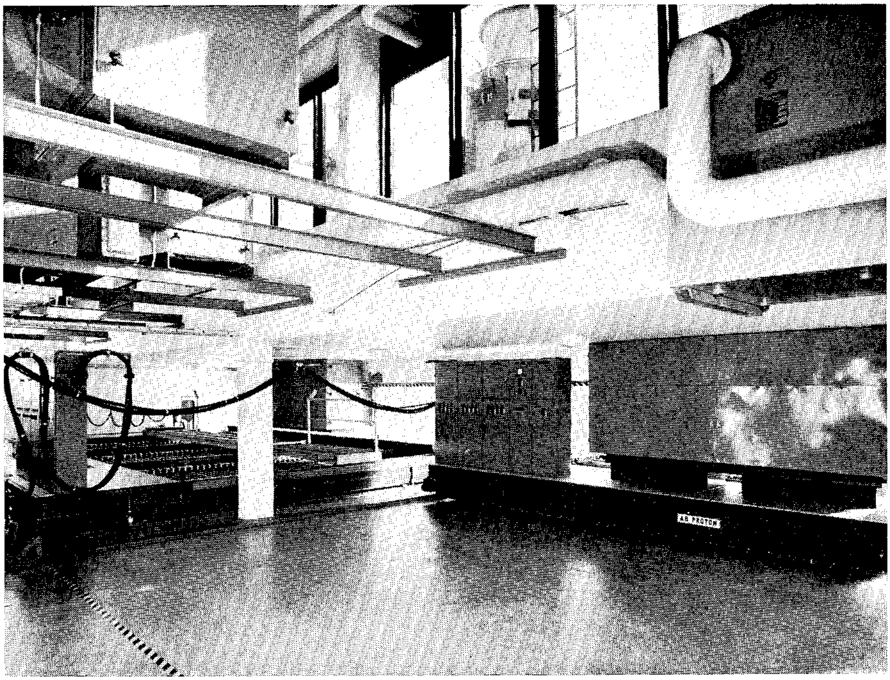

Fig. 5. Telpher cars with mounted fluorescent tubes above the greenhouses. The car on the right is in operating condition over the glass roof, the one on the left is withdrawn to allow use of daylight in the greenhouse. Air conditioners for lamp cooling are at right and top left.

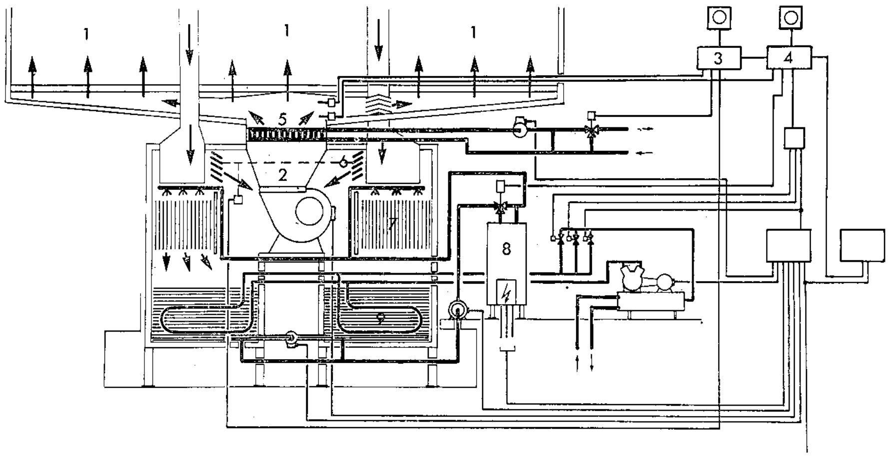

Fig. 6. Diagram showing air circulation and air-conditioning system employed for some of the climate rooms with artificial light. 1, climate room; 2, fan; 3, dry bulb temperature control; 4, wet bulb temperature control; 5, afterheating radiator; 6, by-pass dampers; 7, spray-chamber, where air is treated with water of desired temperature; 8, water heater; 9, water cooling coils.

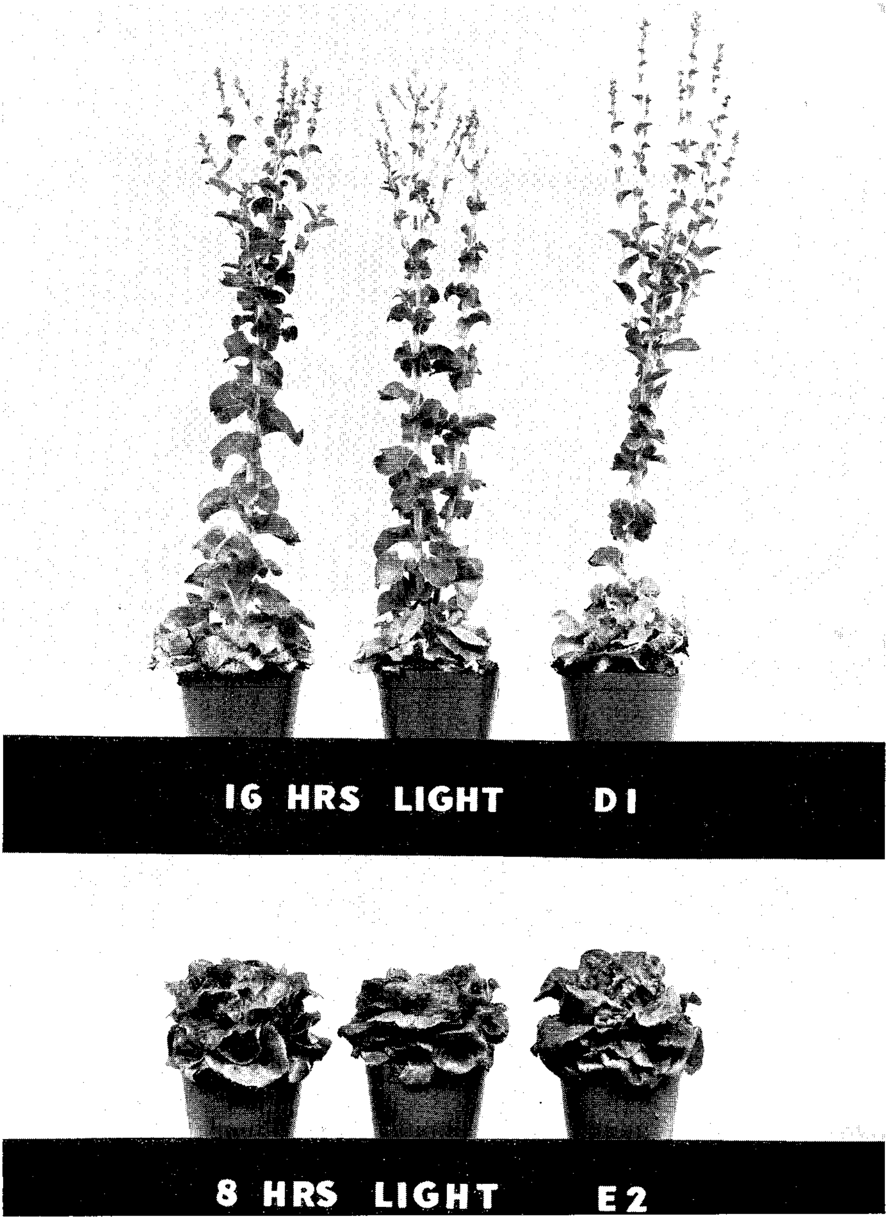

Fig. 7. Lettuce (variety Urania) grown under long-day and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%. Age of plants: 74 days.

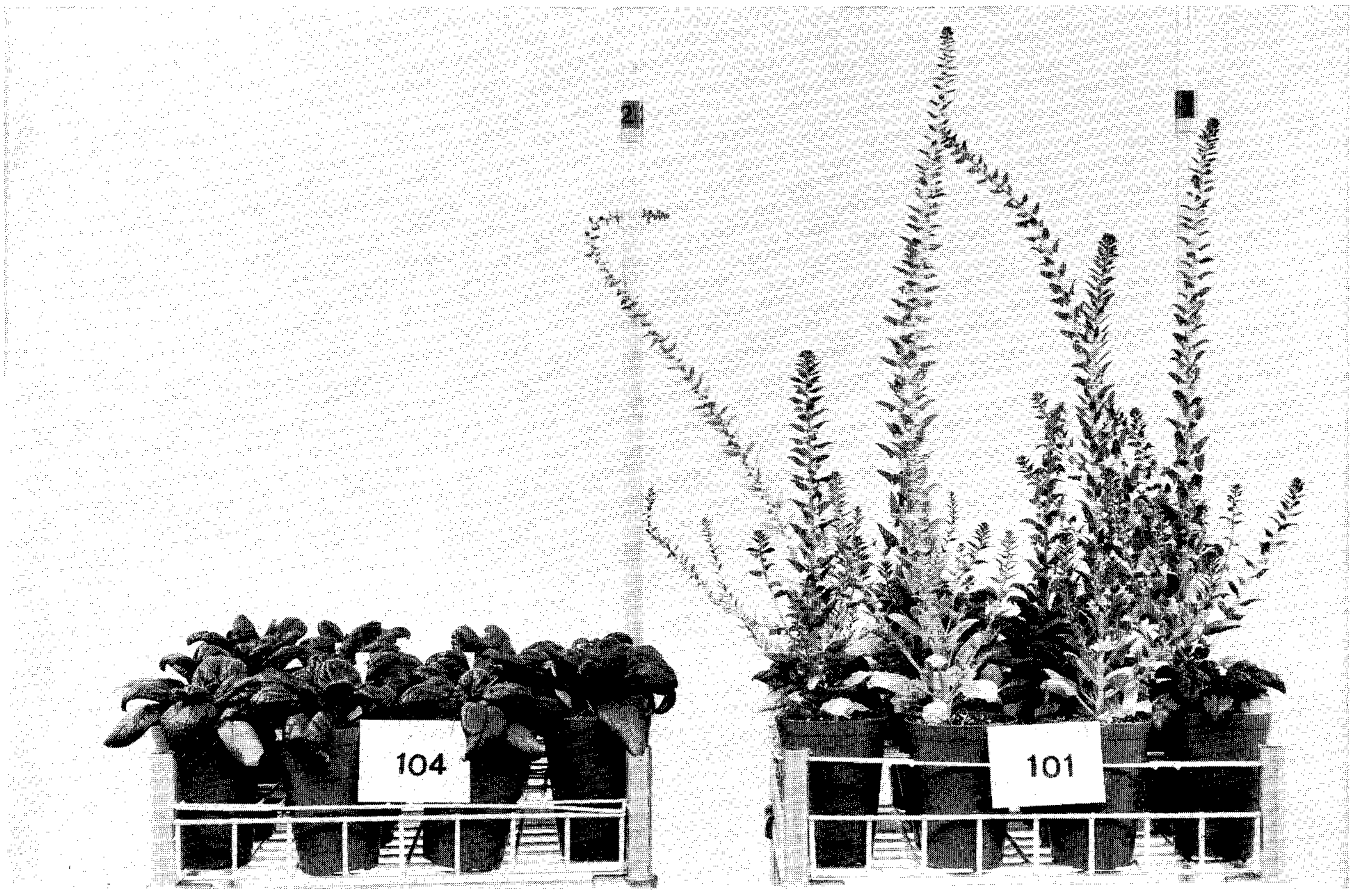

Fig. 8. Spinach (variety Nobel II) at age of 72 days. Left, grown in 8 hour and right, in 16 hour photoperiod. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

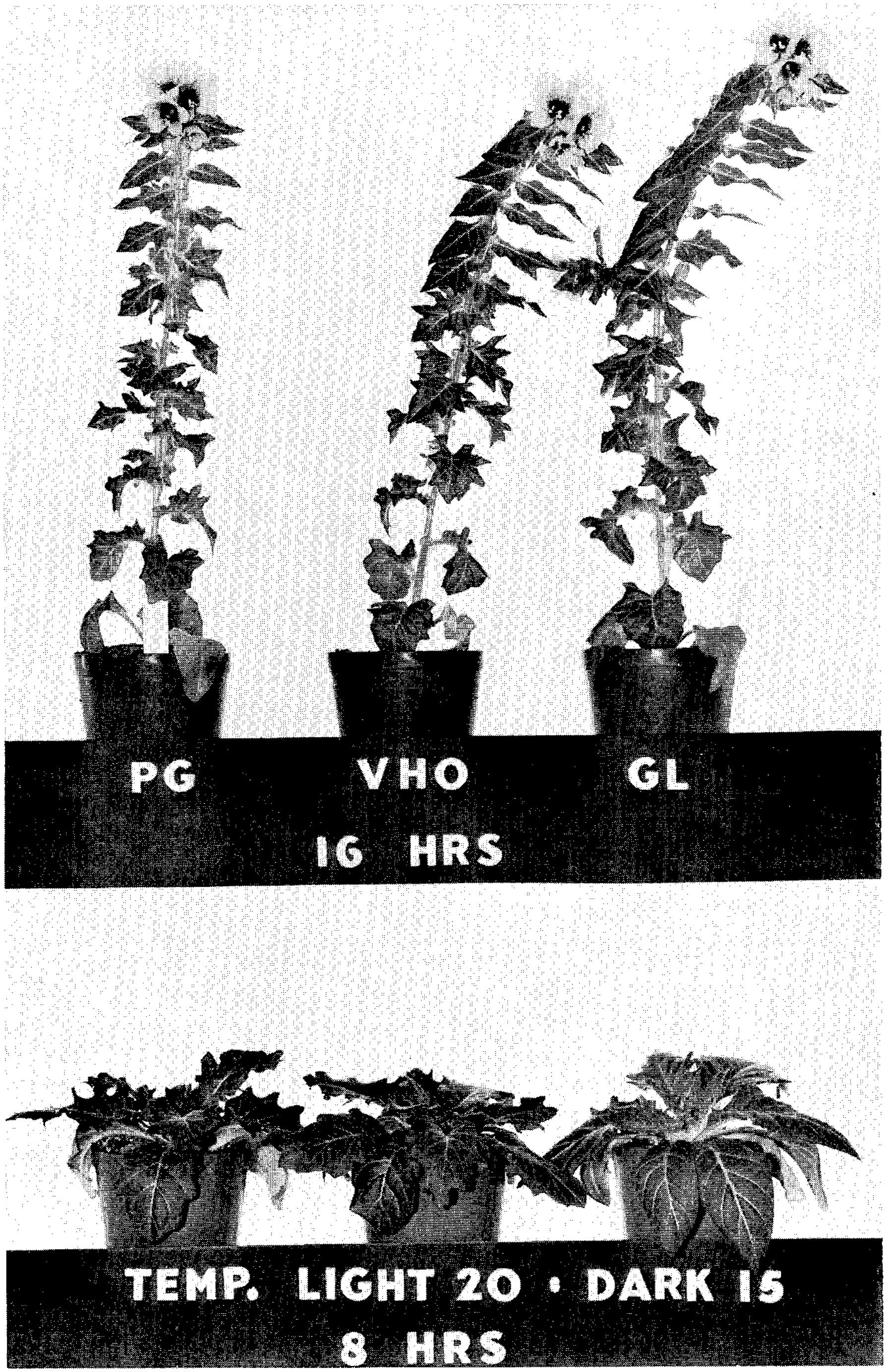

Fig. 9. Plants of *Hyoscyamus niger* $\left(\frac{an}{an}\right)$ grown under long- and short-day conditions using three different light sources. PG = Power Grooves (General Electric); VHO = Very High Output (Sylvania); GL = Grolux (Sylvania). Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%. Age of plants: 150 days.

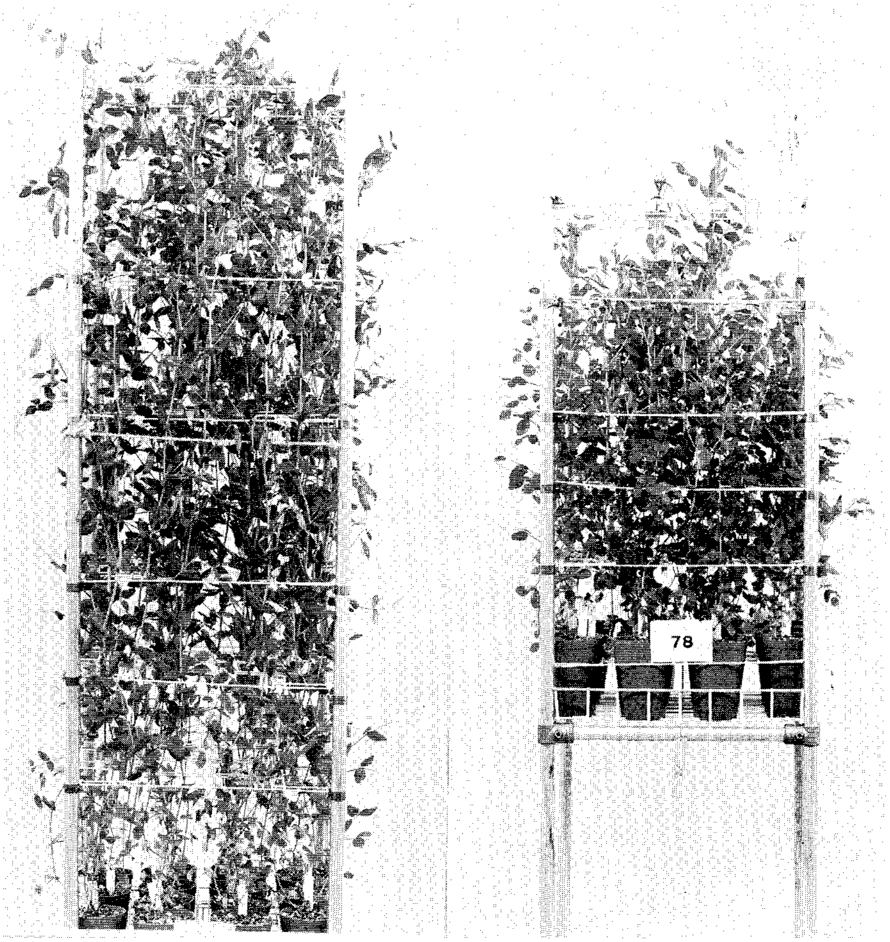

Fig. 10. 70 day old pea plants (variety Strålärt) grown under 16 hour photoperiod, at left, and under 8 hour photoperiod, at right. Flowering and fruitset has taken place only under long-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

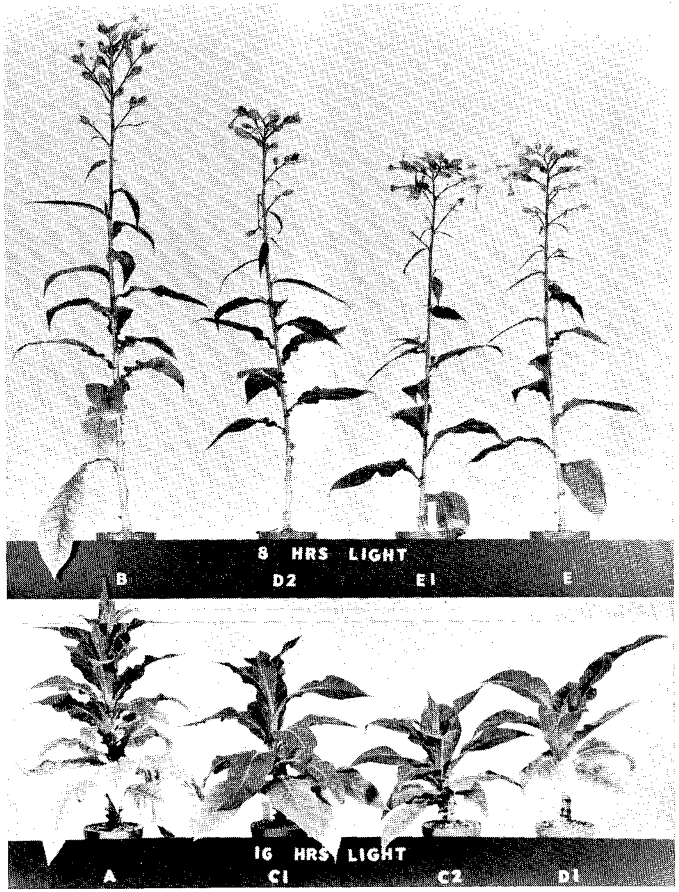

Fig. 11. The short-day plant *Nicotiana tabacum*, Maryland Mammoth grown under long-day and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%. Age of plants: 152 days.

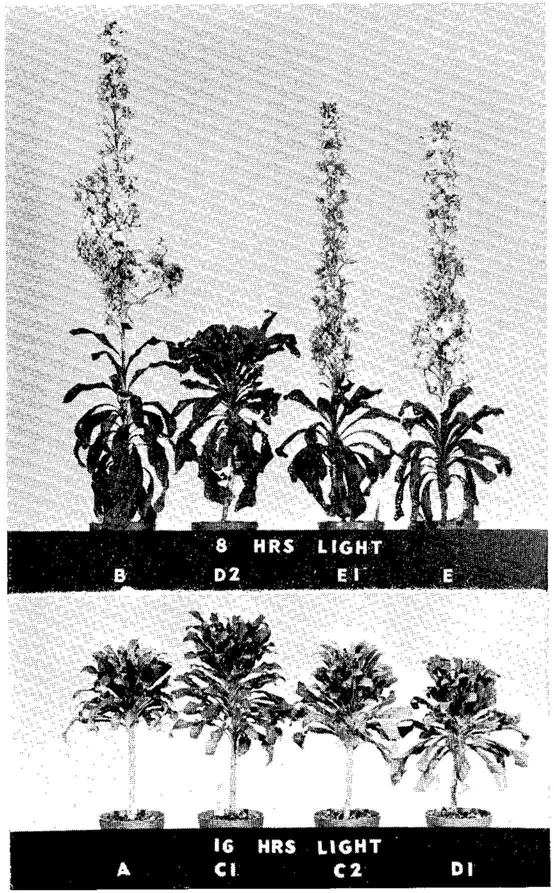

Fig. 12. The short-day plant *Matthiola incana* (variety Brilliant) grown under long-day and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%. In D_2, the temperature of the first and last 4 hours of the dark period was kept at 20°C instead of 15°C. This inhibited flowering in spite of short-day conditions. Age of plants: 150 days.

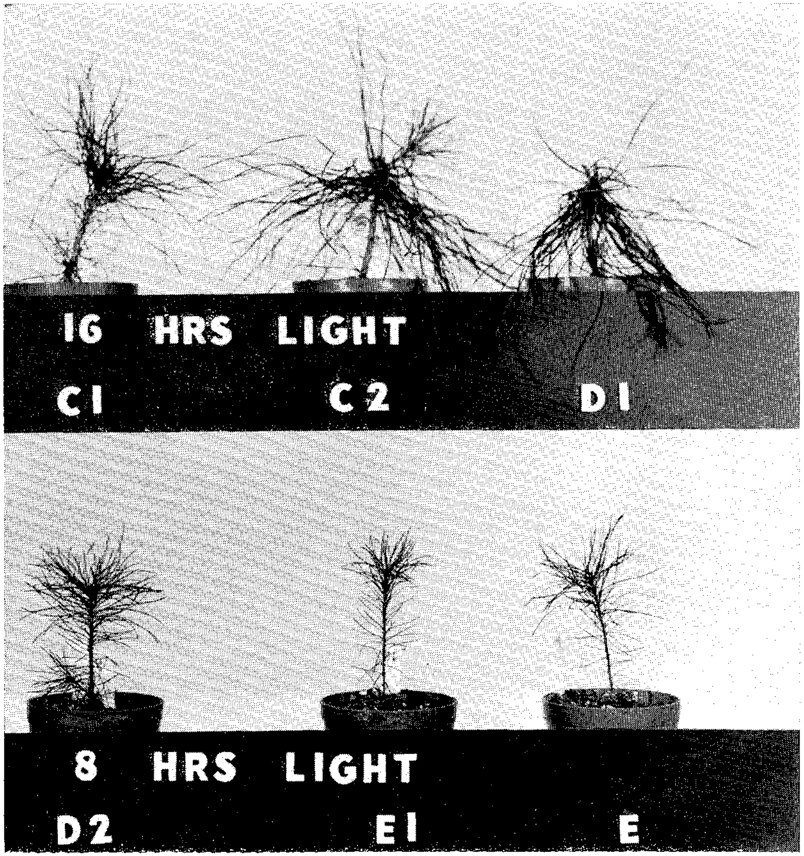

Fig. 13. *Pinus silvestris*, provenance Tabors, Poland. One year old seedlings grown in the phytotron for 150 days under long-day and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

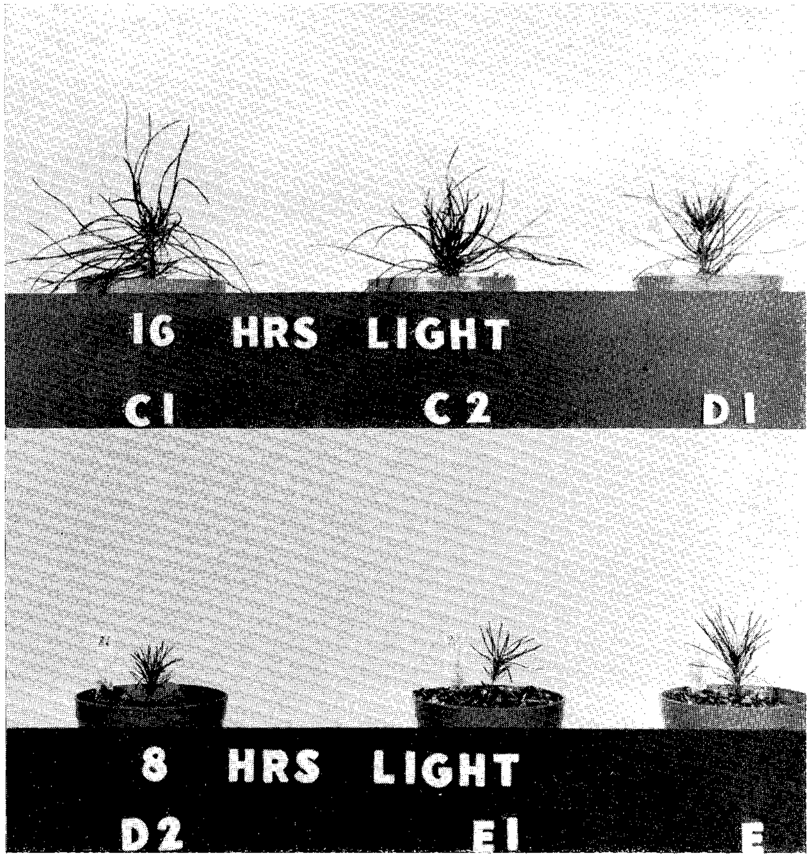

Fig. 14. *Pinus silvestris*, provenance Linalompolo, northern Sweden. One year old seedlings grown in the phytotron for 150 days under long-day and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

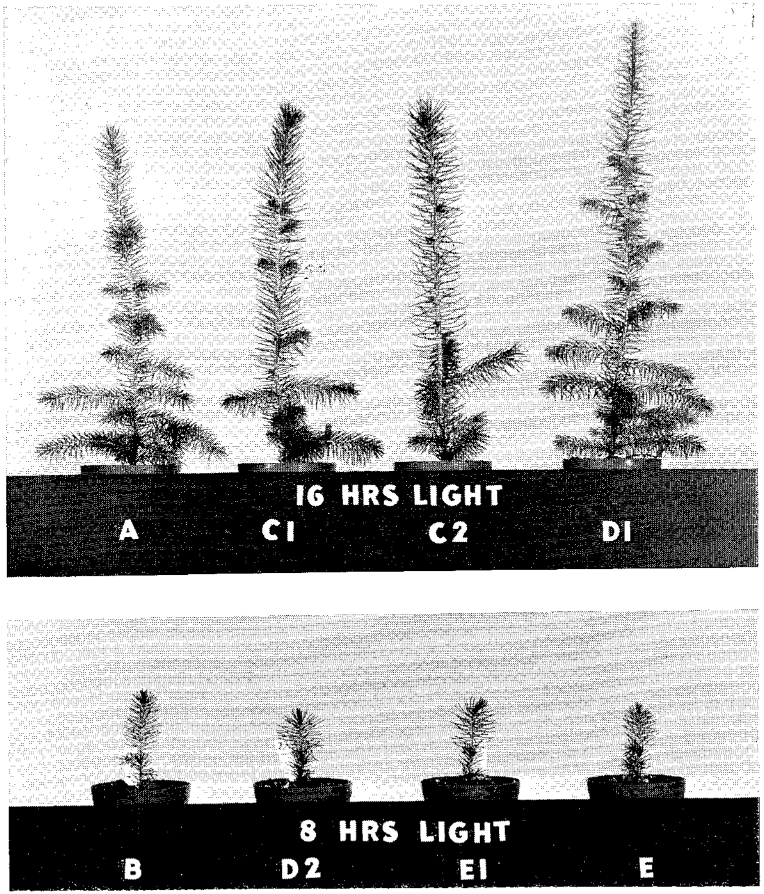

Fig. 15. *Picea abies*, provenance Westerhof, Germany. One year old seedlings grown in the phytotron for 150 days under long- and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

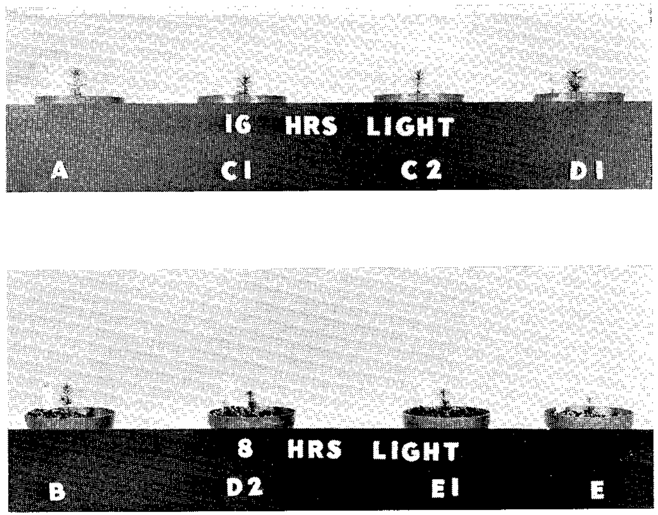

Fig. 16. *Picea abies*, provenance Laitamaa, northern Sweden. One year old seedlings grown in the phytotron for 150 days under long- and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.

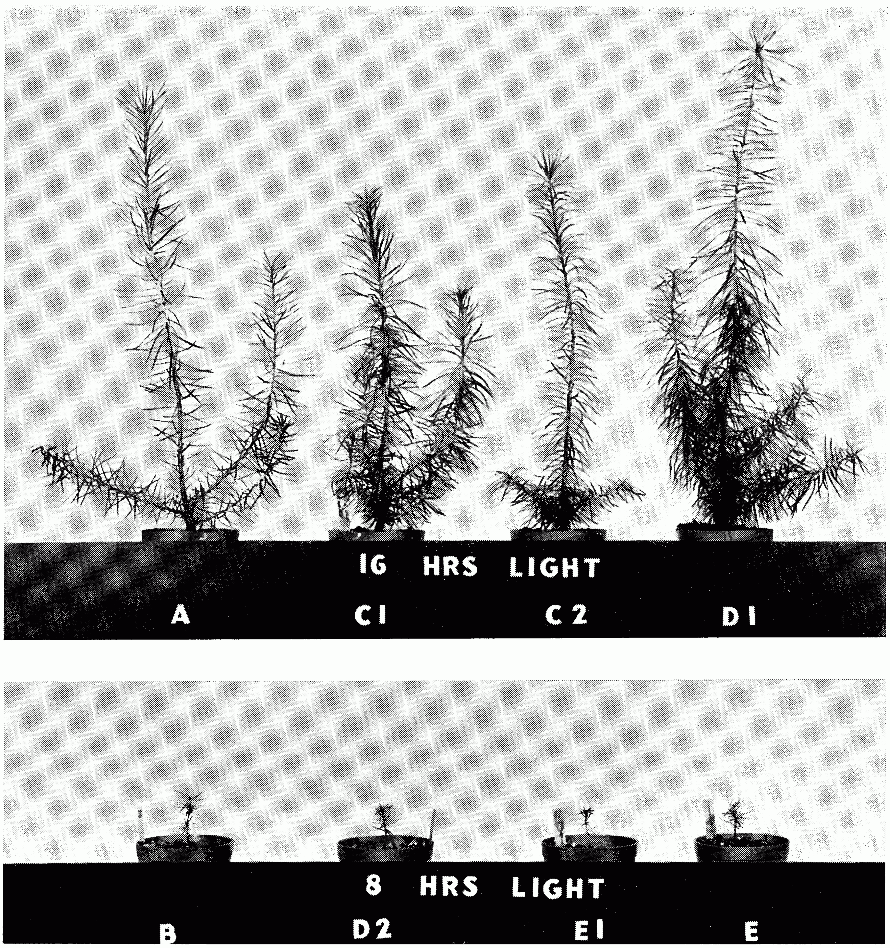

Fig. 17. *Larix decidua,* provenance Strbske pleso, Slovakia (1650 m). One year old seedlings grown in the phytotron for 150 days under long- and short-day conditions. Phototemperature: 20°C, nyctotemperature: 15°C. Rel. humidity: 70%.