PART B

USE OF CONTROLLED ENVIRONMENT FACILITIES

ENVIRONMENTAL CONTROL OF WINTER STRESS TOLERANCE AND GROWTH POTENTIAL IN SEEDLINGS OF *PICEA ABIES* (L.) KARST.

MARTIN SANDVIK
Norwegian Forest Research Institute
1432 Aas-NLH, Norway

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ABSTRACT

Experimental results of artificial regulation of growth cessation, hardening off and growth potential in seedlings of Norway spruce are presented. A temporary drastic shortening of the day (12 hr) toward the end of the growth period when under field conditions daylength was approximately 18 hr, hastened the termination of growth, frost tolerance and storability in early autumn and increased nutrient accumulation within the needles. Irradiance showed a pronounced effect on the rate of hardening-off during short day conditions, and interactions with provenance, night temperature and mineral nutrition were also highly significant on the development of a capacity to withstand prolonged storage. The interaction between irradiance × nutrient concentration was the dominant factor affecting nitrogen accumulation and growth potential.

INTRODUCTION

Within the temperate zone, wintering damage in the nursery and unsuccessful autumn planting constitute major problems and appear to reflect the quality of the seedlings. Among a mass of literature on the subject may be mentioned Lavendar & Wareing (1972) and Hultén & Jansson (1974). Damage during cold storage and distribution is an integral part of the problem complex. Hocking & Nyland (1971) review the literature dealing with storage problems for coniferous seedlings up to 1971; more recently Venn (in prep.) has prepared a new review of literature on these problems.

The most important causes of wintering damage appear to be caused by lack of synchrony between the growth rhythm, and winter vigour, of the seedlings and the climatic conditions to which they are exposed after autumn planting or during cold storage (Magnesen, 1969, 1971, 1972; Sandvik, 1976a; Berglen Eriksen & Gjønnes 1976; Berglen Eriksen 1977; Venn & Chowdry 1976).

The transition to intensive cultivation routines in greenhouses has intensified these problems in the Scandinavian countries. At the same time, the use of greenhouses opens up greater possibilities of controlling environmentally determined qualities in the seedlings than are afforded by cultivation in the open. In a greenhouse one can regulate the supply of light, heat, water and minerals. In order to find out the least resource-demanding combination for such regulation under local conditions, basic knowledge is required of how these factors affect growth cessation, the attainment of winter vigour and the growth potential of the seedling material in question.

In the case of spruce seedlings it is well known that apical growth cessation is primarily a photoperiodic reaction and that different provenances — or ecotypes — have different day-length requirements (Dormling *et al.*, 1968). The critical day-length is in part dependent on the photoperiod during the growth phase, and on changes in the thermoperiod (Dormling,

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1976). A drastic shortening of the photoperiod leads to a quicker cessation of growth than day-lengths close to the critical, and growth temperatures below the optimal (< 20°C) delay the reaction (Heide, 1974; Dormling, 1976).

Bud maturation is retarded by temperatures below the optimal (Dormling *et al.*, 1968), and there is a pronounced interaction between temperature, photoperiod and provenance for the ending of cambial growth and lignification (Heide 1974).

The development of frost tolerance is promoted by low night temperatures, especially during the latter part of the hardening period, and it is hampered by low levels of irradiance during short day conditions (Dormling, 1972; Van den Driessche, 1970).

Sandvik (1968, 1978) reported that height increment in spruce *(Picea abies* (L.) Karst.) seedlings was closely correlated to the nitrogen percentage of the needles in late autumn the previous year as shown in Fig. 1, and several writers have found a positive correlation between autumn fertilising and the growth after planting out in the following spring (Benzian *et al.*, 1974; Solberg, 1968).

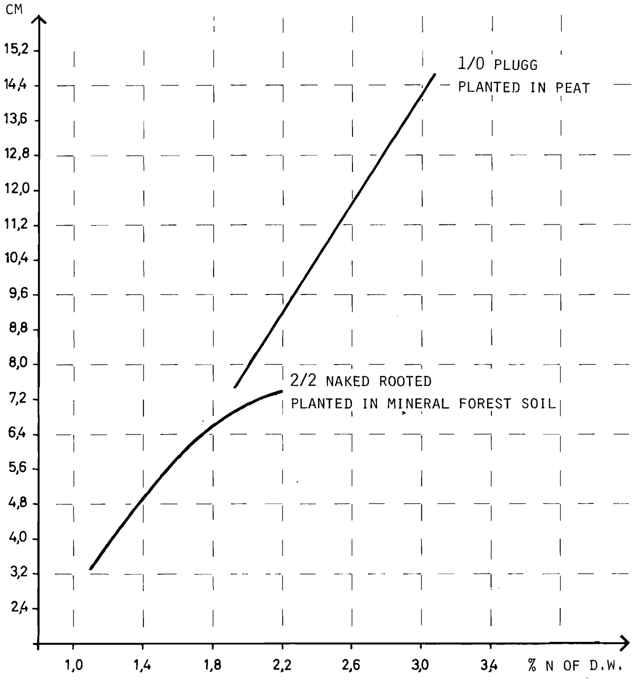

FIG. 1. Height increment compared with nitrogen concentration in the needles in late autumn the previous year.

From this background literature, two alternative methods present themselves as the most likely candidates for regulating the growth rhythm and hardening off spruce seedlings in nursery practice. (A): The simplest solution is to accelerate growth cessation by a drastic shortening of the day-length towards the end of the growth phase, i.e. when the natural length of day is approaching the critical for the provenance in question. The query then is what is the critical duration of day-length regulation. (B): The other alternative is to lengthen the growth period by means of supplementary heat and light until the natural day-length is well below the critical, which allows irradiance levels and thermoperiod to be controlled also during the hardening phase. Important questions here are what limiting values need to be imposed for level of irradiance, temperature and mineral nutrient supply, with regard to the hardening rate and the accumulation of nutrient in the autumn.

In Norway a number of experiments have been carried out with each of these alternatives in the last decade for various provenances of Norway spruce seedlings. The chief results are reported below.

A: SHORT DAY TREATMENT UNDER FIELD CONDITIONS

A photoperiod of 12 hours from 1 August until the natural length of day corresponds to this at the end of September improved survival from 13% to 74% after cold storage from 28 September to 28 May and from 55% to 82% after wintering in the field for the more southerly provenances (Sandvik 1975).

Frost injury to needles after autumn planting was reduced from 63% to 5% after a temporary short day for two weeks in the period from 15 July to 30 August (Sandvik, 1976a), while improved storability after a temporary short day at the beginning of the hardening phase was lost during unfavourable climatic conditions later in the autumn (unpublished).

The start of growth in spring was strongly influenced by two weeks of short days (10 hr) in the previous autumn (Fig. 2). The development of shoots was speeded up by two or three weeks of cool weather in early summer. This effect on the growth rhythm can possibly be traced back to a greater accumulation of nutrient in the autumn due to the short day treatment (Sandvik, 1978).

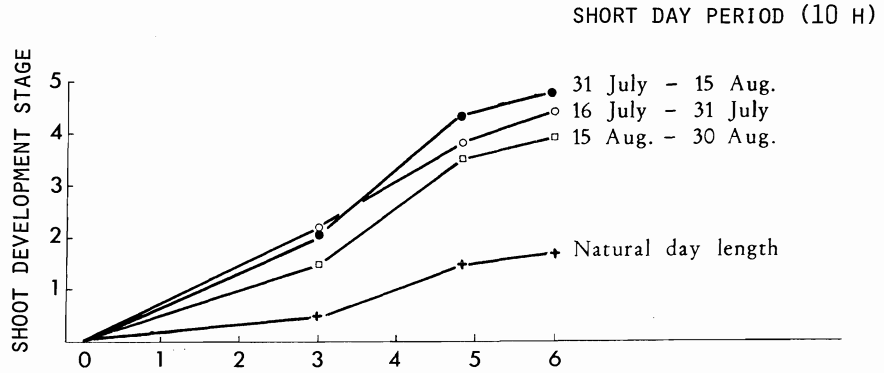

FIG. 2. Effect of temporary short-day treatment in autumn on shoot growth during spring following cold storage during winter. Bud swelled (1) to complete unfolded shoots (5).

B: INTERACTION OF PROVENANCE, IRRADIANCE, NIGHT TEMPERATURE AND NUTRIENT SOLUTION CONCENTRATION DURING SHORT DAY CONDITIONS

These factors and their interrelationships were studied in the phytotron at Oslo University. Spruce seed from three different latitudes were germinated and grown during winter under continuous light (3000 µw/cm^2) at 20°C for 3 months. The growth medium consisted of rockwool immersed in a complete solution of nutrient with a total concentration of 1500 mg/l every other day. After this three month period the seedlings were placed under a 10 hr photoperiod and the effect of the above factors was studied in relation to growth cessation, accumulation of minerals, development of frost tolerance, storability and growth potential during a short day period of nine weeks.

The programme contained the following variables:

Provenance	Latitude	Altitude
Ardenal	58° 30' N	100 m
Steinkjer	64° 00' N	100 m
Rana	66° 10' N	100 m

Irradiance	500 µw/cm^2 1500 µw/cm^2 3000 µw/cm^2
Photoperiod	10 hours
Temperature	20/15° C day/night 20/5° C day/night
Nutrient solution concentration:	1500 mg/l 150 mg/l

Amounts and proportions of elements in the nutrient are described elsewhere (Sandvik, in prep.).

The frost tolerance was tested by exposing seedling samples once a week during the hardening period to a fall in temperature from 20° C to −20° C in the course of 24 hours, and a corresponding rise in the next 24 hours. Frost damage was determined visually after 2 weeks in a growth chamber. After seven and nine weeks of this short-day treatment, other groups of seedlings were stored at −3° C for seven months. The growth potential was determined in the last groups of seedlings by the dry weight of new shoots after one growth season under field conditions in unfertilised peat, the seedlings being transplanted immediately after the end of the hardening period in the phytotron in early summer on 26 June.

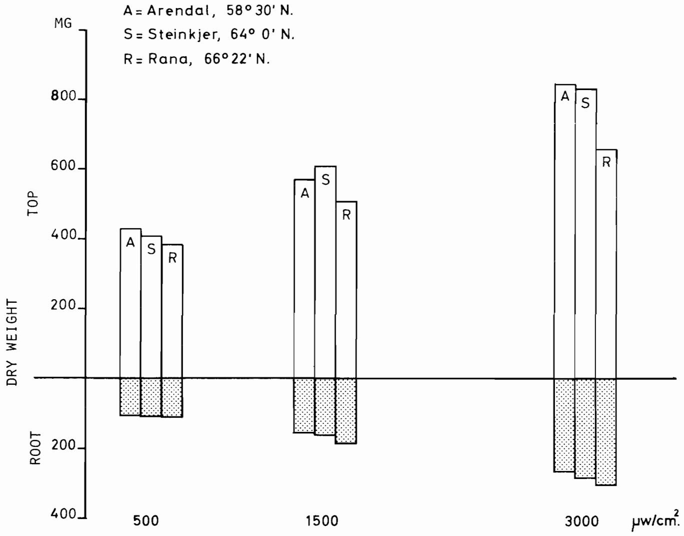

FIG. 3. Dry weight per seedling at the end of the short-day period when grown at different levels of irradiance µw/cm^2.

A number of the main results are presented in Figs. 3-7. A fuller analysis of these experiments is being prepared (Sandvik, in prep.).

The dry weight of the seedlings was greatly influenced by the level of irradiance during the hardening period (Fig. 3). In this period the top weight was doubled and the root weight trebled from the lowest to the highest level of irradiance. The root weight was most strongly influenced in the most northerly provenance. It is well known, moreover, that the level of irradiance affects root growth more than top growth even under natural growing conditions (e.g. Hagem, 1947; Sutton, 1969).

The mineral concentration in the needles at the end of the hardening period was strongly marked by the interaction of irradiance × concentration of nutrient solution in all the provenances. The effect of the increased nutrient supply increased with increasing irradiance. Fig. 4 shows an example of this for nitrogen. The mineral concentration rose successively from the southernmost to the northernmost provenance.

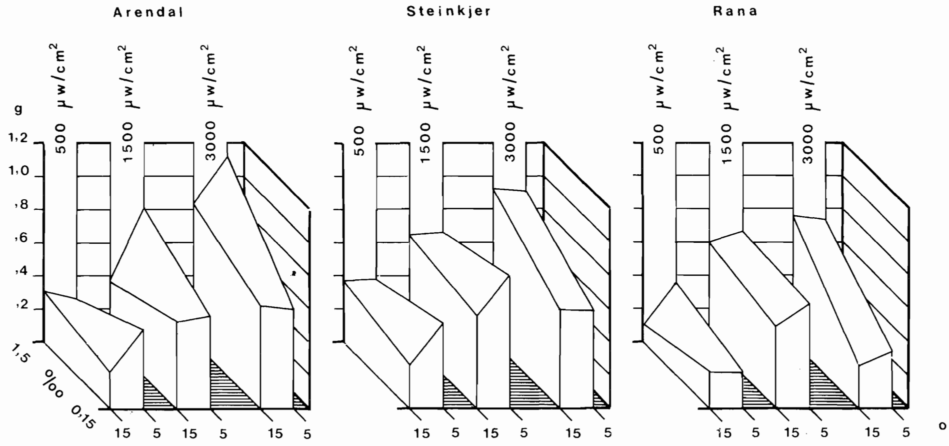

FIG. 4. Nitrogen in mg/g needle fresh weight at the end of the short-day period as affected by irradiance µw/cm², nutrient concentration parts per thousand and night temperature (°C).

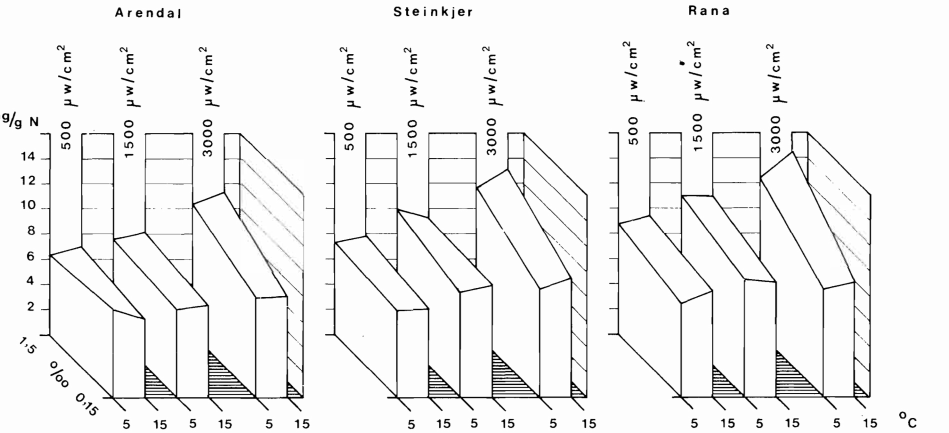

FIG. 5. Dry weight per seedling of second year shoot formed under field conditions as affected by irradiance, nutrient concentration, and night temperature during the previous short-day period.

The growth potential was influenced in a way corresponding to the nitrogen concentration in the needles within the various provenances (Fig. 5). A high irradiance level was a prerequisite for achieving the effect of increased concentration of nutrient solution and *vice versa*. In the second growth period the relation between the provenances was affected by the earlier growth cessation of the more northerly provenances.

Frost tolerance also developed more quickly in the provenances originating further north (Fig. 6). This must be seen as a genetically conditioned difference in speed of hardening after induced growth cessation. The level of irradiance had great influence on the development of frost tolerance in all the provenances. Low night temperatures speeded up this development, especially with lower irradiance levels. No clear difference between the nutrient concentrations however could be shown in this respect.

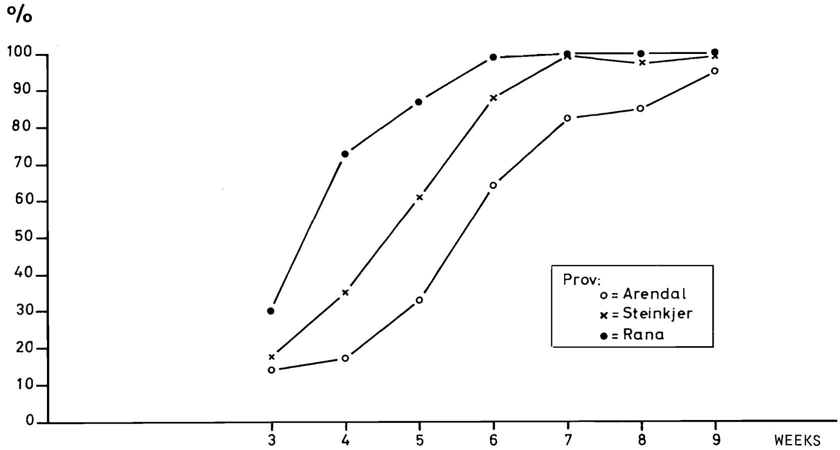

FIG. 6. Percentage undamaged needles after freezing to −20°C at different times during the short-day period. Seedlings from high irradiance.

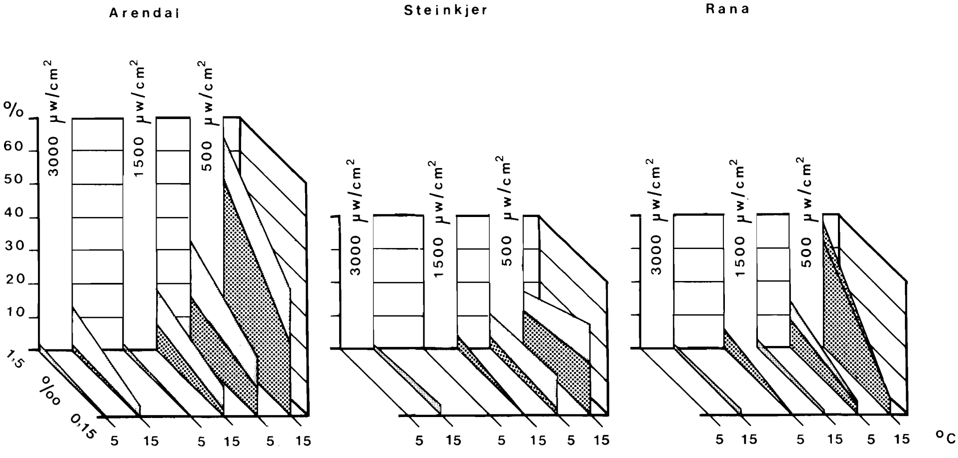

FIG. 7. Percentage of needles damaged during storage at −3°C for 7 months after 7 (pale hatch) and 9 (dark hatch) weeks of short-day treatment before storage.

A high nutrient solution concentration caused the roots of seedlings to die in the course of seven months storage irrespective of the rest of the hardening programme. Needle injury increased with nutrient concentration at the lowest irradiance level during storage for two of the provenances (Fig. 7). The lengthening of the hardening period from 7 to 9 weeks contributed to a reduction of needle injury in the two more southerly provenances, but not in the northernmost (Rana). This also reflects differences in the hardening rate between the provenances.

Survival 4 weeks after planting out of seedlings in growth chambers is shown in Table 1. The seedlings were not capable of surviving cold storage at the lowest level of irradiance provided during hardening. A low night temperature had in other respects a positive effect on storability, and compensated for higher irradiance levels at higher night temperatures in the range 1500 — 3000 µw/cm².

TABLE — 1. Survival perçentage of stored seedlings after 4 weeks in the growth chambers.

Irradiance µw/cm²	500		1500		3000		Hardening period (weeks)
Nutrition mg/l	150		150		150		
Night temp. °C	5	15	5	15	5	15	
Arendal	0	0	82	15	100	95	7
	0	0	100	27	100	100	9
Steinkjer	3	0	100	52	100	63	7
	10	0	100	100	100	100	9
Rana	20	0	100	98	100	100	7
	12	3	100	100	100	100	9

CONCLUSIONS

A temporary, drastic shortening of the photoperiod towards the end of the natural growth period hastened the termination of growth, and increased frost tolerance and storability of spruce seedlings in early autumn.

Improved storability was partly lost in poor light conditions (e.g. cloudy weather) at temperature above 0° C following frost in autumn.

A temporary short day increased the accumulation of nutrients and speeded up the start of growth in the next spring. This effect, however, appeared to be very dependent on light and temperature throughout the whole hardening phase.

The higher nutrient concentration of the growth medium caused root die-back during winter cold storage.

During short day conditions the increase in the dry weight of the seedlings was highly dependent on the level of irradiance provided.

A strong interaction irradiance level × nutrient concentration was the predominant factor in nitrogen accumulation and growth potential.

Irradiance had a marked effect on the rate of hardening off. Frost tolerance and storability responded strongly to interactions of irradiance × night temperature and irradiance × provenance × nutrient concentration respectively.

Photoperiod and irradiance, as well as temperature and nutrient concentration, should be controlled during a 2-3 months hardening period if full control is to be achieved of winter vigour and growth potential of the seedlings.

The level and quality of supplementary light needed during the hardening period should be clarified in relation to localities and provenances in question.

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