EVALUATION OF A MINI-CONTAINER ACCELERATED TRANSPLANT SYSTEM : THE BLACK SPRUCE WINTER CROP

by

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ABSTRACT

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The effects of four factors on nine attributes of black spruce (*Picea mariana* (Mill) B. S. P.) seedlings were investigated. The seedlings were produced under an accelerated transplant system that used a 6 ml Castle and Cooke container. The experiment had two stages. The first stage investigated the effects of the duration of the greenhouse phase (DURATION), outplanting date (OUTPLANTING DATE) and acclimatization of seedlings to outdoor environmental conditions before transplanting (ACCLIMATIZATION) on seedling attributes at the end of the greenhouse phase. The seedling attributes were height and the number of roots outside the growing medium. The second stage investigated the effects of these same factors plus shade in the transplant beds (SHADE) on seedling attributes during, and at the end of, the first growing season. Seedling mortality in the transplant beds and bud-set were monitored during the growing season. Total height, top dry weight, root dry weight, bud diameter, and root collar diameter were measured at the end of the growing season. Analysis of variance was used to investigate the effects of the factors on the response variables. The major conclusions were these. The greenhouse cultural factors studied affected both the morphological state of the seedling and its physiological fitness at the time of transplanting. DURATION was especially influential in this regard. At 7 weeks the seedlings were small and experienced high mortality if transplanted. By 10 weeks the seedlings were larger and survived the transplanting operation well, but they were predisposed to set bud soon after transplanting. Thirteen-week-old seedlings were even larger, and were beginning to outgrow their containers. They survived transplanting well, but were even more predisposed to set bud. DURATION effects also influenced the morphological state of the transplants at the end of the first growing season. Seedlings that set bud early had short, stocky stems with large buds and a high root:top ratio. Seedlings that did not set bud early had tall slender stems with small buds and a low root:top ratio. OUTPLANTING DATE, SHADE and ACCLIMATIZATION also affected the crop and interacted with DURATION and one another. The results provide insight into

the first year response of seedling grown under the Castle and Cooke accelerated transplant system to cultural factors over which nurserymen have control.

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CHAPTER 1

INTRODUCTION

Millions of seedlings are produced each year for reforestation. These include bareroot seedlings (e.g., 3+0), bareroot transplants (e.g., 1.5+1.5), container seedlings, and container plugs or accelerated transplants (e.g., plug+1). The last stock type is produced through a relatively new seedling production system called an accelerated transplant system. This system combines the techniques of both conventional bareroot and container seedling production systems.

Accelerated transplant production includes two stages. In the first stage seedlings are grown in a greenhouse as container seedlings. In the second stage the container seedlings are transplanted to nursery beds and grown as conventional bareroot transplants.

Although the accelerated transplant system is promising, it is still in a developmental stage in terms of both refining the system at the nursery and assessing the plantation potential of the stock (Smith 1982). Thus, research about this system is of great interest and importance.

In the last few years the Thunder Bay Forest Tree Nursery has been interested in testing a new container system for the accelerated transplant production of black spruce (*Picea mariana* (Mill) B. S. P.). This container system, called the Castle and Cooke system, has been successfully used for vegetable seedling production in the United States. Since the Castle and Cooke system has some advantages over other containers, the nursery staff felt that the system had potential for producing high quality accelerated transplants at a low cost.

My research has been to evaluate the Castle and Cooke system for accelerated transplant production of black spruce. My study was limited to the investigation of the effects of 4 cultural factors on the first-year growth of black spruce seedlings grown under the Castle and Cooke system. The factors and their levels investigated were:

1) duration of the greenhouse growth period (7, 10 and 13 weeks),

2) acclimatization to outdoor environmental conditions before transplanting (with and without one week period of acclimatization),

3) transplanting date (June 1, 11, and 21), and

4) shade over the transplant bed (with and without partial shade).

The experiment had two stages. In the first stage, I used a 3 x 3 x 2 factorial experiment, executed in a completely randomized design, to investigate the effects of the first 3 factors associated with the greenhouse phase on the state of the crop at the time of transplanting. Two seedling attributes were measured at the end of this phase of the experiment: total height and a measure of the amount of root outside the growing medium.

In the second stage, seedlings from the greenhouse experiment were transplanted outside, and grown to the end of the first growing season. The experiment was executed in two randomized complete blocks. In addition to the three factors carried forward from the greenhouse phase, the effect of the 4th factor, shading the transplant beds (SHADE), was also studied. Mortality and bud-set were monitored during the growing season. Five seedling attributes measured at the end of the growing season were: total height, top dry weight, root dry weight, bud diameter, and root collar diameter.

The analysis of variance was used to investigate the effects of cultural factors on the response variables. Where the correlation between response variables was 0.5 or higher, multivariate analysis of variance coupled with canonical variates analysis was used to investigate and interpret the multivariate response.

CHAPTER 2

LITERATURE REVIEW

CLASSIFICATION AND COMPARISON OF NURSERY PRODUCTION SYSTEMS

Nursery production systems may be classified according to the stock types produced. One class contains systems designed to produce bareroot stock, and the second class, container stock. Bareroot stock is produced from both conventional bareroot and accelerated transplant systems.

Conventional Bareroot System

This system has played an important part in reforestation. It has been well documented (Aldhous 1972, Armson and Sadreika 1979, Driessche 1969, Duryea and Landis 1984, Stoeckeler and Jones 1957).

There are two ways to produce conventional bareroot stock. One method is to sow the seeds in the nursery beds, and then allow seedlings to grow undisturbed until harvesting. Stock produced in this way is called bareroot seedling (e.g., 2+0). The other method is to sow seeds in nursery beds and later in the rotation transplant the seedlings to transplant beds. Stock produced in this way is termed transplant (e.g., 1.5+1.5).

In 1980, 2-year-old seedlings (2+0) (mainly Douglas-fir) accounted for 79 percent of 278 million seedlings at 21 nurseries in the Pacific Northwest of the United States and Canada (Duryea and Landis 1984). Seedlings cost less than transplants to produce. However, transplants have some advantages over bareroot seedlings. The nurserymen can cull seedlings at transplanting time. Transplanting can result in higher quality seedlings. In black spruce bareroot transplants (1+2) were consistently shorter with a lower shoot:root ratio, larger dry weight and a larger root area index than their bareroot seedling counterparts (3+0) (Mattice 1982). Similar differences between stock types existed with white spruce (Mattice 1982). Field comparisons indicate that transplants perform better in both survival and height growth (Mattice 1982, Mullin 1980).

Current plans call for 77 percent of the spruce nursery stock to be produced as transplants (Cayford 1978), and the proportion of spruce transplants to bareroot seedlings is still growing in Canada (Mullin 1980).

Container Production System

Throughout North America, a dramatic increase in the use of containerized tree seedlings in reforestation practice has taken place during the past decade (Reese and Scarratt 1982). In Canada container-grown seedlings totaled 17 million in 1972, 140 million in 1981, and 220 million estimated in 1983 (Kinghorn 1982). This will continue to increase in the short term (Reese and Scarratt 1982). In Ontario (OMNR 1974 and 1984), containerized seedling production has increased rapidly in the past few years (Table 1).

Table 1. Statistics of seedling production from 1974 to 1984 in Ontario.

Year	Bareroot (000)	Container (000)	Total (000)	Container/total (%)
1974	65362	3402	68765	4.9
1975	59794	3148	62934	5.0
1976	50945	5347	56292	9.5
1977	45981	4292	50273	8.5
1978	48292	5461	53753	10.2
1979	52928	5487	58415	9.4
1980	61453	7945	69398	11.4
1981	65360	10497	75857	13.8
1982	69448	13951	83399	16.7
1983	63660	16465	80126	20.5
1984	67473	40000	107473	37.2

Techniques for rearing container stock have been outlined at great length (e.g., Carlson 1979, Low 1975, Kay 1975, Tinus and McDonald 1979). Container seedling production systems have several advantages over conventional bareroot seedling production systems (Stein, Edwards and Tinus 1975, Mann 1977, Stein and Owston 1976, Brissette 1982, Heeney 1982, Bailey 1982). These are:

1. extending the planting season,
2. making better utilization of labor and equipment,
3. achieving greater production and planting efficiences,
4. making the best use of valuable seeds and reducing seed requirement,
5. producing seedlings of some species more readily,
6. producing seedlings more quickly on more certain and flexible schedules, and
7. protecting root system while seedlings are in

transit and during planting.

Container production systems also have some drawbacks in comparison with the conventional bareroot seedling production systems (Stein, Edwards and Tinus 1975, Johnson 1982, Reese and Scarratt 1982, Scarratt 1974). In summary, the disadvantages are that container stock production:

1. requires a higher level of technical knowledge,
2. demandes more day-to-day attention,
3. accelerates the incidence and effects of disease, nutritional imbalance and other ailments,
4. is more expensive,
5. requires high quality seeds, and
6. container planting with smaller seedlings than than bareroot seedlings is best suited to easy, dry sites of low productivity and supporting light to moderate vegetation of low competition vigor.

In recent years, the total seedling production due to both conventional bareroot and container production systems has increased in response to the expanded reforestation programs in Canada and throughout the world. Interest in containerization, however, has increased faster than in conventional bareroot. In Ontario, total seedling production increased from 68,765,000 in 1974 to 107,473,000 in 1984 (Table 1). In the same period containerized seedlings increased from 5 percent to 37 percent of the total seedlings produced, and bareroot production remained rather stable. In 1983, the estimated area planted with container-grown stock accounted for 45 percent of the total in Alberta, Ontario, Quebec, New Brunswick, and Nova Scotia (Smyth and Ramsay 1982). Today, both conventional and container stocks are popular.

The results of field performance trials of container-grown stock and conventional bareroot stock are not consistent. Some authors report that container-grown seedlings survive and grow better than bareroot seedlings (e.g., Stein and Owston 1976 and 1977, Tinus 1976, Hahn 1976, Ball and Brace 1982, Gardner 1982, Krause 1982, Mattice 1982, Vyse 1982). However, some of the same authors and others report contrary results (e.g., Scarratt 1974 and 1982, Stein and Owston 1976, Gardner 1982, Krause 1982, McClain 1982). Both bareroot and container stocks are important in reforestation programs. Each type of the stock has advantages and disadvantages, and the best programs involve a judicious use of both types (Dancause 1982).

Accelerated Transplant System

The accelerated transplant system is a new method to produce bareroot seedlings. It is a hybrid method combining recently developed containerized seedling production methods with conventional bareroot transplant production methods.

Accelerated transplant production occurs in two stages. In the first stage seedlings are grown, usually in containers, in greenhouses. In the second stage the seedlings are transplanted to nursery beds where they are grown without further disturbance until harvesting as conventional bareroot transplants. The final products are termed plug+x. X is determined according to how many growing seasons or months the seedlings are grown in the nursery beds. Plug+1 production has been well described by Hahn (1984).

The accelerated transplant system utilizes both container and bareroot stock production facilities and technologies. It has the advantages and disadvantages of both systems. The advantage over the other two systems is that high quality seedlings are produced in a shorter rotation. On the negative side, the accelerated transplant method

1. requires greater expertise because it is often difficult to coordinate both technologies,
2. may result in production failure or low quality seedlings if problems occur at either one of the stages, greenhouse and transplant bed, and
3. may be more expensive.

In recent years, accelerated transplant systems have been tested at several nurseries. These include Thunder Bay Nursery, Swastika Nursery, Kemptville Nursery, Orono Nursery, Dryden Nursery, and Maple Nursery in Ontario (Smith 1982), and Ray Leach Nursery and Tyee Tree Nursery in the United States (Hahn 1984). However, there is not much information dealing with seedling performance of the system.

According to OSU (Oregon State University) nursery Survey, plug+1 production reached about 6.5 million seedlings in the Northwest United states and Canada by 1980-about 2 percent of the total seedling production in the Northwest for that year (Duryea and Landis 1984). Since the 1980 tabulation, plug+1 production has achieved greater acceptance in the Northwest and other areas (Hahn 1984).

Excellent bareroot transplants can be produced from container-started seedlings (Kinghorn 1974). Skeates and Williamson (1979) reported that two-year-old container-plugs were comparable to the three-year-old plants grown either as 3+0 seedlings or 1+2 transplants of black spruce. Hahn (1984) stated that the height of plug+1 seedlings at field planting time was comparable to that of the 2+1 seedlings of Douglas-fir, but their root caliper, branch characteristics and total root mass were considerably better than those of 2+1, 2+0, and other containerized stocks in the experiment. At Swastika Nursery large black spruce accelerated transplant stock was produced in two years (Smith 1982).

Based on the limited results after outplanting, the field performances of the accelerated transplant system have shown some encouraging results. Hobbs, et al. (1982) reported that one year after outplanting, Douglas-fir plug+1 stocks had higher survival and better shoot and root growth than 2+0 bareroot stock. They survived as well as 1+0 container stock, but their height increment was higher than 1+0 container stock. Hahn (1984) showed that plug+1 seedlings had good survival and height growth on the typical Northwest transplant sites in the United States. His results also showed, on these sites, a comparable or better total benefit:cost ratio than any other seedling types currently in use.

CONTAINERS AND MEDIA

Many containers have been tested and used in tree seedling production (Sutherland 1984). However, the common types are Japenese paperpot, multipot, BC/CFS styroblock, and Spencer-Lemaire fold-up tray. New containers appear every year, but only a few are found to be successful (Luchkow 1982).

Container media may be divided into two major groups based on their structure and stability. The first type of medium consists of different proportions of soil, peat moss, softwood barks, coal cinders, and vermiculite. These are used in the containers mentioned above. Since the medium is loose, disruption of the root systems of the seedlings during transplanting is unavoidable if containers are removed at planting. In order to remove the plugs from the containers and to reduce damage at planting, seedlings have to grow large enough so that the roots themselves bind the medium. If containers are not removed at planting, as is the case with Walters bullets, paperpots and Ontario tubes, seedling growth and survival may be reduced because the container wall prevents seedling root egression after planting (Gardner 1982, Mattice 1982, McClain 1982, Segaran, et al. 1978, and Day and Cary 1974).

A second type of the medium is represented by the Castle and Cooke system. The medium is dimensionally a stable mixture of peat moss and an inert binder. The Castle and Cooke system has been used successfully for large scale vegetable seedling production in the United States. It has attracted the interests of forest tree nurserymen because of its advantages over the other container systems which use loose media. First of all, the special planting medium allows the seedlings to be extracted and planted with a minimum of disruption to the root system. Thus, seedlings can be transplanted before they become pot-bound. Secondly, because of the stable medium, the system leads to a highly mechanized nursery operation. Thirdly, because the container cavities are small, 6 ml, large quantity of seedlings can be produced in a small space. To date, however, the Castle and Cooke system has received only limited testing in forest nurseries. It remains to be seen whether the system is suitable for accelerated transplant production.

SEEDLING BUD DEVELOPMENT OF BLACK SPRUCE

Bud development of black spruce seedlings is highly correlated with short photoperiod. Colombo, (1982 a, b) reported that shoot elongation ceased and bud development initiated in the first week of an 8-hour photoperiod. After 8 weeks of short days bud development was virtually complete. In another study they found that the critical daylength for bud-set in northeastern Ontario black spruce is 14.5 to 15 hours. (Colombo, Webb, and Glerum 1982). The critical day length also increases with the length of free growing time (Tinus, R.W., in lett., 15 july 1986). Long days at low temperature (day/night: 10/5°C) did not produce visible buds (D'Aoust and Cameron 1982). Lower light intensity induced bud development (Arnott 1979, Arnott and Mitchell 1982). Pollard and Logan (1977) reported that bud morphogenesis in spruce is subject to environmental modification. They also found that temperature and, to a lesser degree, soil moisture and light intensity, are among the most important factors affecting seedling bud development.

CHAPTER 3

GENERAL METHODS

OVERALL ORGANIZATION OF THE EXPERIMENT

The experiment was conducted at the Thunder Bay Nursery in two stages. The nursery is located 20 km west of Thunder Bay at latitude 48°25'N and longitude 89°15'W.

In the first stage, black spruce seedlings were grown in Castle and Cooke flats. The effects of three factors of greenhouse culture on seedling development were studied. The factors were: 1) the length of time the crop spent in the greenhouse (DURATION), 2) the date the crop was transplanted outdoors (OUTPLANT DATE), and 3) a treatment to acclimatize the crop to outdoor conditions prior to transplanting (ACCLIMATIZATION). Response variables measured at the end of the greenhouse period were height (H1), and the number of roots outside the growing medium in different length categories: less than 1, 1-2, 2-3, 3-4, and greater than 4 cm (N1, N2, N3, N4, and N5) outside the growing medium. The total number of roots (N) was the summation of N1, N2, N3, N4, and N5. Details of the greenhouse experiment are presented in the next chapter.

In the second stage the black spruce seedlings from the greenhouse experiment were transplanted outdoors and allowed to grow for the remainder of the growing season. Besides the three factors of the greenhouse culture, the effects of shade (SHADE) on transplanted seedlings were also investigated. Shade was provided by snow fences. Response variables measured during the growing season included survival ratio (SR) and bud-set ratio (BSR). Response variables measured at the end of the growing season included: top dry weight (TDW), root dry weight (RDW), height (H2), root collar diameter (RCD), and terminal bud diameter (BD). Details of the transplant bed experiment are presented in Chapter 5.

ANALYTICAL METHODS

The Q-test (Burr and Foster 1972) was used to examine the homogeneity of variance of all response variables (Anderson and Mclean 1974, p22-23). Variance stabilizing transformations were used as indicated by the Q-test. Transformed variables were used in subsequent analyses of variance, although original values are reported in the Results and Discussion chapters of this thesis.

Pearson correlation analysis was used to examine the degree of linear correspondence between response variables in order to determine whether to use univariate or multivariate analytical methods for different subsets of variables. My criterion for this decision was as follows. If all correlations between a given variable, X, and all the other variables were less than 0.50, then X was treated as an independent variable and a univariate analysis of variance was used to investigate treatment effects on X. Otherwise, a multivariate analysis of variance was used to investigate treatment effects on the vector of intedependent responses to which X belongs.

Univariate analyses of variance were performed at the 5 percent level of significance. The Student-Newman-Keuls test (SNK-test) was used to test the differences between means. This method allows the investigation of all possible pairs of means in a sequential manner, has good power (1-Beta) and keeps the alpha level constant for the investigation of all means (Anderson and McLean 1974).

The multivariate analysis of variance, where its use was indicated, was performed in three stages. These are outlined here as briefly as possible. Readers interested in greater detail will find additional explanation as well as numerical examples in the Results section of Chapter 5.

In stage one of the multivariate analysis, an overall multivariate analysis of variance was performed to identify the sources of variation that were statistically significant at the 5 percent level on the multivariate response vector.

In stage two, those sources for which the null hypothesis was rejected were examined further in order to discover the nature of the response. Canonical variates analysis, a generalized discriminant analysis, was used for this purpose. Briefly stated, the procedure was to sort the response vectors associated with individual experimental units according to the source of variation being examined. In the case of main effects, the groups thus formed corresponded to the levels of the factor in question. In the case of interaction effects, the groups corresponded to the cells in the interaction table. Two examples illustrate the procedure from this point in the analysis.

The first example illustrates the case where the number of groups is less than the number of variables. Suppose that the null hypothesis that DURATION has no effect on, say, a 5-dimensional response vector, has been rejected under the MANOVA. In the context of this thesis, such a vector might consists of an ordered list of 5 measured seedling attributes such as H2, TDW, RDW, BD, and RCD. The problem is to investigate the nature of the DURATION response in greater detail.

The effect of DURATION is reflected in the placement of the centroids of the 3 groups of treatments in 5 dimensional space (5-space). The 3 groups are formed by sorting the response vectors associated with individual experimental units according to the 3 levels of DURATION, 7, 10, and 13 weeks in the greenhouse. One cannot see into 5-space directly, but, fortunately, it is not necessary to do so in this particular case. This is because, for purely geometric reasons, any 3 points in 5-space (or any hyperspace for that matter) lie in a subspace of dimension 2 or less. For example, the 3 centroids might lie in a plane, a subspace of dimension 2, or on a line, a subspace of dimension 1. They might even share a point, a subspace of dimension 0, except for the fact that this case is equivalent to the null hypothesis that DURATION has no effect and this is assumed to have been rejected through the preceeding MANOVA.

The problem of examining the multivariate response to DURATION consists of 2 interior problems. They are 1) to discover the effective dimension of the subspace defined by the 3 DURATION centroids, and 2) to discover linear equations that define a set of orthogonal axes of the subspace in terms of the measured variables. These problems both have routine solutions.

First, canonical variates analysis is used to find a set of orthogonal axes for the subspace of interest. In the case of DURATION, there will be 2 such axes. The axes are defined by an equal number of canonical discriminant functions (CDF). These are linear compounds of the response variables with special properties as follows. The CDF's are extracted one at a time such that the first, CDF1, is the linear compound of the respose variables that best discriminates between the 3 levels of DURATION. CDF2 is then extracted such that a) it is orthogonal to CDF1, and 2) in combination with CDF1, it gives the best 2 dimensional discrimination between the 3 groups.

Second, once the maximum number of CDF's are in hand, in this case 2 CDF's, any one of several criteria may be used to determine how many of these are really necessary to account for the statistically significant pattern in the data. To appreciate why this is necessary, consider that 3 centroids in 5-space will virtually never lie exactly on a line. They might easily, however, lie close enough to a line so that the residual variation is no greater than would be expected due to experimental error. Possibilities such as these must be systematically tested. To do so, I used a procedure based on the Wilkes' lambda statistic to discover the effective dimensionality of the subspace. Hull and Nie (1981) refer to the procedure I used as "dimension reduction analysis". Chatfield and Collins (1980) discussed a similar procedure for testing "the dimensionality of the alternative hypothesis".

In stage 3, the centroids associated with the 3 levels of DURATION were plotted in the canonical variates-space (CV-space) of appropriate dimension. The result is to map the multivariate respose from 5-space, where it cannot be easily visualized, into a 1- or 2-space canonical variates plot (CV-plot) defined by the first, or the first and second, canonical variates functions. Once the CV-plot is at hand, the radius of the confidence limit centroids associated with a given effect is calculated by the following formula:

$$R=(X_{0.05,m}/(r \times n))^{1/2}$$

where: m = effective dimensions,

0.05 = significant level,

r = error degree of freedom,

n = the number of observations per mean.

An example of the calculation is given in Appendix 21. The radius is used to construct a confidence region for multiple comparison of the centroids of the effect. Then the nature of the response can be visualized and given a biological interpretation.

The second example illustrates the case where the number of groups is more than or equal to the number of response variables. Suppose that the null hypothesis that the DURATION x OUTPLANT DATE (D x O) interaction had no effect on a 5-dimensional multivariate response vector has been rejected under MANOVA. The problem is to investigate the nature of the D x O interaction in greater detail.

The D x O interaction is defined by 9 factorial combinations of the DURATION and OUTPLANT DATE. The effect of the interaction is reflected in the placement of the centroids of these 9 groups in 5-space. In this case, the 9 group centroids must lie in a space of dimension 5 or less. The effective dimension of the data cannot exceed 5 since that is the total dimension of the response-space. As in the previous example, canonical discriminant analysis was used to discover the 5 canonical discriminant functions. Dimension reduction analysis was then used to discover the maximum number of these that are necessary to describe the statistically significant pattern in the data. Finally, the 9 centroids were plotted in the minimum CV-space to provide a low-dimensional approximation of the multivariate response. In at least some cases, this led me to a biological interpretation of the response that might not have been recognized in the original response-space.

CHAPTER 4

GREENHOUSE EXPERIMENT

MATERIALS AND METHODS

Materials and Operations

The greenhouse phase of this study was conducted on raised benches in a Vary-type greenhouse. The dimensions of the greenhouse were: length 43.9 m (144 ft), width 9.8 m (32 ft), and height 4.9 m (16 ft). The greenhouse was covered with an inflated, double layer of polyethylene and had insulated lower sidewalls. Heat was provided by 2 gas-fired furnaces and ventduct tubing. Ventilation was accomplished by means of 3 large exhaust fans located at the south end of the greenhouse and 3 intake vents at the north end. Ventilation was regulated by means of an automatic, 4-stage control system. Water and fertilizer were provided through an automatic irrigation system equipped with a Moses fertilizer injection system.

Seeds were sown in Castle and Cooke flats. Each flat was a styrofoam block with a 20-by-20 grid of planting cavities. The cavities were 6 ml in volume and pass completely through the block so that seedlings could be pushed out from below when they were ready to be planted. This also allowed the roots of the seedlings to be air-pruned. Each cavity was filled with Castle and Cooke's patented planting medium, a dimensionally stable mix of peat moss and a inert binder. Castle and Cooke flats are produced in a variety of sizes. The unit used in this study was based on a 32 x 32 x 4.5 cm styrofoam flat with individual planting cavities with a diameter of 1.3 cm and a depth of 4. cm.

The black spruce seeds used in this study were randomly obtained from those that remained after sorting on a gravity table.

The greenhouse study was a 3 x 3 x 2 factorial experiment involving the following factors and levels: DURATION of the seedlings in the greenhouse (7, 10 and 13 weeks); OUTPLANT DATE (June 1, 11, and 21); and ACCLIMATIZATION to outside environmental conditions (with and without one week before planting). The combinations of DURATION and OUTPLANT DATE resulted in 9 sowing dates (Table 2). The total number of treatment combinations was eighteen. The experiment was executed as a completely randomized design with 4 replicates. The experimental units were the individual Castle and Cooke flats of seedlings.

Table 2. Nine sowing dates in 1984 that resulted from the factorial combinations of DURATION x OUTPLANT DATE

	Duration (weeks in greenhouse)		
Outplant date	7	10	13
June 1	April 13	March 23	March 2
11	April 23	April 2	March 12
21	May 3	April 12	March 22

Eleven flats were sown by hand on every sowing date; one of them was for refilling blank cavities in the other 10 flats. Two of them were randomly chosen and used as replicates in the transplant bed experiment with each in one of the two blocks. Care was taken to sow one seed in each cavity. In the greenhouse the study area was subdivided into three adjacent areas. The freshly seeded flats were placed at random in the first area where they received water but no fertilizer for the first two weeks. At the end of the week two, the flats were moved to the second area where again they were arranged at random. Here, they received water with 75 ppm of N, 10-50-10 fertilizer for two additional weeks. Finally, the flats were moved to the third area and arranged at random. Here, 100 ppm of N, 20-20-20 fertilizer was applied once a day through the watering system. Flats were heavily watered when the container surface was dry. The temperature was set at 25°C during the 18 hour days and 18°C during the 6 hour nights. Forty days after seeding, if there were more than one seedling in a cavity, all but the largest were removed. At the same time, refilling was conducted so that the number of seedlings in each flat was almost the same for the flats from the same sowing date.

One week before each outplanting date, 5 flats of each duration level were randomly chosen from each sowing date. These flats were moved out of the greenhouse to an acclimatization area. The other 5 were kept in the greenhouse. The acclimatization area was surrounded by a snow fence and covered with shade cloth to provide partial protection from wind and direct sunlight. Flats in the acclimatization area were watered as needed and fertilized on the same schedule as those that remained in the greenhouse.

On each outplanting date, the 10 flats in each duration treatment were planted outdoors. Five of them were outplanted directly from the greenhouse and the other five, from the acclimatization area.

Data Collection

On each outplanting date, 12 seedlings were randomly sampled from each flat. Top height was measured in milimeters with vernier calipers. The seedlings were pushed out from the flat and the roots outside the growing medium of each sampled seedling were sorted into 5 classes according to length: 0-1, 1-2, 2-3, 3-4, and >4 cm. Sample estimates of the average height and average number of roots in each class were calculated for each flat, and these values were used in the subsequent analyses.

RESULTS

Test of Homogeneity of Variance

Q-test results are given in Table 3. For the variables N, N1, N2, N3, N4, and N5, homogeneity of variance was accepted at the 1 percent level of significance, and therefore, no transformation was indicated. For the variable height at planting time, H1, several variance stabilizing methods were tried in an attempt to achieve homogeneity of variance at 1 percent level of significanc level, but all failed to reach this goal. However, the transformation 1/H1 gave the best result of the transformations tried, and was therefore used.

Table 3. Q-test results of homogeneous variance for height (H1) and root variables at planting time.

Variable[1/]	Experimental Q-value[2/] original	transformed	Method
H1	0.1700	0.1568	1/H1
N	0.0999		
N1	0.0970		
N2	0.0989		
N3	0.1053		
N4	0.1124		
N5	0.0940		

1/ N1, N2, N3, N4, and N5 are the number of roots of different length classes: 0-1, 1-2, 2-3, 3-4, and longer than 4 cm measured at planting time. N is the summation of these five variables.

2/ Critical Q-values are 0.114 and 0.135 for significant levels of 1 and 0.1 percent respectively.

Correlation Analysis

The correlation matrix for total height and root variables is presented in Table 4. All correlations are different from zero at 0.1 percent significance level. Since the root variable N and its components, N1, N2, N3, N4, and N5, were highly correlated with one another (Table 4), I decided to include only one of this set and the total height, H1, in the analysis of variance. I chose N since this variable is most highly correlated with the other root variables.

The correlation coefficient between N and 1/H1 was -0.907. These variables are clearly not independent. Thus, I chose to use multivariate methods in their analysis.

Table 4. Correlation coefficients[1/] for variables H1, N1, N2, N3, N4, N5 and 1/H1[2/].

Variable	H1	N	N1	N2	N3	N4	N5	1/H1
H1	1.000							
N	0.89	1.00						
N1	0.78	0.94	1.00					
N2	0.84	0.95	0.87	1.00				
N3	0.89	0.92	0.77	0.88	1.00			
N4	0.82	0.87	0.78	0.77	0.80	1.00		
N5	0.55	0.61	0.47	0.52	0.53	0.71	1.00	
1/H1	-0.94	-0.91	-0.79	-0.87	-0.90	-0.81	-0.54	1.00

1/ All the correlation coefficients are significant at the 5 percent level.

2/ N1, N2, N3, N4, and N5 are averages of total roots in different length classes: 0-1, 1-2, 2-3, 3-4, and longer than 4 cm at planting. N is the summation of these five variables.

Multivariate Analysis

The MANOVA results are shown in Table 5, and for the significant effects, raw and standardized discriminant function coefficients are summarized in Table 6. The results of the dimension reduction analysis are summarized in Table 7 and represented in detail in Appendices 9 through 14 for those effects with greater than zero effective dimension. The radius of the centroids for those effects are summarized in Appendix 20. The canonical variates plots of each effect are presented in Figures 1, 2, 3, 4, and 5. In each case, all of the centroids are significantly different from one another at the 5 percent level.

Table 5. results of multivariate analysis of variance for variables 1/H1 (1/average height at planting) and N (average total number of roots).

Source of variation[1/]	Experimental statistics df	Wilks' lambda	F-rtio[2/] (apparoximate)	Probability of greater F
A	1	0.7363	9.4908	0.0000
D	2	0.0429	101.4913	0.0000
O	2	0.4886	11.4112	0.0000
A x D	2	0.7715	3.6693	0.0080
A x O	2	0.7879	3.3539	0.0130
D x O	4	0.4331	6.8842	0.0000
A x D x O	4	0.8198	1.3838	0.2150

1/ A, D, and O are factors ACCLIMATIZATION, DURATION and OUTPLANT DATE respectively.

2/ Wilke's lambda statistics can be transformed into a statistic distributed approximately as F. The degree of freedom of the approximate sampling distribution is calculated from the number of response variables (2), the degrees of freedom of the hypothesis (1 to 4) and the degrees of freedom for error (54). For hypothesis degree of freedom 1, 2, and 4, the test degrees of freedom are 2, 53; 4, 106; and 8, 106 respectively.

Table 6. Raw and standardized canonical discriminant function coefficients associated with the significant effects in MANOVA[1/].

Effects and variable	Raw coefficients CDF#1	CDF#2	Standardized coeffiecients[2/] CDF#1	CDF#2
A				
H1	14.94		2.35	
N	0.38		2.12	
D				
H1	17.36	13.24	0.88	0.67
N	0.08	0.40	-0.23	1.09
O				
H1	14.46	7.07	2.31	1.13
N	0.47	.03	2.56	0.14
A x D				
H1	20.72	13.62	0.96	0.63
N	0.03	0.42	-0.08	1.15
A x O				
H1	16.54	5.25	2.67	0.85
N	0.50	0.03	2.80	-0.16
D x O				
H1	13.41	17.34	0.64	0.83
N	-0.34	0.45	-0.59	0.86

1/ see Table 5.

2/ CDF#1 and CDF#2 refer to canonical discriminant functions 1 and 2 respectively.

Table 7. Results of dimension reduction analysis for 1/H1 (1/height) and N (average total number of roots).

Effect	Effective dimension[1/] of canonical discriminant function space	Percent of variance due to CDF#1	CDF#2	cumulative[2/]
A	0	100		100
D	1	99.97	0.03	100
O	1	99.69	0.31	100
A x D	2	98.67	1.33	100
A x O	1	96.67	3.33	100
D x O	2	96.06	3.94	100

1/ Additional statistics associated with these tests are presented in Appendix 9.

2/ CDF#1 and CDF#2 refer to canonical discriminant functions 1 and 2 respectively.

Outplant Date x Duration Interaction

Cell means of the OUTPLANT DATE x DURATION interaction are given in Table 8 for the variables H1 and N. The table represents a univariate view of these responses.

Table 8. The DURATION x OUTPLANT DATE interaction table for H1 (average height) and N (average number of roots). Results are based on a random sample of 12 seedlings collected at planting.

Response variable and duration (weeks)	Outplant date (June) 1	11	21
H1	....	cm	....
7	1.7	1.6	1.6
10	2.8	3.4	3.1
13	3.4	3.8	3.6
N	..... No.	of roots	....
7	3.3	1.7	3.5
10	9.1	15.3	12.9
13	10.8	14.1	16.4

A multivariate view of the OUTPLANT DATE x DURATION interaction is presented in Figure 1. The figure was produced by means of canonical variates analysis of 9 groups of the experimental units defined by the O x D interaction. The multivariate response vector is the ordered pair of numbers (1/H1 and N). Recall that variable H1 was transformed to 1/H1 to control the problem of heterogeneous variance. In the figure, each of the 72 experimental units is represented by a point in a 2-dimensional rectangular coordinate system. (In general, it is convenient to refer to a n-dimensional rectangular coordinate system as n-space, or R_n.).

The 9 centroids of D x O interaction lie in a plane (Table 7). Since the response variables themselves also lie in a plane, the canonical variates analysis provides no advantage over the original variables, and so I plotted the 9 centroids in the 2-space defined by the original variates H1 and N (Figure 6).

Figures 1 and 6 suggest that the 9 group centroids lie in 2 clusters. Canonical variates function 1 (CVF1) separates the two clusters (Figure 1). One cluster has 3 members associated with the 7-week level, and the other cluster has 6 memebers associated with the 10 and 13-week levels of the factor DURATION. Within each level of DURATION, OUTPLANT DATE seems to have affected N more than H1 (Figure 6).

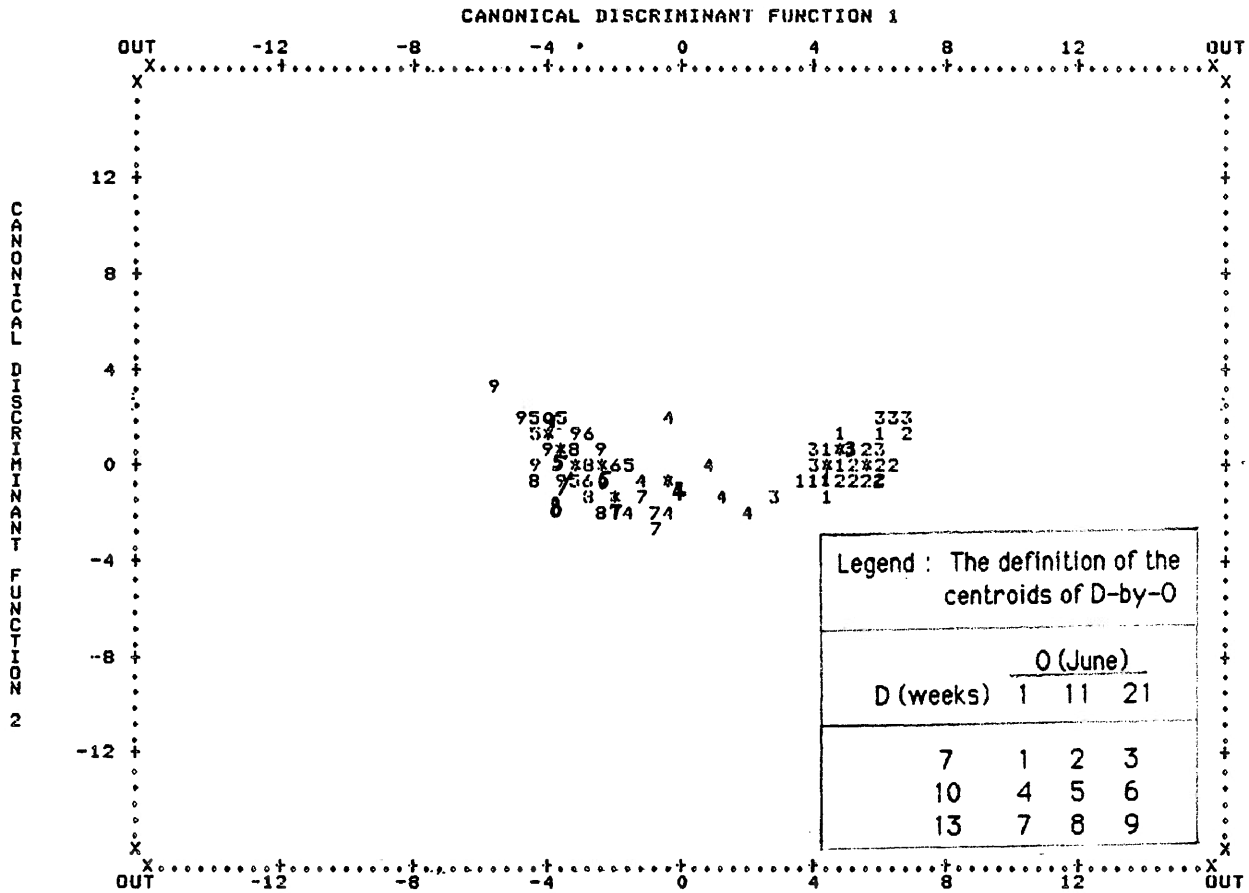


Figure 1. Canonical variates plot of the DURATION x OUTPLANT DATE interaction for variables height and total number of roots at planting time. The extra black numbers present centroids.

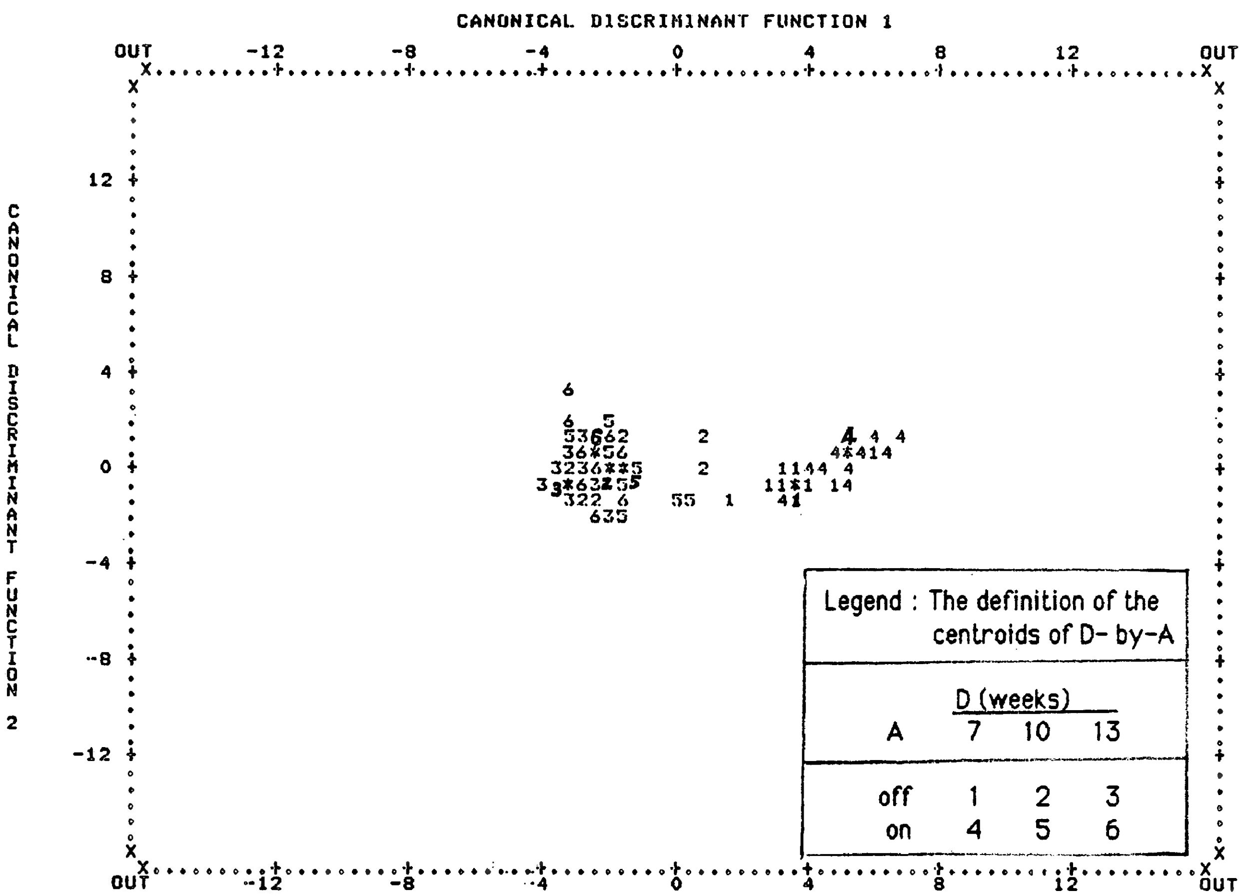
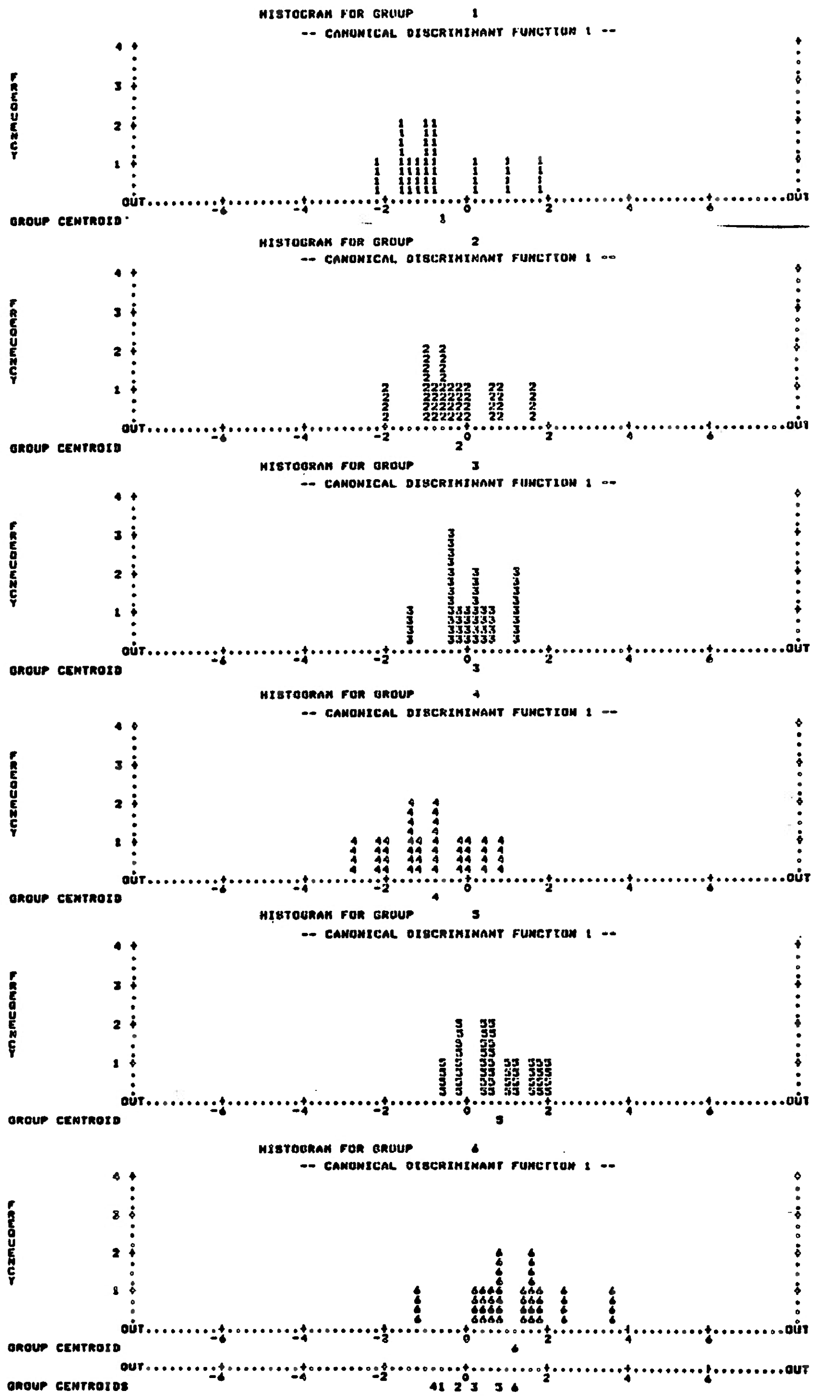


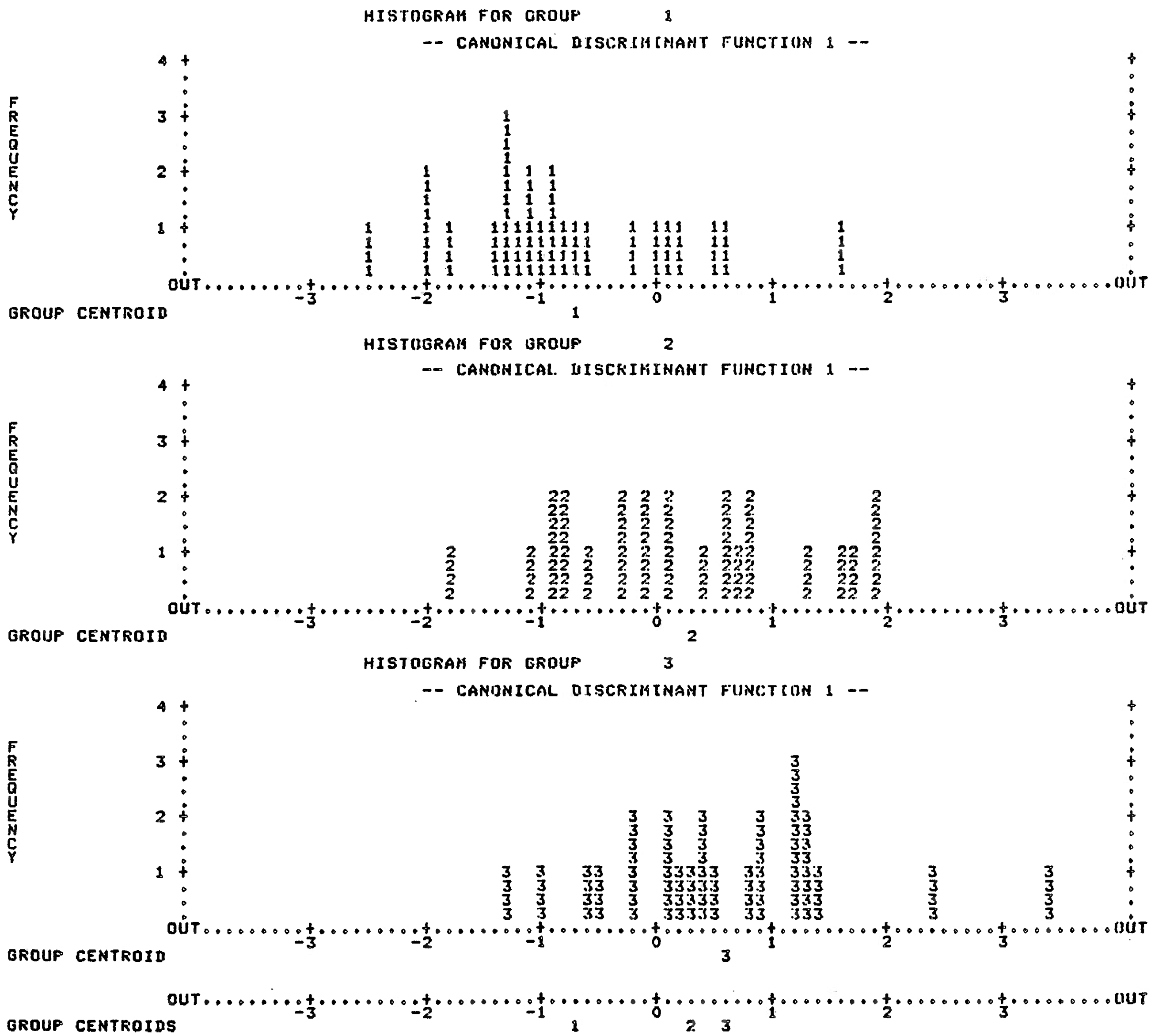
Figure 2. Canonical variates plot of the ACCLIMATIZATION x DURATION interaction for variables height and total number of roots at planting time. The extra black numbers present centroids.



Legend : The definition of the centroids of O-by-A

A	O (June) 1	11	21
off	1	2	3
on	4	5	6

Figure 3. Canonical variates plot of the ACCLIMATIZATION x OUTPLANT DATE interaction for variables height and total number of roots at planting time.



Legend : The definition of the centroid of the O			
	O (June)		
	1	11	21
centroid	1	2	3

Figure 4. Canonical variates plot of the factor OUTPLANT DATE for variables height and total number of roots at planting time.

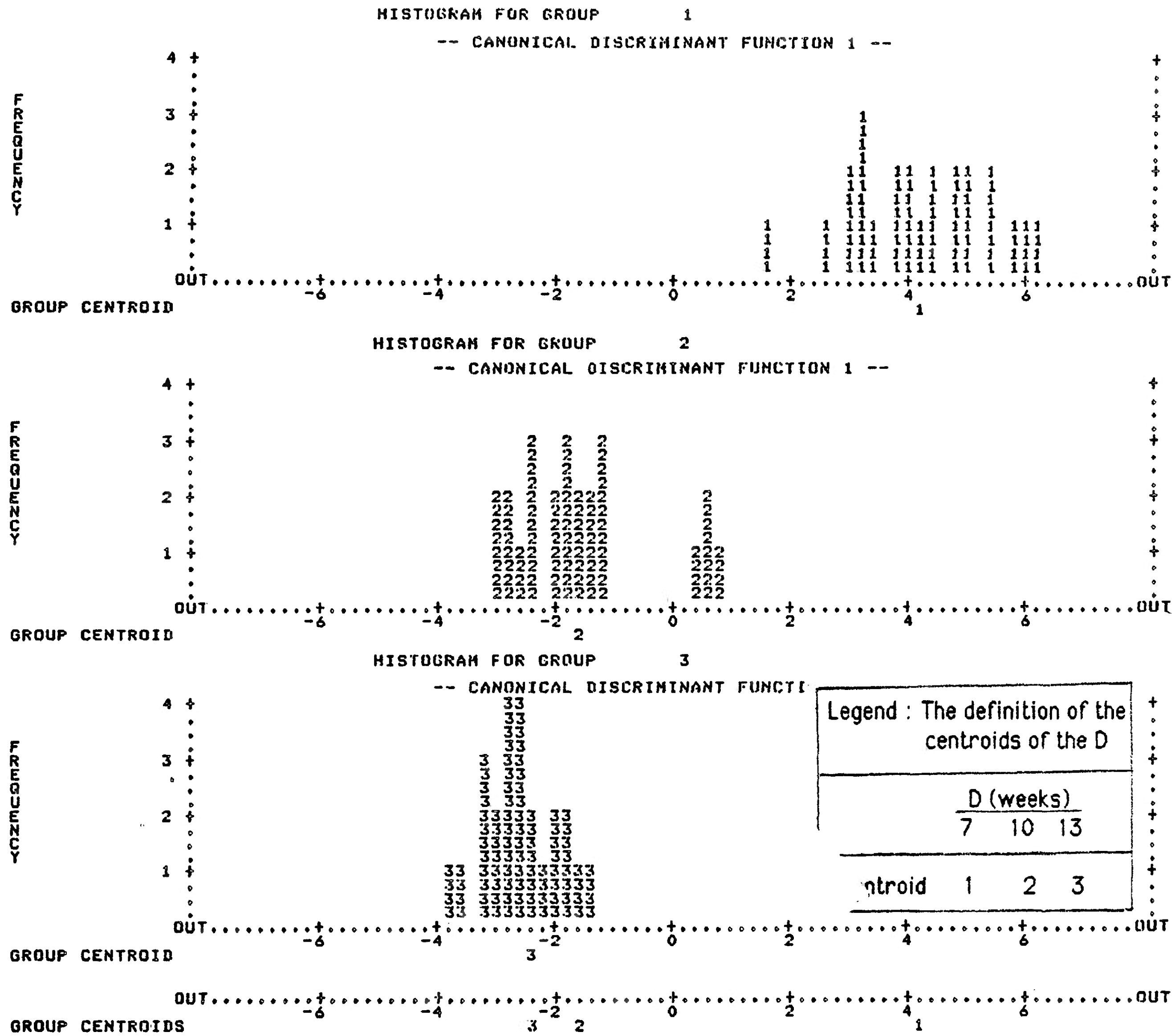


Figure 5. Canonical variates plot of the DURATION factor for variables height and total number of roots planting time.

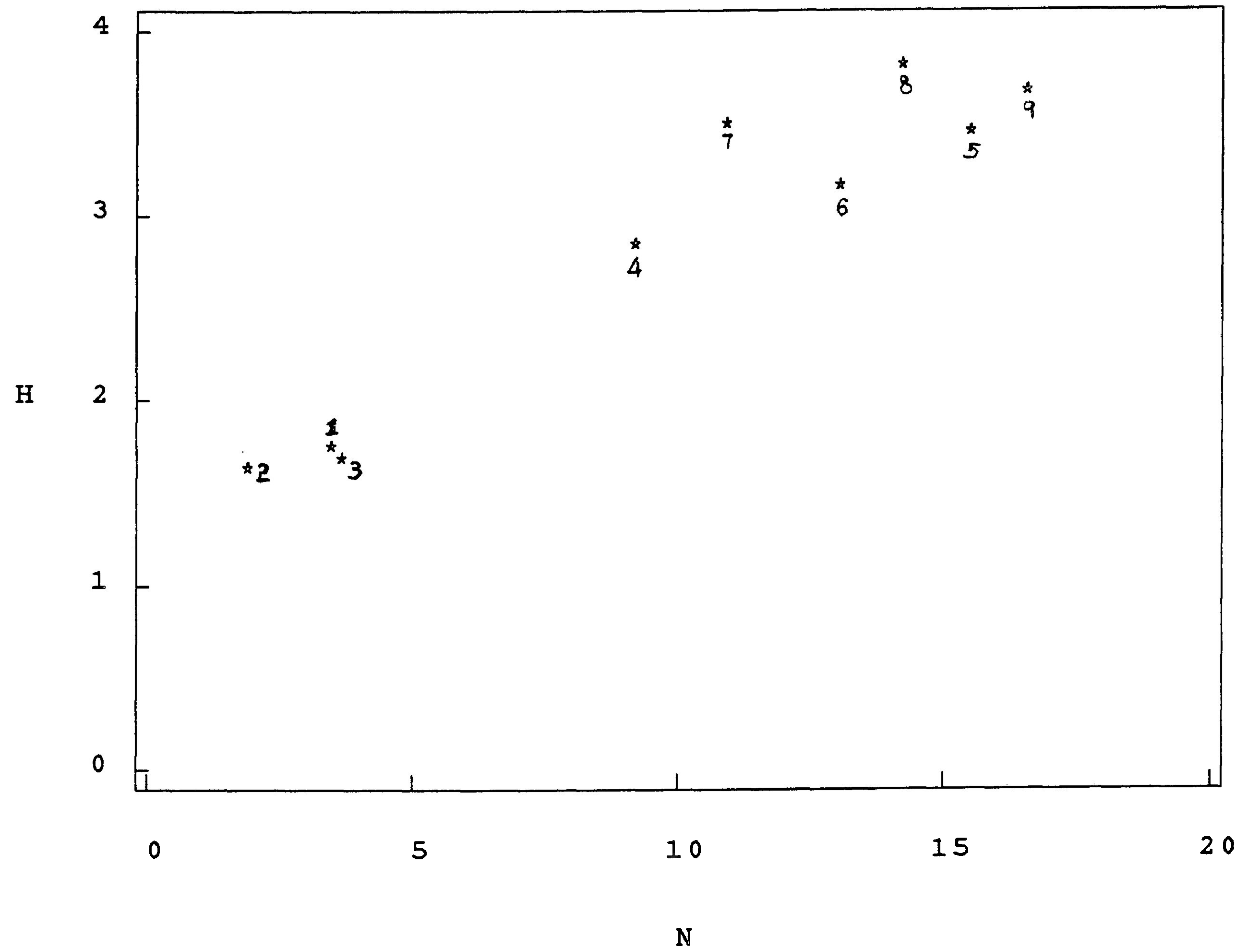


Figure 6. seedling height (H) plotted against total number of roots (N) at planting for the 9 centroids of the DURATION x OUTPLANT DATE interaction.

<u>**Acclimatization x Duration Interaction**</u>

A univariate view of the ACCLIMATIZATION x DURATION interaction is given in Table 9 for variables H1 and N. A multivariate view of the intercation A x D is presented in Figure 2. Figure 2 was produced by means of canonical variates analysis of the 6 groups of the experimental units defined by the A x D interaction. The multivariate response vector is the ordered pair of numbers (1/H1 and N). The effective dimensionality of the space of the interaction was 2 (Table 7). As in the case of the O x D interaction, centroids of all 6 groups of the A x D interaction are plotted in Figure 7. As in the 2-space defined by the original variables, H1 and N. Figures show that the 6 group centroids lie in 2 clusters separated by the first canonical variates function. One cluster has 2 members associated with the 7-week level, and the other has 4 members associated with the 10 and 13-week levels of the DURATION factor.

Table 9. The DURATION x ACCLIMATIZATION interaction table for the average height (H1) and total number of roots (N). Results are based on a random sample of 12 seedlings collected on the planting date.

Response variable and Acclimatization	Duration (weeks)		
	7	10	13
H1	......	cm	......
no	1.7	3.2	3.8
yes	1.5	3.0	3.4
N	.. No.	of roots	..
no	3.0	13.0	13.1
yes	2.7	11.9	14.4

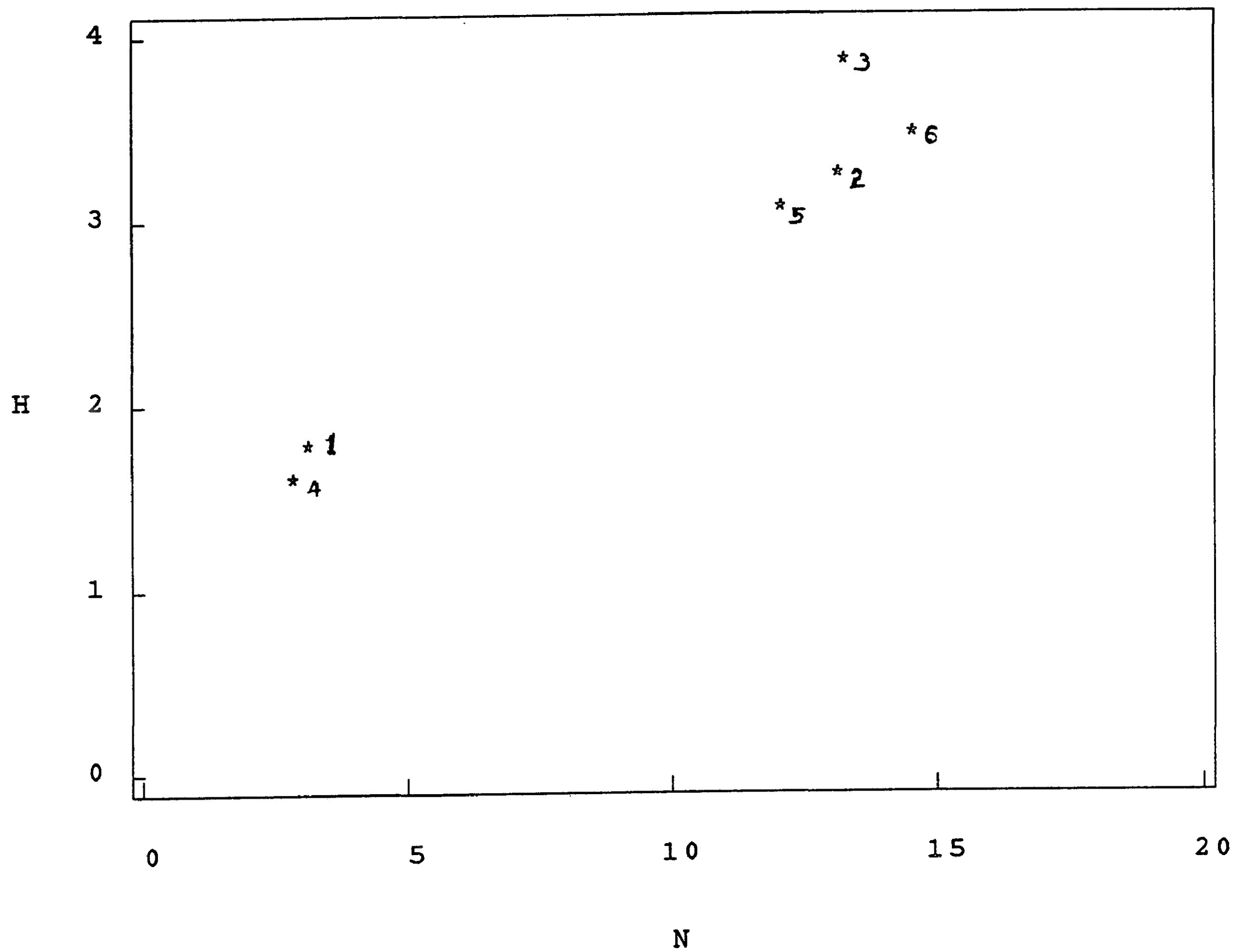


Figure 7. Seedling height plotted against total number of roots (N) at planting for the 6 centroids of DURATION x ACCLIMATIZATION interaction.

Acclimatization x Outplant Date Interaction

A univariate view of the ACCLIMATIZATION x OUTPLANT DATE interaction is given in Table 10 for variables H1 and N. A multivariate view of the interaction is presented in Figure 3. The figure was produced by means of the canonical variates analysis of the 6 groups of the experimental units defined by the interaction. The multivariate response vector is the ordered pair of numbers (1/H1 and N). The effective dimensionality of the space defined by the 6 group centroids was 1 (Table 7).

Table 10. The ACCLIMATIZATION x OUTPLANT DATE interaction table for average height (H1) and total number of roots (N). Results are based on a random sample of 12 seedlings collected at planting time.

Response variable and Acclimatization	Outplant date (June) 1	11	21
H1	....	cm	....
no	2.7	3.0	3.0
yes	2.6	2.8	2.6
N	... No.	of roots	...
no	8.2	9.8	11.0
yes	7.2	10.9	10.8

Outplant Date

Cell means of OUTPLANT DATE factor are given in Table 11 for variables H1 and N. The table presents a univariate view of the responses.

A multivariate view of the OUTPLANT DATE factor is presented in Figure 4. The figure was produced by means of canonical variates analysis of the three groups of the experimental units defined by the three levels of OUTPLANT DATE. The multivariate response vector is the ordered pair of numbers (1/H1 and N). The effective dimensionality of the factor was 1 (Table 7). The figure suggests that the 3 group centroids lie in 2 clusters. One cluster has 1 member associated with planting date June 1st, and the other has two members associated with planting dates June 11th and 21st.

Table 11. The OUTPLANT DATE table for the average height (H1) and total number of roots (N). Results are based on a random sample of 12 seedlings collected on the planting date.

	Outplanting date (June)		
	1	11	21
H1	....	cm	....
	2.7	2.9	2.8
N	....	No. of roots	....
	7.7	10.4	10.9

Duration

Cell means of the DURATION factor are given in Table 12 for the variables H1 and N. The table represents a univariate view of the responses.

Table 12. The DURATION table for the average Height (H1) and total number of roots (N). Results are based on a random sample of 12 seedlings collected at outplanting time.

	Duration (weeks)		
	7	10	13
H1	....	cm	....
	1.6	3.1	3.6
N	....	No. of roots	....
	2.8	12.4	13.7

A multivariate view of the DURATION factor is presented in Figure 5. The figure was produced by means of canonical variates analysis of the 3 groups of the experimental units defined by the three levels of the factor DURATION. The multivariate response vector is the ordered pair of numbers (1/H1 and N). The effective dimensionality of the factor was

1 (Table 7).

Acclimatization

The effects of ACCLIMATIZATION were significant at the 0.05 level in the MANOVA analysis (Table 5). However, in the canonical variates analysis, zero dimensionality of the space defined by the 2 group centroids of the factor ACCLIMATIZATION was not rejected at 0.05 significance level (Table 7). It may be that the effects of ACCLIMATIZATION are near the boundary of statistical significance. I examined the cell means of ACCLIMATIZATION for variables H1 and N (Table 13), and found that the number of roots were the same for the 2 levels of the factor, and the height growth of the seedlings without acclimatization was only 2 mm greater than those with acclimatization. Therefore, the effects of ACCLIMATIZATION on seedling growth are not sufficient to be of practical significance even if the differences are significantly greater than zero.

Table 13. The ACCLIMATIZATION table for the average height (H1) and total number of roots (N). Results are based on a random sample of 12 seedlings collected on the outplanting date.

	Response variable	
Acclimatization	H1	N
	... cm ...	... No. of roots...
no	2.9	9.7
yes	2.7	9.7

DISCUSSION

Among all the significant treatments, the DURATION factor and its interactions with other factors produced the greatest effects on H1 and N. As duration was increased, seedling grew bigger in both height and root system (Table 12), but the major difference of the seedling growth lay between 7 and 10-week levels of DURATION.

ACCLIMATIZATION modified the effects of DURATION. Generally, the ACCLIMATIZATION treatment reduced seedling height growth (Table 9). This is also true for the root growth of the seedlings of 7 and 10 weeks old (Table 9). These results may be caused by the lower temperatures and shorter photoperiod in the acclimatization area than in the greenhouse. However, acclimatization increased the seedling root growth of 13 week duration (Table 9), and the reason is not known.

The major differences of the seedling growth were caused by DURATION factor in the D x A interaction (Table 9). Seedling growth increased dramatically from 7 to 10 weeks, and increased little from 10 to 13 weeks. Thus, seedlings held in the greenhouse for 10 or more weeks were under some stresses. Therefore, there may be an optimum duration between 7 and 10 weeks for seedlings to grow in the greenhouse under the conditions of this experiment. However, this optimum duration needs further study.

The container itself is an important component of the seedling environment because it determines the size and shape of the root system (Biran and Eliassaf 1980). Container volume determines the size of the tree that can grow in the container (Tinus 1982). By 10 weeks in the greenhouse seedlings might have been or were beginning to be pot-bound because of the small container cavity (6 ml), thus resulting in little growth when seedlings were 9 or more weeks old.

OUTPLANT DATE also modified the effects of DURATION (Table 8). But it did not have a consistent effect pattern in the three levels of DURATION on either height or total number of roots (Table 8). However, within different levels of DURATION, OUTPLANT DATE seems to have affected N more than H1 (Figure 6). The possible reasons may be 1) root and height growth were not synchronized so that at some stages one of them may grow more than the other; and 2) the greenhouse conditions may have resulted in a shift in physiological balance that favored root growth over top growth.

OUTPLANT DATE was significant on seedling growth (Table 5). Since the photoperiod was controlled constantly with 16 hour during the days, the significant effect may be caused mainly by the variable temperatures in the greenhouse (Appendix 1) although the temperature was set at 25°C during the days and 18° in the nights. Because the records were not complete, this argument is not conclusive. The effects of OUTPLANT DATE were more pronounced on root growth (Table 11). Probably, in the later stage of the greenhouse period, the temperature favored root growth more than shoot growth.

The effects of OUTPLANT DATE were modified by ACCLIMATIZATION (Table 10). Acclimatization reduced seedling height growth in each level of OUTPLANT DATE, but this effect pattern was not consistent on root growth (Table 10), and the reason is not known.

CHAPTER 5

TRANSPLANT BED EXPERIMENT

MATERIALS AND METHODS

Overview of the Experiment

The transplant bed experiment was designed to follow the effects of the 3 factors controlled in the greenhouse experiment (DURATION, OUTPLANT DATE, and ACCLIMATIZATION) and one additional factor, SHADE. The shade treatment had 2 levels (on and off). Plots that received shade were covered with a section of snow fence that was a little longer than the plot itself. The light intensity was reduced to about 50 percent of the full sunlight under the shade.

The experiment was set out in 4 adjacent transplant beds in the Thunder Bay Nursery. In general, the experiment proceeded as follows. On each of the 3 outplant dates seedlings belonging to the appropriate crop were moved from their respective greenhouse and acclimatization area to the transplant beds. The beds were 140 m long and 1.3 m wide, and they had been prepared according to the nursery's conventional methods. The seedlings in each Castle and Cooke flat were hand-planted into one plot. Each plot contained 8 rows of seedlings. The rows were spaced 15 cm apart, and the seedlings were planted 7.5 cm apart in the rows. During the growing season, all the plots received conventional tending treatments, including irrigation, fertilization, and weed control. The details of these operations are outlined below.

Seedling mortality and bud-set were monitored at regular intervals during the growing season. In the fall, following ceasation of growth and just before freeze-up, randomly selected seedlings were harvested from each plot and several growth attributes were measured. The details of sampling and mensurational procedures are outlined below.

Experimental Design and Field Layout

The transplant bed experiment was a 3 x 3 x 2 x 2 factorial design executed in 2 randomized complete blocks. Since this design provides no estimate of experimental error, 9 treatment combinations were selected at random from each block. These provided an estimate of the experimental error with 18 degrees of freedom.

Figure 8 shows the field layout for this expriment.

Cultural Operations

Transplant beds were fertilized with P and K incorporated before transplanting (P: Triple Superphosphate at 770 kg/ha; K: 0-0-5 at 165 kg/ha). The beds were well plowed and rolled the day before the first outplanting date and heavily watered the day before each outplanting date. Thirty flats were planted on each outplanting date. The flats were randomly assigned to blocks. Each flat was randomly assigned to one of the plots. Before outplanting the flats were

	Beds 1	No	Beds 2	No	Beds 3	No	Beds 4	No
Block 1	2-1-1-1*	44	2-2-1-2*	23	2-1-1-3	22		
	1-2-2-3	43	1-2-1-3	24	1-1-3-3*	21	2-1-3-3*	2
	2-2-2-3*	42	1-2-1-1	25	2-1-1-2	20	2-2-1-3	3
	2-1-2-2	41	1-1-3-2	26	1-2-2-1*	19	2-2-1-2	4
	2-2-2-1	40	1-2-3-1	27	2-1-2-3	18	2-2-1-1	5
	2-1-2-1*	39	2-2-3-1	28	1-1-3-1	17	2-1-1-1	6
	1-2-2-1	38	2-1-3-2	29	2-1-3-3	16	1-1-2-3	7
	1-1-2-1	37	1-1-2-3*	30	1-2-3-3	15	1-1-1-2	8
	1-1-1-1	36	1-1-3-3	31	1-1-2-2	14	1-1-1-3	9
	1-2-2-2	35	2-2-3-2	32	2-1-2-1	13	2-2-3-3	10
	1-2-2-2*	34	2-2-2-2	33	1-2-3-2	12	2-2-2-3	11
Block 2	1-2-3-3*	45			2-1-3-1	1	1-2-1-2	45
	2-2-1-3	44	2-1-3-2	23	2-1-2-2*	22	1-2-3-3	1
	1-2-3-2*	43	1-2-1-3*	24	2-1-2-2	21	1-1-2-1	2
	1-1-2-2	42	2-1-1-3	25	2-1-2-1	20	1-1-1-3	3
	1-2-3-1	41	2-2-3-1*	26	2-1-2-3	19	2-1-1-1	4
	2-2-3-3	40	1-2-2-2	27	2-2-1-1*	18	1-1-3-2	5
	1-1-3-3	39	2-2-2-3	28	1-1-3-1*	17	1-2-2-3	6
	1-2-1-3	38	2-1-3-3	29	1-2-3-2	16	1-1-2-3	7
	2-2-1-2	37	2-2-2-2	30	1-2-1-1	15	1-1-3-1	8
	1-2-2-1	36	1-1-1-2	31	2-1-3-1	14	2-2-3-1	9
	2-2-3-2	35	1-1-1-1	32	1-2-1-2	13	2-1-1-2	10
	1-1-1-2*	34	2-2-1-1	33	2-1-1-3*	12	2-2-2-1	11

N ↑

Legend: No = plot number,
* = a duplicate treatment comibination,
2-1-3-3 = a code denoting the treatment combinmation, (see Table 14).

Fig. 8. The field layout of the transplant bed experiment.

Table 14. Cipher for the treatment combination code used in Figure 8[1/].

Factor	Position in the code: First digit	seconed digit	third digit	fourth digit
SHADE	1=off 2=on			
ACCLIMATIZATION		1=no 2=yes		
DURATION in greenhouse			1= 7 weeks 2=10 weeks 3=13 weeks	
OUTPLANT DATE				1=June 1 2=June 11 3=June 21

1/ The code 2-1-3-3 denotes: shade, no acclimatization, 13 weeks in the greenhouse, and transplanted on June 21.

well watered. The seedlings were dibble-planted by hand. The shade treatment was randomly assigned to flats. The plots were shaded according to the treatment combinations of the flats. Shading and watering were conducted as soon as outplanting was finished. The seedlings in each plot were counted after planting.

During the growing season the plots were watered through a Rainbird watering system whenever the surface of the beds was dry. Nitrogen (34-0-0 at 35 kg/ha) was applied in top dress 6 times during the growing season through the watering system. The beds were weeded by hand twice in the growing season as needed.

Sampling and Mensurational Procedures

During the growing season live seedlings in each plot were counted on the following dates: July 25, August 5, September 5, 15, and 25, and October 5 and 15. Bud-set was first monitored on August 5 and again on every sampling date thereafter.

On October 20 and 21, 25 seedlings were sampled at random and excavated carefully from each plot. Care was taken to prevent roots from breaking. The height (H2), root collar diameter (RCD) and bud diameter (BD) were measured with a caliper with 0.1 mm accuracy. The seedlings were then cut at the root collar. The tops and roots from each experimental unit were oven-dried at 100°C for 35 to 40 hours. Top dry weight (TDW) and root dry weight (RDW) were weighed to the nearest 1 mg. Total dry weight was computed by summation. Plot averages were calculated for each variable and used in subsequent analyses.

Preliminary Data Analysis

The following 3 analyses were performed in addition to the procedures outlined in Chapter 3.

First, the subpopulations defined by the 2 levels of factor SHADE were tested to see whether they were the same going into the transplant bed experiment with respect to the multivariate response, (H1 and N). The method used was multivariate analysis of variance.

Second, the survival and bud-set tallies were converted to survival and bud-set ratios respectively. Then these ratios were adjusted for the following reasons. Survival and bud-set were monitored on fixed dates irrespective of the transplant date. As a result, on any particular sampling date, the seedlings planted on June 1 had been in the ground for 10 days longer than those planted on June 11 and 20 days longer than those planted on June 21. After the measurements had been taken, I realized that this arrangement made it inappropriate to compare the survival and bud-set ratios of treatment combinations transplanted on different dates. In order to arrive at a set of survival and bud-set variables that avoided this problem, I defined 2 new variables named "corrected survival ratio", CSR, and "corrected bud-set ratio", CBSR, as follows: Bud-set ratio collected on August 5 and 25 were taken as CBSR for outplant dates June 1 and 21, and the average bud-set ratio of these two dates was taken as CBSR for outplant date June 11; survival ratios collected on July 25 and August 5 were taken as CSR for outplant dates June 1 and 11, and the average survival ratio collected on August 5 and 25 was taken as CSR for outplant date June 21.

Third, all response variables in the transplant bed experiment were tested for block effects. Corrected survival ratio and corrected bud-set ratios were tested by means of univariate ANOVA's; the set of end-of-season variables were tested by multivariate ANOVA.

RESULTS

Preliminary Analysis

Test for the Differences Between Shaded and Not-shaded Subpopulations at Transplanting

The null hypothesis of no difference between the levels of factor SHADE was accepted (Table 15).

Table 15. Multivariate analysis of variance on the differences of the average height (H1) and total number of roots (N) for the two levels of SHADE at the end of the greenhouse phase.

Factor	Variables	Significance of F
SHADE	H1, N	0.854

Survival Ratio and Bud-set Ratio

Corrected bud-set ratio and corrected survival ratio are given in Appendices 4 and 5 respectively, along with the original values of bud-set and survival ratios.

Homogeneity of Variance

The Q-test was performed as if the experimental design had been completely randomized. The variances tested were based on 36 samples, each of which contained the responses from a single treatment combination. Block effects were ignored. Thus, some samples contained 2 observations, and others, 3 observations from both of the blocks. It is shown below that block differences were not statistically significant, so my procedure is justifiable.

The results for the bud-set ratio variables are presented in Table 16, and for survival ratio variables, in Table 17. In every case the hypothesis of common error variance failed at 1 percent significance level. Several transformation methods were tried in an effort to overcome this difficulty. Only the best transformations are reported in the tables.

The results of Q-test are given in Table 18 for variables TDW, TRDW, RDW, H2, RCD, and BD. Homogeneity of variance was accepted for the variables at the significance level 1 percent. Therefore, no data transformation was indicated.

Table 16. Results of Q-test for homogeneity of variance for the bud-set and corrected bud-set data.

Response variable	Date sampled	Experiment Q-value[1/] original	transformed	Transform method
CBSR		0.114	0.0903	arcsine
BSR1	Aug. 5	0.139	0.1125	arcsine(sqrt)
BSR2	Aug. 25	0.139	0.1081	arcsine(sqrt)
BSR3	Sept. 5	0.138	0.1099	arcsine(sqrt)
BSR4	Sept. 15	0.118	0.0812	arcsine
BSR5	Sept. 25	0.127	0.1065	arcsine

1/ Critical Q-values are 0.1125 and 0.1445 for the significant levels 1 and 0.1 percent respectively.

Table 17. Results of Q-test for homogeneity of variance for variables of survival ratios[1/].

Response variable	Date sampled	Experiment Q-value original	Experiment Q-value transformed	Transform method
CSR		0.1427	0.0947	arcsine
SR1	July 25	0.1565	0.1031	arcsine
SR2	Aug. 5	0.1624	0.1074	arcsine
SR3	Aug. 25	0.1623	0.1075	arcsine
SR4	Sept. 5	0.1632	0.1087	arcsine
SR5	Sept. 15	0.1626	0.1090	aicsine
SR6	Sept. 25	0.1615	0.1081	arcsine
SR7	Oct. 5	0.1623	0.1064	arcsine

1/ Critical Q-values are 0.1125 and 0.1445 for the significant levels of 1 and 0.1 percent respectively.

Table 18. Results of Q-test for homogeneity of variance for variables measued at the end of the growing season[1/].

Response variable[2/]	Experimental Q-value
TRDW	0.0729
TDW	0.0950
RDW	0.0079
H2	0.0783
RCD	0.0773
BD	0.0586

1/ Critical Q-values are 0.1125 and 0.1445 for the significant levels of 1 and 0.1 percent respectively.

2/ TDW: top dry weight; RDW: root dry weight; H2: height; RCD: root collar diameter; BD: bud diameter; and TRDW: total dry weight.

Correlation Analysis and Variable Selection

Bud-set ratio

The correlation matrix for the transformed bud-set and corrected bud-set variables is presented in Table 19.

Table 19. Correlation matrix for bud-set variables.

variable[1/]	TCBSR	TBSR1	TBSR2	TBSR3	TBSR4	TBSR5
TCBSR	1.0000					
TBSR1	0.9819	1.0000				
TBSR2	0.9614	0.9270	1.0000			
TBSR3	0.9676	0.9373	0.9914	1.0000		
TBSR4	0.9712	0.9429	0.9894	0.9976	1.000	
TBSR5	0.9200	0.8987	0.9243	0.9312	0.9328	1.0000

1/ T: transformed; C: corrected; BSR: bud-set ratio; 1, 2, 3, 4, and 5: different collecting dates: Aug. 5, and 25, Sept. 5, 15, and 25 for bud-set ratios. All the coefficients are significant at 0.1 percent level.

All the correlation coefficients of the bud-set variables are significantly different from zero at the 0.001 significant level (Table 19). Furthermore, these variables are so highly correlated that analysis of any one of them is sufficient for practical purposes. I chose the transformed corrected bud-set ratio (TCBSR) as the sole bud-set ratio variable for further analysis for the following reason. Early bud-set is an undesirable event in the context of this study and in practice, and therefore TCBSR is the most interesting of bud-set variables from a nurseryman's point-of-view.

Correlation coefficients of TCBSR with other variables measured at transplant bed phase are given in Table 20. The absolute values were all less than 0.50. Therefore, TCBSR was analysed as independent variable under ANOVA.

Table 20. Correlation coefficient table for variables measured at transplant bed phase.

Variable	TCSR	TCBSR	H2	RCD	BD	TDW	RDW	TRDW[1/]
TCSR	1.00							
TCBSR	0.44	1.00						
H2	-0.05	-0.49*	1.00					
RCD	-0.06	0.14	0.42**	1.00				
BD	0.27	0.35*	0.42**	0.64**	1.00			
TDW	-0.14	-0.28	0.86**	0.72**	0.54**	1.00		
RDW	0.12	0.36*	0.47**	0.83**	0.79**	0.70**	1.00	
TRDW	-0.06	-0.07	0.78**	0.82**	0.67**	0.96**	0.86**	1.00

Note: *: significant level 0.01,
**: significant level 0.001.

1/ TCSR: transformed corrected survival ratio, TCBSR: transformed corrected bud-set ratio, H2: height, RCD: root collar diameter, BD: bud diameter, TDW: top dry weight, RDW: root dry weight, and TRDW: TDW+RDW.

Survival Ratio

The correlation matrix for the survival ratio variables is given in Table 21. All the correlation coefficients are significantly different from zero. Furthermore, these variables are so highly correlated that analysis of one of them is sufficient for practical purposes. I chose the transformed corrected survival ratio (TCSR) as the sole survival ratio variable for the following reason. The survival ratio changed little from July 25 to the end of the growing season (Table 22). The survival ratios collected in the early growing season were the most important variables for examining the effects of the treatments on seedling survival, and the transformed corrected survival ratio (TCSR) is the most interesting of the variables from a nurseryman's point-of-view.

Table 21. Correlation matrix for the transformed survival ratios (TSR) and the transformed and corrected survival ratio (TCSR)[1/].

Variable[2/]	TCSR	TSR1	TSR2	TSR3	TSR4	TSR5	TSR6	TSR7
TCSR	1.00							
TSR1	0.99	1.00						
TSR2	0.99	0.99	1.00					
TSR3	0.99	0.99	0.99	1.00				
TSR4	0.99	0.99	0.99	0.99	1.00			
TSR5	0.99	0.99	0.99	0.99	0.99	1.00		
TSR6	0.98	0.99	0.99	0.99	0.99	0.99	1.00	
TSR7	0.98	0.98	0.98	0.99	0.99	0.99	0.99	1.00

1/ These coefficients are significant at 0.1 percent level.

2/ TSR1, TSR2, TSR3, TSR4, TSR5, TSR6, and TSR7 are collected on July 25, Aug. 5, and 15, Sept. 5, 15, and 25, and Oct. 5 for the survival variables respectively.

Table 22. Average survival ratio for selected dates.

Sampling dates	July	August		September			October	
	25	5	25	5	15	25	5	15
Survival percent	87.7	87.0	86.4	86.2	86.1	85.8	85.6	85.6

The correlation coefficients of variable TCSR with other variables measured in the transplant bed phase are given in Table 20. The absolute values are all less than 0.50. Therefore, TCSR was analysed as an independent variable by means of ANOVA.

Variables Measured at the End of the Growing Season

Each of the variables TRDW, TDW, RDW, H2, RCD, and BD had correlation coefficients with at least one other variable in the data set greater than 0.50 (Table 20). Therefore, multivariate analysis of variance was indicated.

Since TRDW is the sum of TDW and RDW, only 2 of the 3 variables were included further analysis and TRDW was dropped.

Test for Block Effects

The results of univariate tests for block effects are given in Table 23 for the survival ratio and bud-set ratio data. Table 24 presents similar multivariate results for variables TDW, RDW, RCD, H2, and BD. Since the block effects were not significant at 0.05 level for any of the variables, I decided to analyse the transplant bed lete experiment as a completely randomized design.

Table 23. Univariate F-test for the block effects on transformed corrected bud-set ratio (TCBSR) and transformed corrected survival ratio (TCSR).

Response variable	Source of variation[1/] blocks df	MS	error df	MS	Experimental F-ratio[2/]
TCSR	1	0.0795	18	0.0443	1.7937 ns[3/]
TCBSR	1	0.0426	18	0.0131	3.2542 ns

1/ The error mean squares were estimated from 9 duplicates combinations within each block.

2/ The critical F-value for 1 and 18 degree of freedom confidence level is 4.41.

3/ Not significant.

Table 24. Univariate F-test for block effects on top dry weight (TDW), root dry weight (RDW), root collar diameter (RCD), height (H2), and bud diameter (BD).

Response variables	Source of variation[1/] blocks df	MS	error df	MS	Experimental F-ratio[2/]
TDW	1	0.00148	18	0.0047	0.3159 ns[3/]
RDW	1	0.00007	18	0.0008	0.0875 ns
RCD	1	0.00623	18	0.0243	0.6564 ns
H2	1	1.45039	18	0.8931	1.6240 ns
BD	1	0.01739	18	0.0413	0.4210 ns

1/ The error mean squares were estimated from the 9 duplicate combinations within each block.

2/ The critical F-value for 1 and 18 degrees of freedom confidence level is 4.41.

3/ Not significant.

Final Analysis

Bud-set Ratio

The transformed corrected bud-set ratio (TCBSR) data were analysed for treatment effects by means of univariate analysis of variance (ANOVA). Significant effects were further examined through the multiple comparison of means according to the Student-New-Keuls test (Anderson and McLean 1974).

The ANOVA results are summarized in Table 25. Cell means for significant main effects and interaction effects are presented in the following order: D, D x A, D x O, D x S, S, O, and O x A in Tables 26 through 32 respectively.

Table 25. Results of univariate analysis of variance for transformed corrected bud-set ratio (TCBSR).

Source of[1/] variation	df	MS	Sig. of F
Error	54	0.0142	
S	1	0.2517	0.000
A	1	0.0060	0.521
D	2	6.0003	0.000
O	2	0.2140	0.000
S x A	1	0.0319	0.142
S x D	2	0.0488	0.043
S x O	2	0.0268	0.166
A x D	2	0.0804	0.007
A x O	2	0.1130	0.001
D x O	4	0.0476	0.020
S x A x D	2	0.0033	0.795
S x A x O	2	0.0027	0.830
S x D x O	4	0.0059	0.794
A x D x O	4	0.0582	0.080
S x A x D x O	4	0.0177	0.309

1/ S, A, D, and O are factors SHADE, ACCLIMATIZATYION, DURATION and OUTPLANT DATE respectively.

Table 26. Mean bud-set ratios[1/] for the factor DURATION[2/].

Duration (weeks in the greenhouse)		
7	10	13
0.02	0.63	0.82

1/ The means are original values, but the ANOVA and the SNK-test were performed on the transformed variable, TCBSR.

2/ All TCBSR means were different from one another at 5 percent level under the SNK-test.

Table 27. Mean bud-set ratios[1/] for the 6 levels of the DURATION x ACCLIMATIZATION interaction[2/].

Duration (weeks in greenhouse)	Acclimatization	
	on	yes
7	0.03	0.01
10	0.66	0.61
13	0.77	0.87

1/ The means are original values, but the ANOVA and the SNK-test were performed on the transformed variable TCBSR.

2/ Cell means joined by an underline are not different at the 5 percent level under the SNK-test.

Table 28. Mean bud-set ratios[1/] for the 9 levels of the DURATION x OUTPLANT DATE interaction.

Duration (weeks in greenhouse)	Outplant date (June)		
	1	11	21
7	0.0574	0.0017	0.0014
10	0.7312	0.6793	0.4933
13	0.8405	0.8722	0.7428

1/ The means are the original values.

Table 29. Mean bud-set ratios[1/] for the 6 levels of the DURATION x SHADE interation[2/].

Duration (weeks in greenhouse)	Shade	
	off	on
7	0.006	0.035
10	0.594	0.675
13	0.756	0.880

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the variable TCBSR.

2/ The means joined by an underline are not different at the 5 percent level under the SNK-test.

Table 30. Mean bud-set ratios[1/] for factor SHADE[2/].

Shade off	Shade on
0.45	0.53

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the transformed variable, TCBSR.

2/ The means are different from one another at the 5 percent level under the SNK-test.

Table 31. Mean bud-set ratios[1/] for factor OUTPLANT DATE[2/].

Outplant date (June) 1	11	21
0.54	0.52	0.42

(0.54 and 0.52 are joined by an underline.)

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the variable TCBSR.

2/ Cell means joined by an underline are not different at the 5 percent level under the SNK-test.

Seedling Survival

The analysis of the transformed corrected survival ratio (TCSR) data paralleled that of the bud-set analysis. The data were analysed for treatment effects by means of univariate ANOVA. The significant effects were further analysed through the multiple comparison of the means according to the SNK-test.

The ANOVA results are summarized in Table 33. Cell means for significant main effects and interactions are presented in the following order: S, D, O, and S x O in Tables 34 through 37 respectively.

Table 32. Mean bud-set ratios[1/] for the 6 levels of the OUTPLANT DATE x ACCLIMATIZATION interaction.

Acclimatization	Outplant date (June) 1	11	21
off	0.54	0.55	0.36
on	0.54	0.48	0.46

1/ The means are the original values and they are different at 5 percent level under the SNKL-test.

Table 33. Results of univariate analysis of variance for the transformed corrected survival ratio (TCSR).

Source of variation[1/]	df	MS	Sig. of F
Error	54	0.0135	
S	1	0.5707	0.000
A	1	0.0014	0.747
D	2	0.2105	0.000
O	2	0.2014	0.000
S x A	1	0.0123	0.334
S x D	2	0.0105	0.467
S x O	2	0.0685	0.012
A x D	2	0.0030	0.805
A x O	2	0.0076	0.575
D x O	4	0.0328	0.066
S x A x D	2	0.0018	0.876
S x A x O	2	0.0075	0.582
S x D x O	4	0.0037	0.893
A x D x O	4	0.0063	0.761
S x A x D x O	4	0.0119	0.487

1/ S, A, D, and O are factors SHADE, ACCLIMATIZATION, OUTPLANT DATE, and DURATION respectively.

Table 34. Mean survival ratios[1/] for factor SHADE[2/].

Shade: off	on
0.82	0.91

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the transformed variable, TCSR.

2/ The TCSR means were different from one another at the 5 percent level under the SNK-test.

Table 35. Mean survival ratios[1/] for the factor DURATION[2/].

Duration (weeks in the greenhouse)		
7	10	13
0.81	0.89	0.90

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the variable TCSR.

2/ Cell means joined by an underline are not different at the 5 percent level under the SNK-test.

Table 36. Mean survival ratios[1/] for factor OUTPLANT DATE[2/].

Outplant date (June)		
1	11	21
0.82	0.90	0.88

1/ The means are the original values, but the ANOVA and the SNK-test were performed on the variable TCSR.

2/ Cell means joined by an underline are not different at the 5 percent level under the SNK-test.

Table 37. Mean survival ratios[1/] for the OUTPLANT DATE x SHADE interaction.

	Outplant date (June)		
Shade	1	11	21
off	0.80	0.86	0.81
on	0.85	0.94	0.95

1/ The means are the original values, and they are different at 5 percent level under the SNK-test.

End of Season Attributes

Seedling attributes measured at the end of the first growing season in the transplant beds include H2, TDW, RDW, RCD, and BD. Since these variables are correlated to an extent that cannot be ignored, the data were analysed for treatment effects by means of multivariate analysis of variance (MANOVA). Significant effects were further examined by means of canonical variates analysis.

The MANOVA results are summarized in Table 38. The results of the dimension reduction analyses are summarized in Table 39, and presented in detail in the Appendices 15 through 19. The radius of the centroids associated with the effects in dimension reduction analysis are given in Appendix 20. The canonical discriminant function analyses, and other treatment response information are presented individually for the significant effects in the order in which they are later discussed.

Table 38. Multivariate analysis of variance for variables top dry weight, root dry weight, root collar diameter, height and bud diameter at the end of the growing season.

Source of variation	df	Experimental statistics[1/] Wilks' lambda	F-ratio (approximate)	Probability of greater F
S	1	0.1904	27.2069	0.000
A	1	0.8000	1.6011	0.188
D	2	0.0853	15.5191	0.000
O	2	0.5248	2.4346	0.016
S x A	1	0.6957	2.8000	0.033
S x D	2	0.5112	2.5513	0.012
S x O	2	0.6020	1.8487	0.070
A x D	2	0.6041	1.8341	0.072
A x O	2	0.7440	1.0201	0.437
D x O	4	0.2537	2.7428	0.000
S x A x D	2	0.6426	1.5835	0.132
S x A x O	2	0.8678	0.4703	0.903
S x D x O	4	0.4965	1.2584	0.224
A x D x O	4	0.5083	1.2120	0.259
S x A x D x O	4	0.5613	1.0184	0.448

1/ Wilks' lambda statistic can be transformed into a statistic that is distributed approximately as F. The degrees of freedom of the approximate sampling distribution are calculated from the number of response variables (5), the degrees of freedom of the hypothesis (1 to 4), and the degrees of freedom for error (36). For hypothesis degrees of freedom 1, 2 and 4, the test degrees of freedom are 5, 32; 10, 64; and 20, 107 respectively.

Table 39. Results of dimension reduction analysis of groups of treatment combinations based on the levels of single factors S, D, and O and 2-way interactions A x S, S x D and D x O. The multivariate response involves five variables: top dry weight, root dry weight, root collar diameter, height and bud diameter at the end of the growing season.

Effect	Effective dimension[1/] of canonical discriminant function space	Percent of variance due to CDF#1	CDF#2	cummulative[2/]
S	1	100		100
D	1	96.01	3.99	100
O	0	80.59	19.41	100
A x S	1	89.09	9.61	98.7
S x D	3	63.74	31.26	95.5
D x O	2	84.59	8.71	93.3

1/ Additional statistics associated with these tests are presented in Appendices 15 through 19.

2/ CDF#1 and CDF#2 refer to canonical discriminant functions 1 and 2.

Duration

Cell means for the three levels of DURATION are presented for each of the 5 variables in Table 40. According to the dimension reduction analysis, the 3 DURATION centroids are collinear, i.e. they lie in a 1-dimensional subspace of the response space (Table 39). Thus, the first canonical discriminant function (CDF1) provides the best (in the least squares sense) 1-dimensional view of the multivariate response. The raw and standardized coefficients of CDF1 are presented in Table 41. The distribution of individual plots in each level of DURATION along the axis defined by CDF1 is illustrated in Figure 9.

Table 40. The DURATION effect table for the variables measured at the end of the growing season.

Duration (weeks)	TDW	RDW	RCD	H2	BD	TDW/RDW
	..g..	..g..	..mm..	..cm..	..mm..	
7	0.163	0.068	1.216	6.208	2.004	2.397
10	0.158	0.095	1.341	5.619	2.221	1.663
13	0.140	0.108	1.431	5.138	2.228	1.296

Table 41. Raw and standardized canonical discriminant function coefficients of the factor DURATION.

Response variable	Raw coefficients CDF#1	Standardized coefficients CDF#1
TDW	-21.10	-1.38
RDW	71.40	2.08
RCD	-0.41	-0.12
H2	-0.55	-0.70
BD	1.03	0.20

Outplant Date

Cell means for the 3 levels of OUTPLANT DATE are presented for each of the 5 response variables in Table 42. According to the dimension reduction analysis (Table 39), the 3 centroids lie sufficiently close to one another in response space so that the null hypothesis that they occupy a common point is accepted. But in the MONOVA, the hypothesis that the main effect of OUTPLANT DATE was zero was rejected (Table 38). This conflict apparently resulted from the two different methods of analysis. In variance analysis the experimental error was from the duplicates of the same treatments, but in canonical discriminant analysis, it was the error within the 3 groups of the OUTPLANT DATE. Therefore, I have elected to look at the CDF1. The raw and standardized coefficients of CDF1 are presented in Table 43. The distribution of the individual plots in each OUTPLANT DATE along the axis defined by CDF1 is illustrated in Figure 10.

Table 42. The OUTPLANT DATE effect table for the variables measured at the end of the growing season.

Outplant date (June)	TDW	RDW	RCD	H2	BD	TDW/RDW
	..g..	..g..	.mm.	.cm.	.mm.	
1	0.1579	0.0933	1.37	5.54	2.16	1.69
11	0.1465	0.0891	1.27	5.52	2.18	1.64
21	0.1577	0.0876	1.35	5.91	2.12	1.80

Table 43. Raw and standardized canonical discriminant function (CDF) coefficients associated with the factor OUTPLANT DATE.

Response variable	Raw coefficients	Standardized coefficient
	CDF#1	CDF#1
TDW	-31.42	-2.07
RDW	-6.47	-0.22
RCD	5.98	1.74
H2	1.44	1.92
BD	-4.39	-0.98

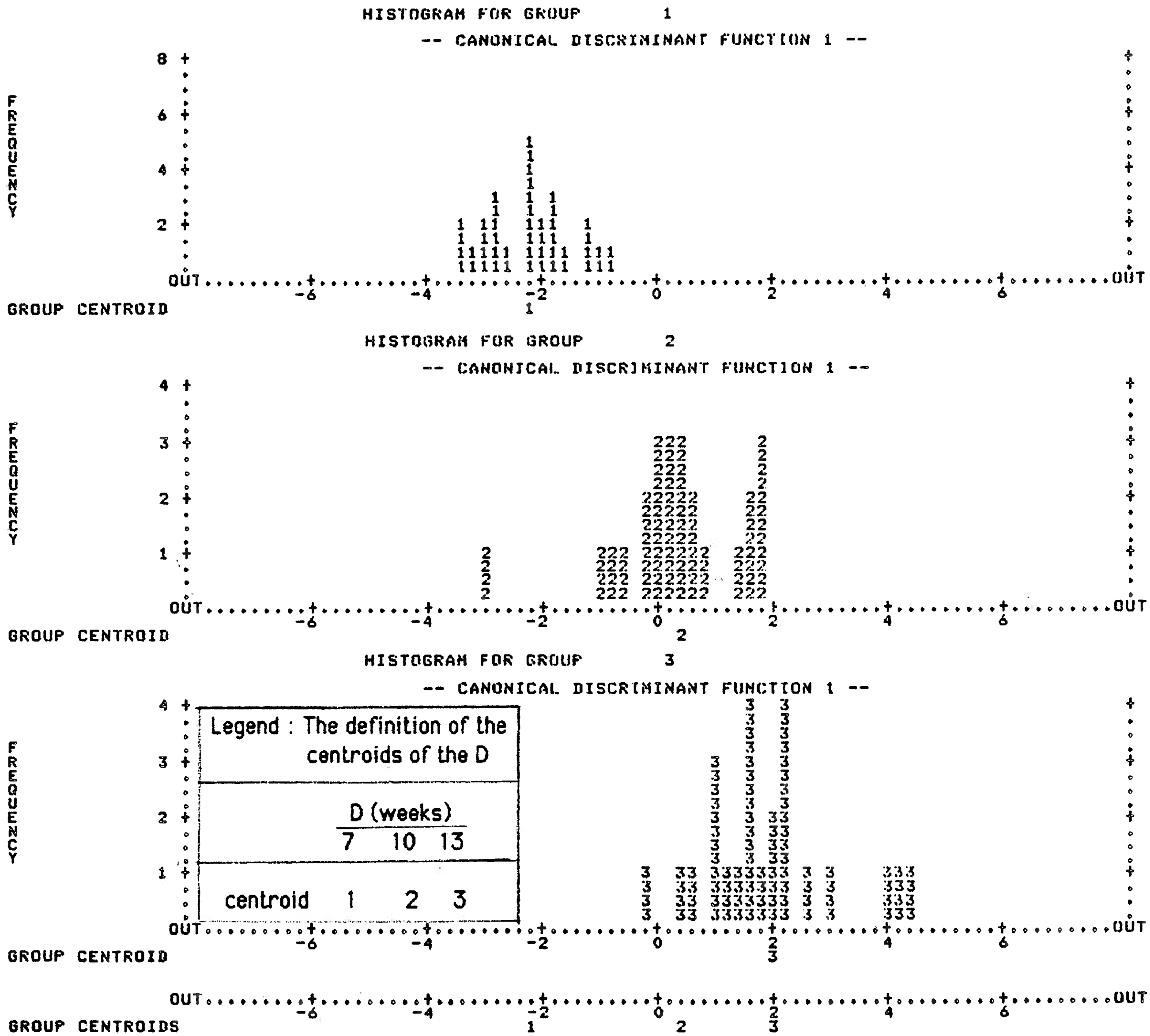
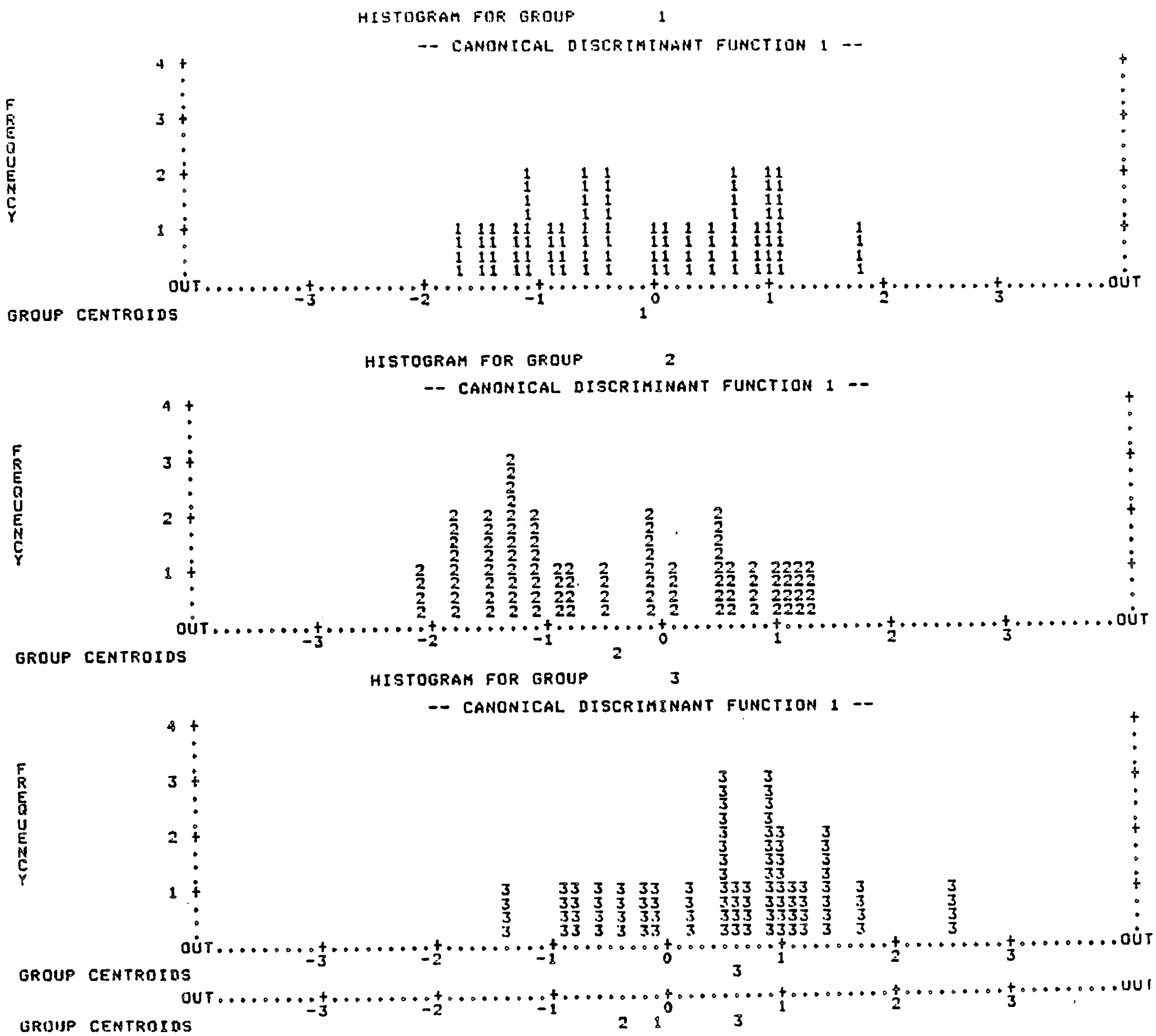


Figure 9. The canonical variates plots of the DURATION factor for variables top dry weight, root dry weight, root collar diameter, and bud diameter measured at the end of the growing season.



Legend : The definition of the centroids of the OUTPALNT DATE factor.

	Outplant date (June)		
	1	11	21
Centroids	1	2	3

Figure 10. The canonical variates plots of OUTPLANT DATE factor for variables top dry weight, root dry weight, root collar diameter, height, and bud diameter measured at the end of the growing season.

Duration x Outplant Date Interaction

The cell means of the DURATION x OUTPLANT DATE interaction table are presented for each of the five variables in Table 44. According to the dimension reduction analysis (Table 39), the 9 centroids of D x O interaction table lie in a 2-dimensional subspace of the response space. Therefore, the first 2 canonical discriminant functions CDF1 and CDF2, provide the best 2-dimensional view of the D x O response. The raw and standardized coefficients of the two functions are presented in Table 45, and the 9 group centroids are illustrated in Figure 11.

Shade

Cell means for the two levels of SHADE are represented in Table 46 for each of the five variables. Of course, the 2 group centroids must lie in a 1-dimensional subspace of response space. The raw and standardized coefficients of CDF#1 are presented in Table 47. The distribution of the individual plots at each level of SHADE along the axis defined by CDF1 in illustrated in Figure 12.

Table 44. The DURATION x OUTPLANT DATE interaction table for the variables measured at the end of the growing season.

Variable and duration	Outplant date (June) 1	11	21
TDW	....	g	
7	0.21	0.14	0.14
10	0.12	0.19	0.17
13	0.15	0.11	0.16
RDW	....	g	
7	0.09	0.06	0.06
10	0.08	0.11	0.09
13	0.12	0.10	0.11
RCD	....	mm	
7	1.36	1.14	1.15
10	1.28	1.40	1.35
13	1.49	1.27	1.54
H2	....	cm	
7	6.86	5.89	5.88
10	4.61	6.04	6.20
13	5.13	4.64	5.64
BD	....	mm	
7	2.13	1.94	1.94
10	2.15	2.36	2.15
13	2.21	2.22	2.26
TDW/RDW			
7	2.46	2.48	2.31
10	1.53	1.63	1.87
13	1.25	1.18	1.74

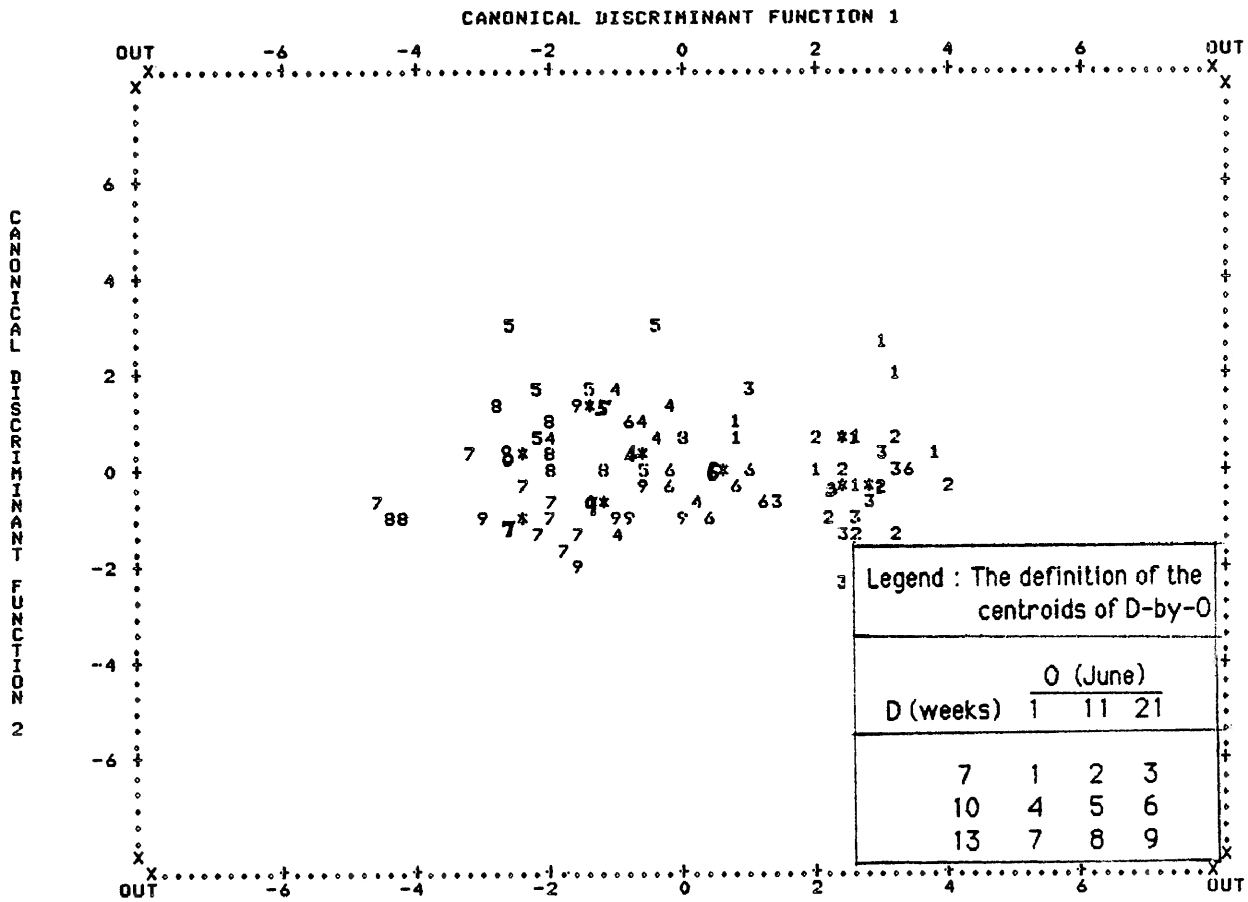


Figure 11. The canonical variates plot of the interaction OUTPLANT DATE x DURATION for variables top dry weight, root dry weight, root collar diameter, height and bud diameter measured at the end of the growing season. The extra black numbers are group centroids.

Table 45. Raw and standardized canonical discriminant function coefficients associated with the DURATION x OUTPLANT DATE interaction.

Response variable	Raw coefficients		Standardized coefficients	
	CDF#1	CDF#2	CDF#1	CDF#2[1/]
TDW	11.61	42.79	0.719	2.647
RDW	-78.02	-23.96	-2.146	-0.659
RCD	2.30	-5.51	0.634	-1.519
H2	1.02	-1.26	1.210	-1.507
BD	-2.15	6.09	-0.410	1.158

1/ CDF#1 and CDF#2 are canonical discriminant functions 1 and 2 respectively.

Table 46. The SHADE effect table for the variables measured at the end of the growing season.

SHADE	TDW	RDW	RCD	H2	BD
	..g..	..g..	..mm..	..cm..	..mm..
no	0.18	0.10	1.53	5.85	2.21
yes	0.12	0.08	1.13	5.46	2.09

Table 47. Raw and standardized canonical discriminant function coefficients for factor SHADE.

Response variable	Raw coefficients	Standardized coefficients
	CDF#1	CDF#1[1/]
TDW	22.52	1.31
RDW	-33.65	-1.03
RCD	6.14	1.30
H2	-0.89	1.17
BD	-0.04	-0.01

1/ CDF#1 denotes canonical discriminant function.

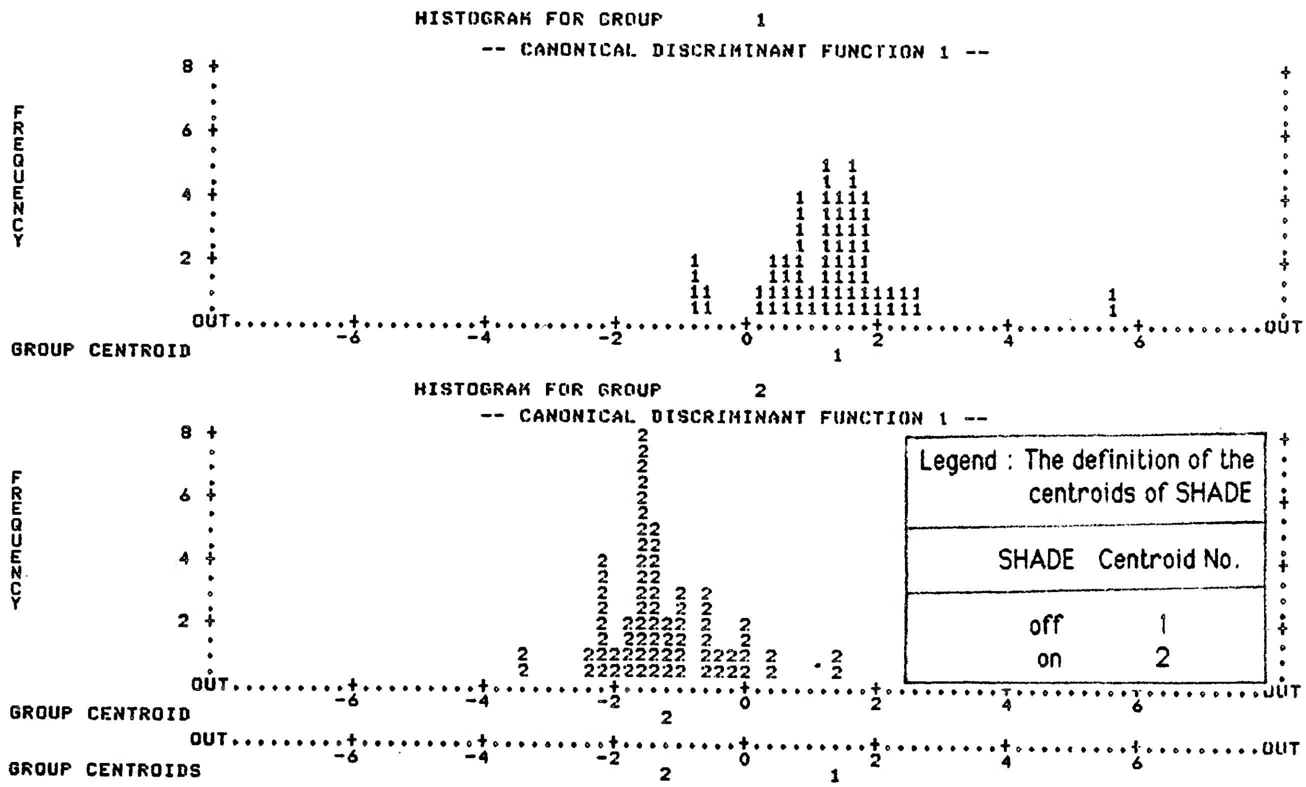


Figure 12. The canonical variates plots of the SHADE factor for the variables top dry weight, root dry weight, root collar diameter, bud diameter and height measured at the end of the growing season.

Duration x Shade Interaction

The cell means of DURATION x SHADE interaction are given in Table 48 for the five response variables. According to the dimension reduction analysis (Table 39), the 6 centroids of the D x S interaction table lie in 3-dimensional subspace of the response space. Therefore, the first 3 canonical discriminant functions CDF1, CDF2, and CDF3 provide the best 3-dimensional view of the response. The raw and standardized coefficients of CDF1, CDF2, and CDF3 are presented in Table 49.

Table 48. The SHADE x DURATION interaction table for the variables measured at the end of the growing season.

SHADE	variable	DURATION (weeks) 7	10	13
	TDW	.... g	....	
no		0.20	0.19	0.17
yes		0.14	0.13	0.11
	RDW	.... g	....	
no		0.08	0.11	0.13
yes		0.06	0.08	0.09
	RCD	.... mm	....	
no		1.42	1.53	1.64
yes		1.01	1.15	1.23
	H2	.... cm	....	
no		6.25	5.81	5.50
yes		6.16	5.43	4.78
	BD	.... mm	....	
no		2.04	2.25	2.34
yes		1.96	2.19	2.12
no	TDW/RDW	2.55	1.75	1.33
yes		2.45	1.56	1.25

Table 49. Raw and standardized canonical discriminant function coefficients associated with the SHADE x DURATION interaction.

Response variable	Raw coefficients CDF#1	CDF#2	CDF#3	Standardized coefficients CDF#1	CDF#2	CDF#3[1/]
TDW	-13.26	40.65	-42.83	-0.78	2.39	-2.53
RDW	54.30	-58.04	10.88	1.42	-1.52	0.28
RCD	2.55	4.59	5.86	0.50	0.91	1.16
H2	-0.82	-1.13	-1.69	-1.04	-1.43	2.15
BD	1.05	-0.16	-4.12	0.20	-0.03	-0.78

1/ CDF#1, CDF#2, and CDF#3 are canonical discriminant functions 1, 2, and 3 respectively.

It is possible, but inconvenient, to look at the plot of discriminant scores in the 3-dimensional space defined by CDF1, CDF2 and CDF3. However, CDF1 and CDF2 together account for 95 percent of the total variation in the measured response variates (Appendix 18). CDF3, on the other hand, carries only a little additional information even though this information is significantly different from zero. Therefore, I have elected to ignore CDF3 and analyse the best 2-dimensional view of the response. The discriminant scores of the experimental units in each group, and the 6 group centroids are illustrated with respect to the first 2 canonical discriminant functions in Figure 13.

Shade x Acclimatization Interaction

The cell means of the SHADE x ACCLIMATIZATION interaction are given in Table 50 for each of the five variables. According to the dimension reduction analysis (Table 39), the 4 centroids of the S x A interaction lie in a 2-dimensional subspace of the response space. Therefore, the first 1 canonical discriminant function, CDF1 provides the best 1-dimensional view of the response. The raw and standardized coefficients of CDF1 is presented in Table 51. The discriminant scores of the experimental units in each group, and the 4 group centroids are illustrated in Figure 14.

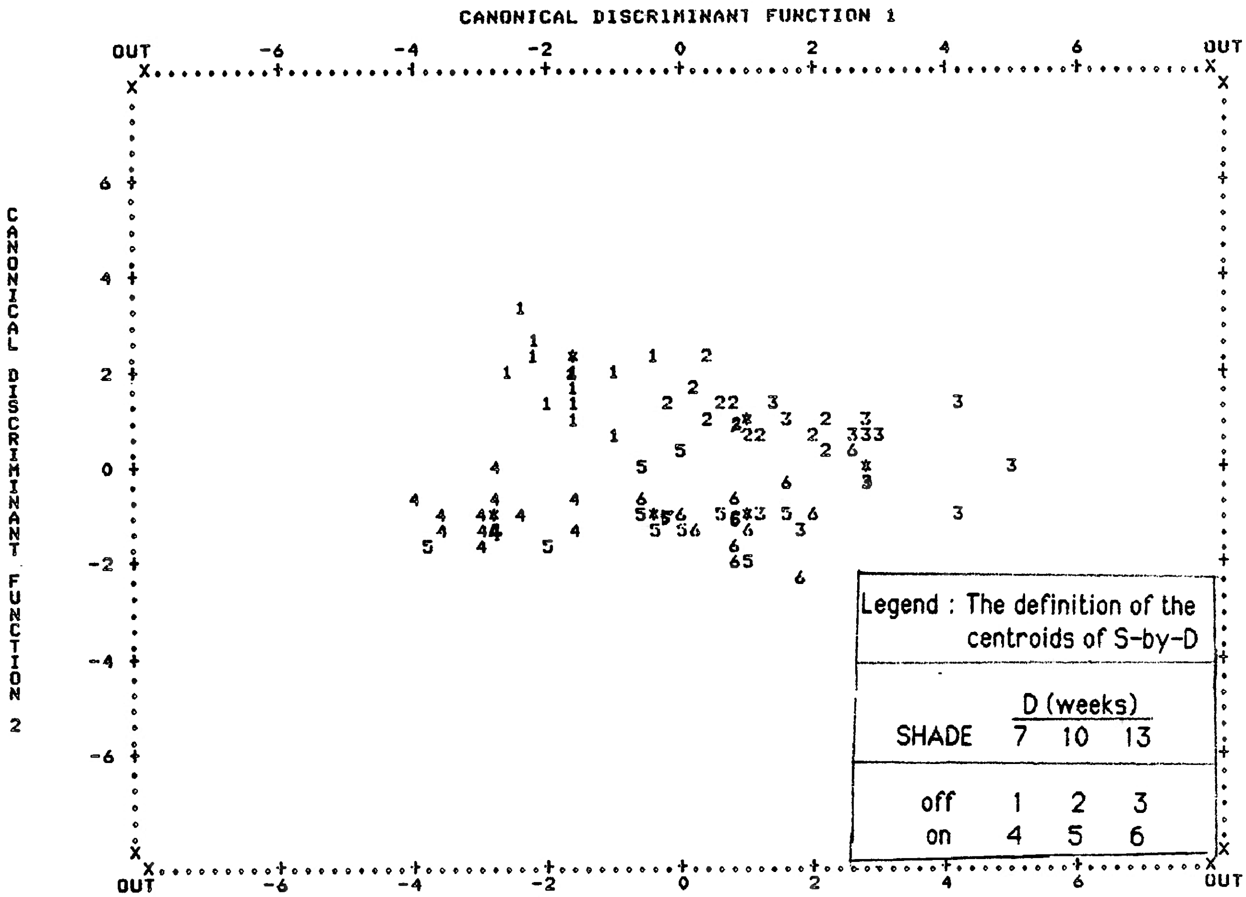


Figure 13. The canonical variates plot of the DURATION x SHADE interaction for variables top dry weight, root dry weight, root collar diameter, height, and bud diameter measured at the end of the growing season.

Table 50. The SHADE x ACCLIMATIZATION interaction table for the variables measured at the end of the growing season.

Shade	variable	ACCLIMATIZATION no	ACCLIMATIZATION yes
	TDW	.... g	....
no		0.18	0.19
yes		0.13	0.12
	RDW	.... g	....
no		0.10	0.10
yes		0.08	0.07
	RCD	.... mm	....
no		1.55	1.51
yes		1.19	1.08
	H2	.... cm	....
no		5.75	5.95
yes		5.62	5.30
	BD	.... mm	....
no		2.17	2.25
yes		2.16	2.02

Table 51. Raw and standardized canonical discriminant function coefficients associated with the SHADE x ACCLIMATIZATION interaction.

Response variable	Raw coefficients CDF#1	Standardized coefficients CDF#1 1/
TDW	21.73	1.27
RDW	-33.98	-1.05
RCD	6.16	1.29
H2	-0.86	-1.15
BD	0.05	0.22

1/ CDF#1 is the anonical discriminant function.

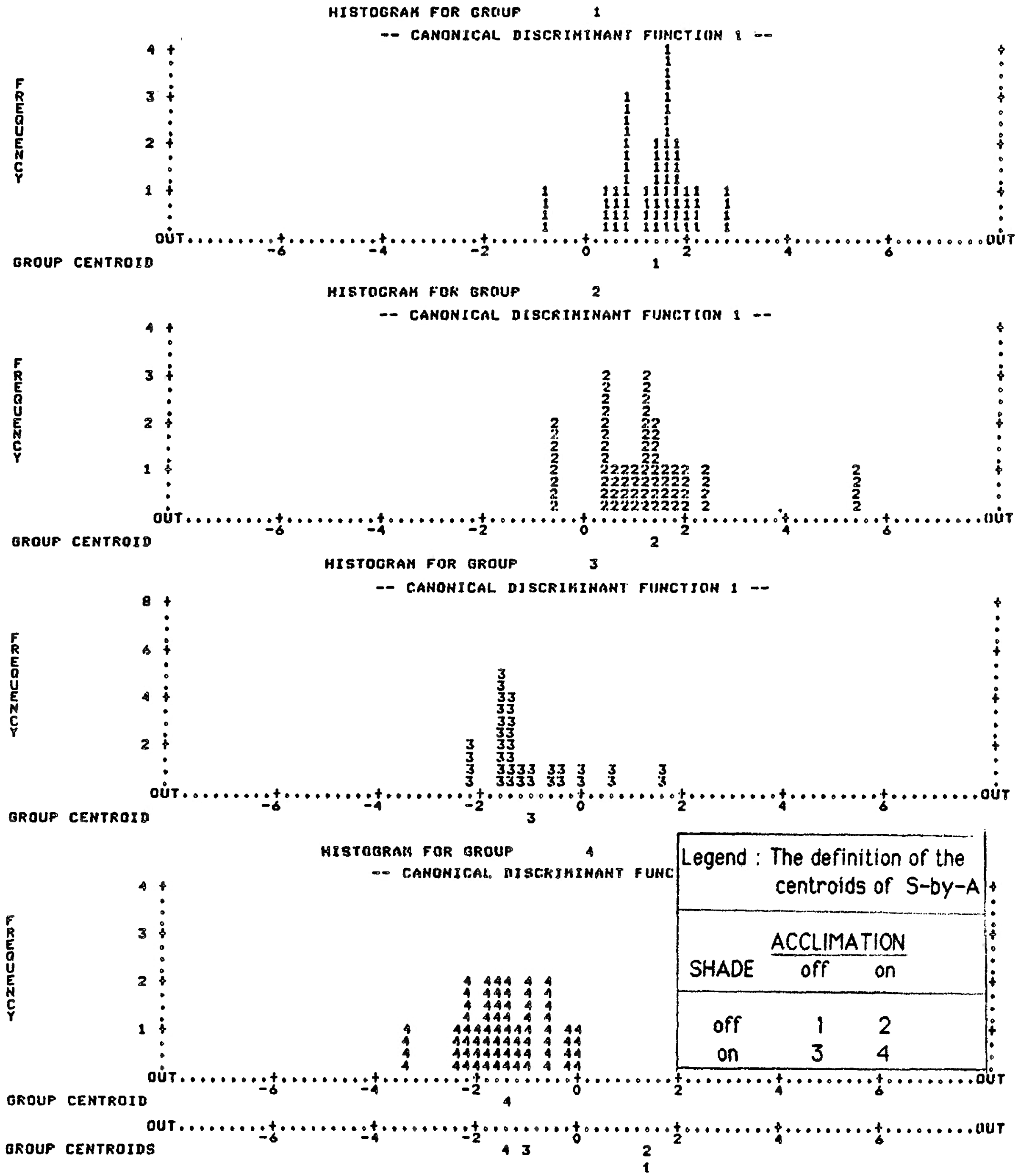


Figure 14. The canonical variates plots of the interation SHADE x ACCLIMATIZATION for the variables top dry weight, root dry weight, root collar diameter, height, and bud diameter at the end of the growing season.

DISCUSSION

In this section, I attempt to highlight the results of the transplant bed experiment, and to give a biological interpretation to these results whenever possible. As in the RESULTS section of this chapter, the 2 uncorrelated response variables, bud-set ratio and survival ratio, are discussed first followed by a discussion of the multivariate response of the 5, correlated, end-of-season attributes.

In the next chapter, I will again discuss the results of both greenhouse and transplant bed experiment and attempt to give an integrated biological interpretation of all the results. I will also interpret the results for nurserymen.

Bud-set

One of the most surprising, interesting, and important results of my experiment was the earlier than expected bud-set that occurred in some of the treatment combinations. I first began monitoring for normal, end-of-season bud-set on August 5. By that time, most of the premature bud-set that was going to occur had already taken place. Apparently, bud-set occurred, at least in some cases, soon after transplanting. Since I did not expect premature bud-set, I missed the opportunity to monitor it as well as I might otherwise have done. Specifically, I did not observe the chronological progression of premature bud-set through the treatment combinations.

Further, because I did not anticipate premature bud-set, I did nothing experimentally to investigate factors that are known to influence bud development in black spruce seedlings. These factors include: temperature, photoperiod, light intensity, moisture regime, and nutrient regime (Colombo 1982, 1984, D'Aoust and Cameron 1982, Pollard and Logan 1977). As a result of these oversights in the design and execution of my experiment, I can make only indirect inferences about the phenomenon of premature bud-set as it affected my experiment.

Duration in the Greenhouse

Factor DURATION had by far the greatest single effect on premature bud-set (Table 26). Only 2 percent of the 7-week crop had set buds after about 9 weeks in the transplant beds. The 10-week and 13-week crops, on the other hand, had 63 and 82 percent set buds after the same period in the transplant beds. It seems likely that some physiological threshold was exceeded between 7 and 10 weeks in the greenhouse that triggered the bud-set response. The threshold may have been related to either the physiological maturity of the seedlings or to moisture stress and/or nutrient stress imposed on the seedlings that were held in the greenhouse for 10 or more weeks.

Duration x Acclimatization Interaction

The effect of DURATION seems to have been modified by the acclimatization treatment although some of the trends that I am about to discuss were not significant according to the SNK-test (Figure 15). In the case of 7 and 10-week seeldings, acclimatization depressed bud-set slightly, but not enough so that the means within a given level of DURATION were significantly different under the SNK-test. At 13-weeks, however, acclimatization promoted premature bud-set. One explanation is this: by 12 weeks (the age of the 13-week crop at the beginning of their acclimatization treatment), seedlings must have been subjected to the highest level of moisture and /or nutrient stress seen in this experiment. The additional stress of being moved outside, where both the minimum temperature and photoperiod were lower than in the greenhouse, may have triggered additional bud-set. Given the SNK-test results on mean differences, it is perhaps trying to read too much into the results to ask why the 7 and 10-week crops were affected in the opposite way. In any case, I have no explanation.

Duration x Outplant Date Interaction

The effect of DURATION was also modified by outplant date (Fig. 16). In general, the later the outplant date, the lower the incidence of premature bud-set (Table 31). The O x D interaction seems to have resulted from the unusually high bud-set response that affected the 13-week crop planted on

June 11. There is no obvious reason for this anomaly although any single event, or combination of events, associated with the greenhouse or the field environment experienced during the culture of this crop could be responsible.

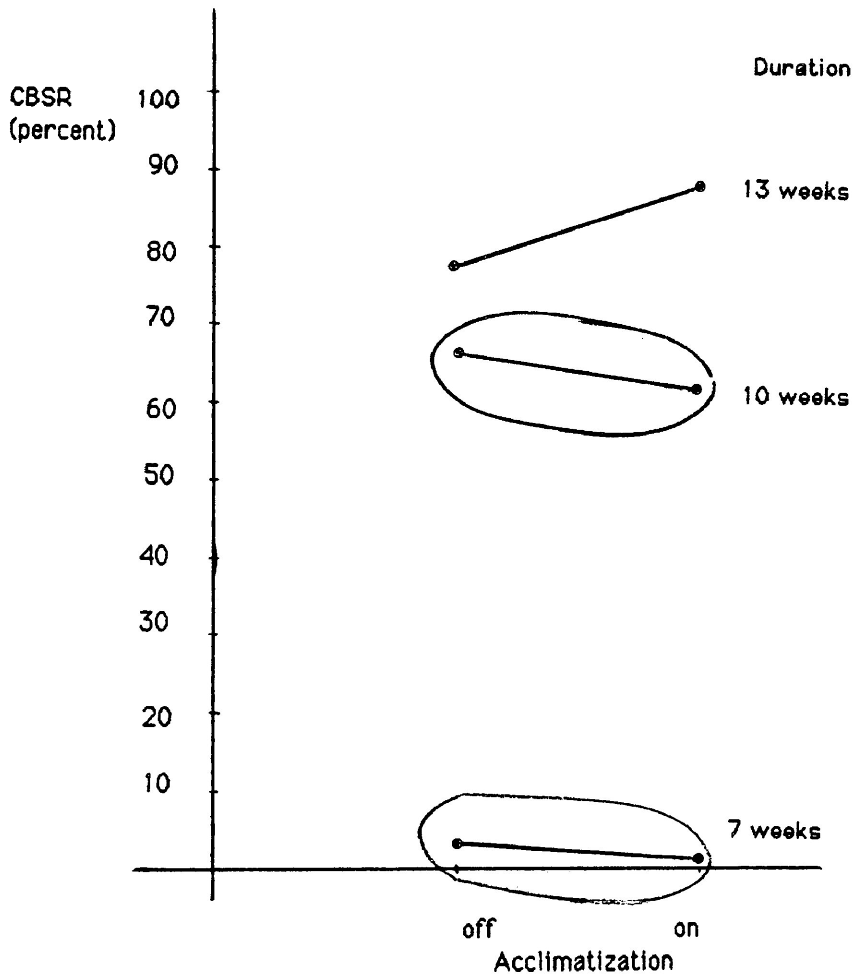


Figure 15. ACCLIMATIZATION * DURATION CBSR (corrected bud-set ratio) means. The means located in the same circle are not significantly different at 5 percent level under SNK-test.

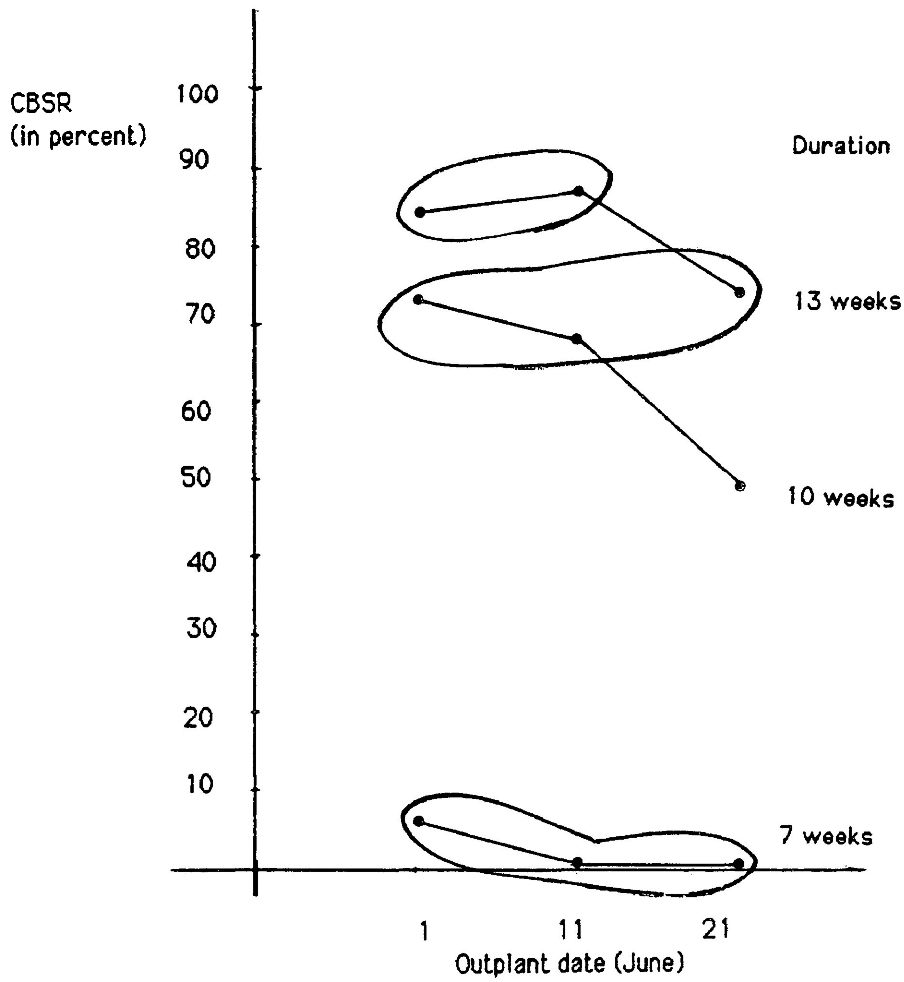


Figure 16. DURATION * OUTPLANT DATE CBSR (corrected bud-set ratio) means. The means located within the same circle are not significantly different at the 5 percent level under the SNK-test.

Duration x Shade Interaction

Finally, the effects of DURATION were modified by the shade treament (Fig. 17). Overall, the effect of shade was to promote premature bud-set (Table 30). However, the effect seems to have been more pronounced as DURATION increased. Probably, the environmental conditions under the shades must have been more favorable to the seedlings with respect to moisture stress, but less favorable with respect to light, than conditions in the open. Therefore, it may have been that the negative effects of reduced light in combination with the increasing stressed condition of the seedlings of 10 and 13-week crops in the greenhouse resulted in the observed D x S interaction.

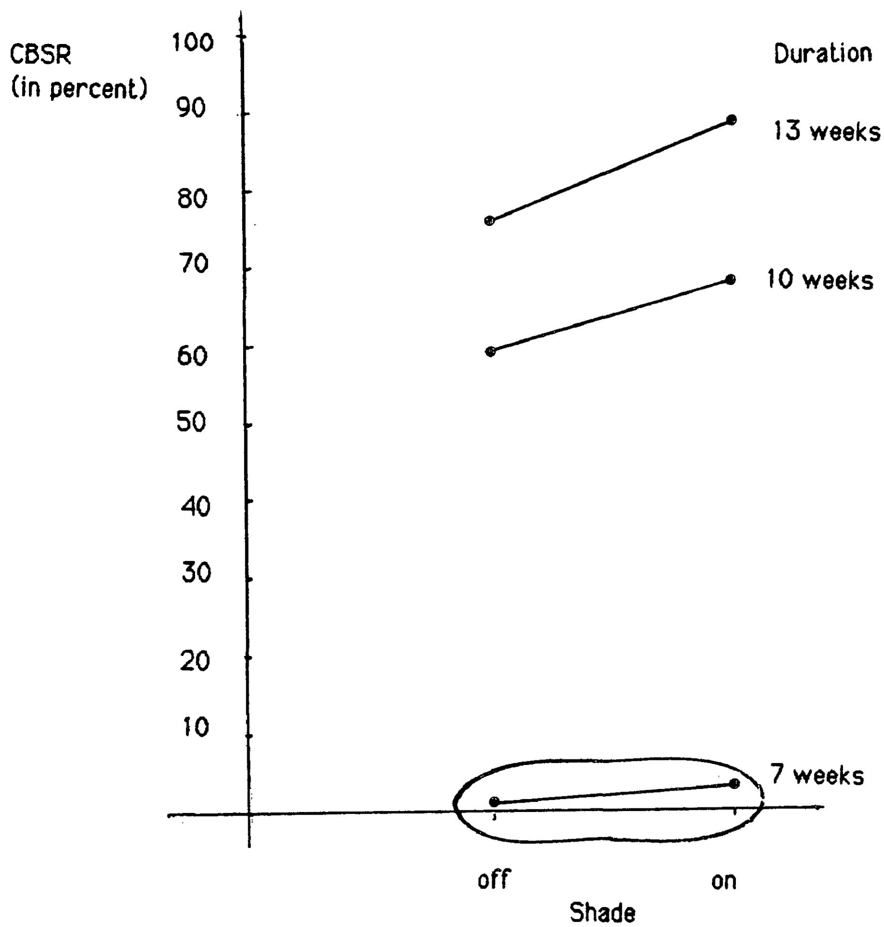


Figure 17. DURATION *SHADE CBSR (corrected bud-set ratio) means. The means within the same circle are not significantly different at the 5 percent level under the SNK-test.

<u>Outplant Date x Acclimatization Interaction</u>

The main effect of OUTPLANT DATE suggests a gradual decline in the incidence of bud-set from the first (June 1) to the last (June 21) outplanting date (Table 31). The effect of outplanting date was modified, however, by whether or not the seedlings were acclimatized before transplanting (Fig. 18). The June 21 crops experienced higher rates of bud-set when the seedlings were acclimatized. In the case of June 11 crops, however, the opposite pattern was observed. The explanation may have to do with the number of times that seedlings in each crop were exposed to low temperature.

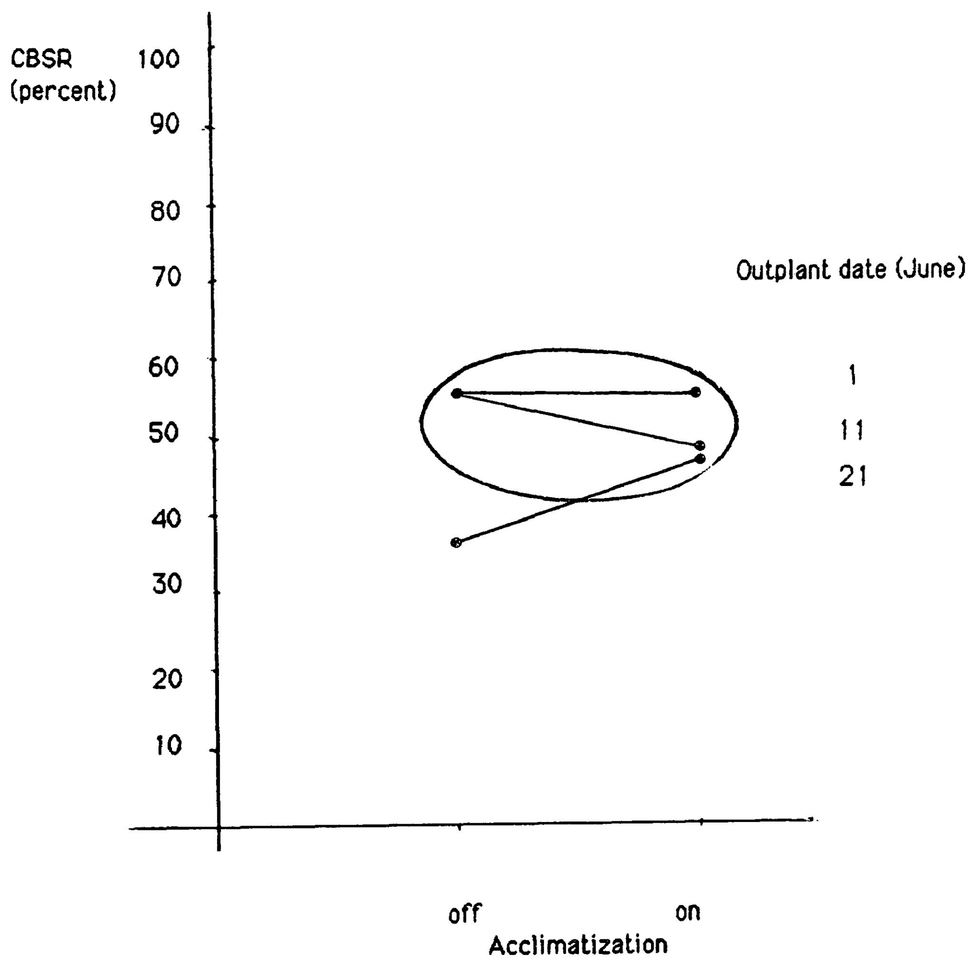


Figure 18. ACCLIMATIZATION x OUTPLANT DATE CBSR (corrected bud-set ratio) means. The means located within the same circle are not significantly different at the 5 percent level under the SNK-test.

Bud-set and dormancy can be induced by low temperature. In black spruce, the critical temperature occurs between -5 and +5°C (Glerum 1982). Was low temperature the cause of premature bud-set in my experiment? To find out, I looked at local weather records for the period beginning on May 25, the first day when seedlings to be acclimatized were placed outside, and August 5, the first day when bud-set was monitored in the transplant beds. Table 52 summarizes the number of days when the minimum temperature was +5°C or lower for each combination of ACCLIMATIZATION x OUTPLANT DATE.

Table 52. The number of days on which the minimum temperatures experienced by seedlings in each of the 6 categories of ACCLIMATIZATION and OUTPLANT DATE were equal to or lower than 5°C.

Acclimatization	Outplant date (June)		
	1	11	21
no	7	6	2
yes	13	7	5

If low temperature were an important contributor to premature bud-set, then bud-set ratio should have increased with the number of sub +5°C days. Figure 19 illustrates that this may be the case, although the trend is weak.

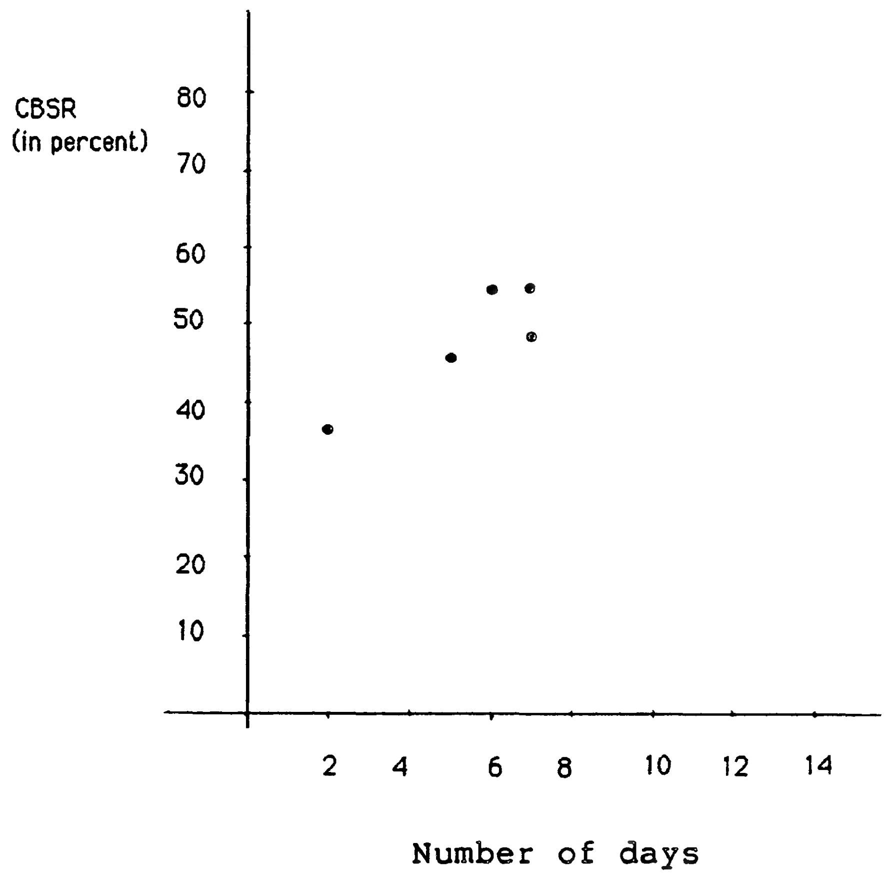


Figure 19. CBSR (corrected bud-set ratio) plotted against the number of days with temperature equal to or lower than 5°C.

When the different outplanting dates are compared with each other (Table 52), it is apparent that the acclimatized half of the crops outplanted on June 1 and June 21 experienced substantially more sub +5°C days than did the unacclimatized half of these crops. On June 11, the differential between the number of sub +5°C was slight.

Care must be taken, however, not to read too much into these results. According to the SNK-test, only one average bud-set ratio in the A x O interaction table is significantly different from the other means. Thus, there is some evidence that low temperature had an effect in promoting premature bud-set. As in the D x O interaction, any number of other environmental factors acting either singlarly or together could have caused the observed response.

Seedling Survival

Seedling survival was first monitored on July 25. Most of the seedling mortality during the growing season had already taken place by that time. Therefore, I missed the opportunity to observe the chronological progression of the seedling mortality through the treatment combinations.

Duration in the Greenhouse

As duration was increased, seedling survival improved. The major difference occurred between the 7 and 10-week levels of the DURATION factor (Table 35). There seems to be a threshold between the two levels of the DURATION at which higher seedling survival was reached. The threshold may be associated with the level of seedling lignification and the number of the seedling roots at transplanting (Tables 12 and 35).

Seedling survival at the 13-week level of DURATION was not significantly different from that of 10-week level at the 5 percent level of significance under the SNK-test (Table 35). Thirteen-week old seedlings were pot-bound (by visual observation) and may have been subjected to moisture and/or nutrient stress before transplanting. These stresses might have resulted in seedlings with low vigor, thus reducing the seedling's ability to absorb moisture and nutrients and to regenerate new roots after transplanting. These low vigor seedlings had high mortality in the transplant beds.

Outplant Date

The significant effects of the OUTPLANT DATE factor on seedling survival lay between the June 1 planting date and the other two dates, June 11 and June 21 (Table 36). After transplanting, besides the morphological and physiological conditions of the seedlings, moisture and temperature were the most important factors affecting seedling survival in this study. However, the moisture regime in the transplant beds was not monitored. Comparing the maximum temperatures during the first 10 days following each planting date (Table 53), it may be possible to conclude that the extremely high temperatures in the first a few days might have caused the high mortality of the seedlings planted on June 1 and 21.

It is also possible that after the first planting date, June 1, soil temperature was low and not favorable for root regeneration. The difficulty for the seedlings to establish a new root system plus the extremely high temperature just after planting may result in high moisture deficits in the seedlings. This may have caused the high mortality of the crop planted on June 1.

Table 53. Maximum temperatures (in °C) during the first 10 days following each of the 3 outplanting dates.

Planting date	days 1	from 2	3	the 4	5	outplanting 6	7	8	date 9	10
June 1	17.0	24.7	28.4	20.5	17.6	16.7	17.8	21.7	14.4	12.8
June 11	22.5	14.7	19.4	19.0	17.2	22.0	16.1	27.1	15.9	20.2
June 21	18.8	14.7	25.3	20.5	21.8	23.1	21.2	20.4	24.9	26.9

Outplant Date x Shade Interaction

The effects of OUTPLANT DATE were modified by the shade treatment (Fig. 20). Overall, shade increased seedling survival (Table 34). The effects of shade were more pronounced in association with the later outplanting dates. Seedlings planted on June 21 had an unusually low survival ratio if they were not shaded after planting. This may have caused the significant effects of the interaction on the seedling survival. The maximum temperatures during the first 10 days following planting date June 21 were usually higher than those following the other planting dates (Table 53). Seedlings planted on June 21 may have suffered high moisture stress if they were not shaded during that period and this may have caused the unusually low seedling survival ratio.

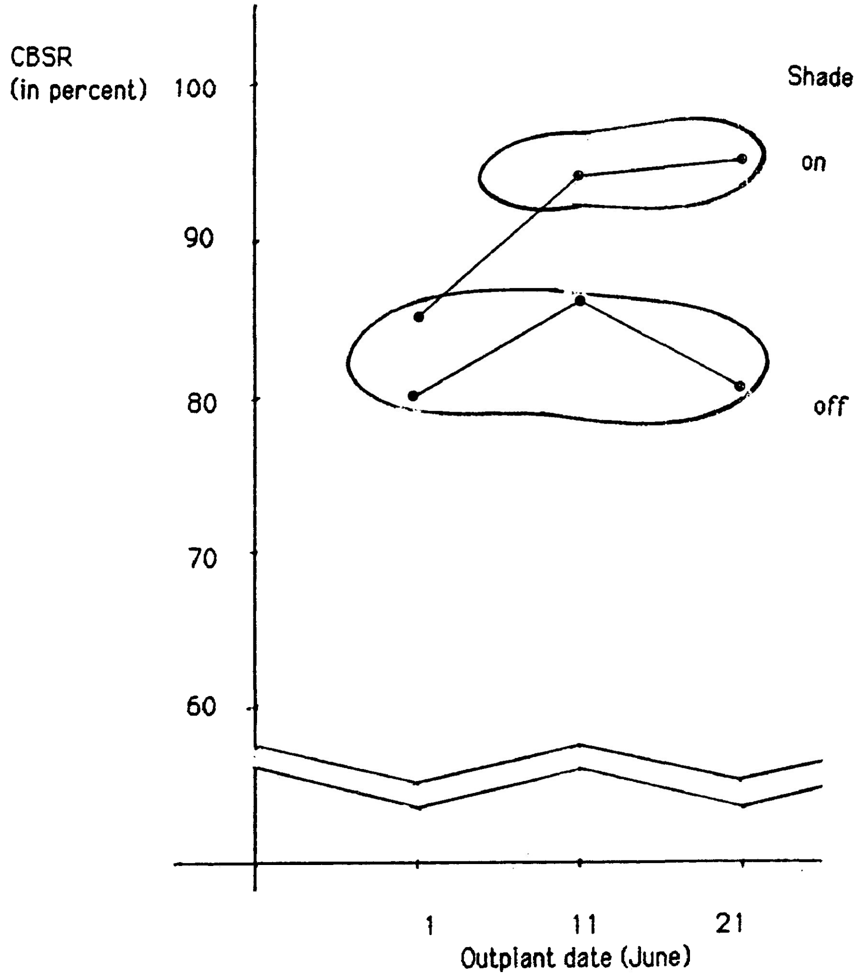


Figure 20. OUTPLANT DATE * SHADE CBSR (corrected survival ratio) means. The means located within the same circle are not different at the 5 percent level of significance under the SNK-test.

Seedling Attributes at the End of the Growing Season

The five end-of-season response variables were: height (H2), top dry weight (TDW), root dry weight (RDW), root collar diameter (RCD), and bud diameter (BD). Since the end-of-season response was multivariate, its interpretation follows somewhat different lines from the interpretation of the univariate analyses presented above.

According to the MANOVA, 6 sources of variation had significant effects on the multivariate response. They were the main effects of DURATION (D), SHADE (S), and OUTPLANT DATE (O), and the interaction effects, D x S, D x O, and S x A. Each of these effects will be discussed in turn in the section that follows.

<u>**Duration**</u>

No doubt, some readers are unfamiliar with the interpretation of multivariate analysis of variance. Since this is a technical subject, I will discuss the response of this first effect, DURATION, in somewhat more detail than in the sections that follow. Specifically, I will try to be clear about the basis for each inference.

Factor DURATION dominated the response of the 5, end-of-season seedling attributes just as it did during the earlier stages of the crop development (Table 38). To discover the nature of the DURATION response, I first examined the results of the canonical discriminant function analysis (Tables 39, and 41). According to the dimension reduction analysis, the effective dimension of the DURATION response is 1. This means that the centroids of the 3 levels of DURATION lie in, or at least close to, a line in 5-dimensional response space. This implies that I can map the response onto a single axis where it is easier to view and interpret than it would be in the original 5-space.

Canonical discriminant function 1 (CDF1) is the equation of the line in 5-space that gives the best 1-dimensional approximation of the DURATION response in the least square sense. CDF1 is valuable in three ways. First, the canonical discriminant score associated with each level of DURATION provides the basis for a multiple comparison of centroids similar to that of means of theSNK-test in the univariate analysis. This idea was mentioned in Chapter 3. An example is given in Appendix 21. In the case of DURATION, it is clear from Figure 9 that the multivariate response of the 10 and 13-week crops were more similar to one another than to the 7-week crop.

Second, when the sign is ignored, the standardized coefficient associated with each measured variable (H2, TDW, RDW, RCD, and BD) indicates the relative importance of that variable to the canonical discriminant function. In the case of factor DURATION, the largest standardized coefficient is that associated with RDW (the value is 2.08 in Table 41 followed by TDW (-1.38), H2 (-0.70), BD (0.20) and RCD (-0.12)). Thus, RDW is about 1.5 times (2.08/1.38) more important than TDW, and 17 times (2.08/0.12) more important than RCD, in characterizing the multivariate response of the seedlings to factor DURATION.

Third, the different signs of the coefficients tell the correlation between different variables. Variables with the same sign are positively correlated, and those with different signs are negatively correlated to one another.

This might be useful in investigating the effect patterns of the factor on different response variables, and the relationship between variables.

Guided by the magnitude of the standardized CDF coefficients, the next step is to examine means associated with the most important variables. In the case of DURATION, variables RDW, TDW and H2 seem important enough to warrant further notice (Tables 40 and 41, and Fig. 21 and 22). These results show that at the end of the first growing season in the transplant bed experiment, the crop that spent 13 weeks in the greenhouse had heavier roots (+59 percent more RDW), but a smaller top (14 percent less TDW, and 17 percent less H2), than the crop that spent 7 weeks in the greenhouse. The response of the 10-week crop was intermediate, but was more similar to the 13 than to 7-week crop.

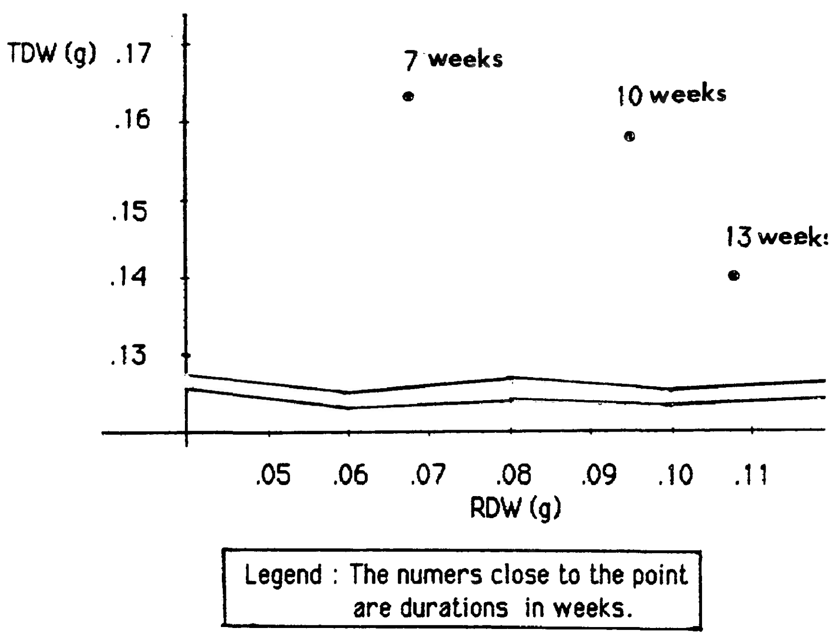


Figure 21. TDW (top dry weight) plotted against RDW (root dry weight) for the factor DURATION.

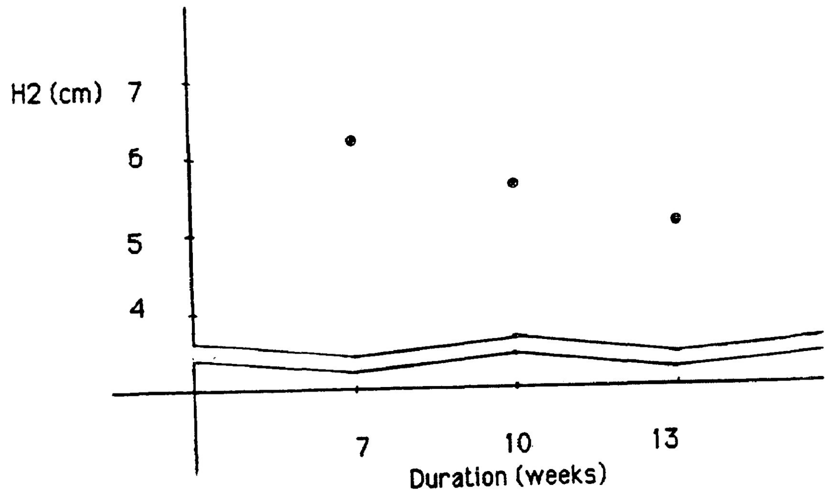


Figure 22. Seedling height at the end of the growing season (H2) plotted against the factor DURATION.

I believe these results stemmed from the effect of DURATION on bud-set ratio. The 10 and 13-week crops set buds prematurely, while the 7-week crop did not. Thus, the 7-week crop produced height growth throughout the entire growing season. The 10 and 13-week crops, produced little additional height growth following transplanting although root growth apparently continued at a rapid rate.

Shade

The seedling growth was depressed when shade was applied (Table 46). TDW, RDW, and H2 seem to have been affected equally (Table 47). Scarratt (1974) also found that shade caused a significant depression of the growth of black spruce seedlings 12 weeks after planting. The reason may be that low light intensity reduces photosynthesis (Mooney 1972, Brix 1967), and so seedling growth.

Duration x Shade Interaction

The 6 centroids of the interaction D x S are significantly different from one another (Figure 13). Variables TDW, RDW, and H2 are all important in discriminating between the 6 groups of D x S (Table 49). It seems however that the interaction is not present in TDW (Figure 23) although the standardized coefficient associated with it is the largest in the second function (Table 49). Indeed, the D X S interaction seems to be due to RDW and H2 (Figures 24 and 25). Shade had an increasing by negative effect on RDW and H2 as duration increased (Figures 24 and 25). The effect patterns were opposite to those of the same interaction on bud-set (Figure 17). This reflects the negative effects of premature bud-set on seedling growth attributes RDW and H2 during the growing season.

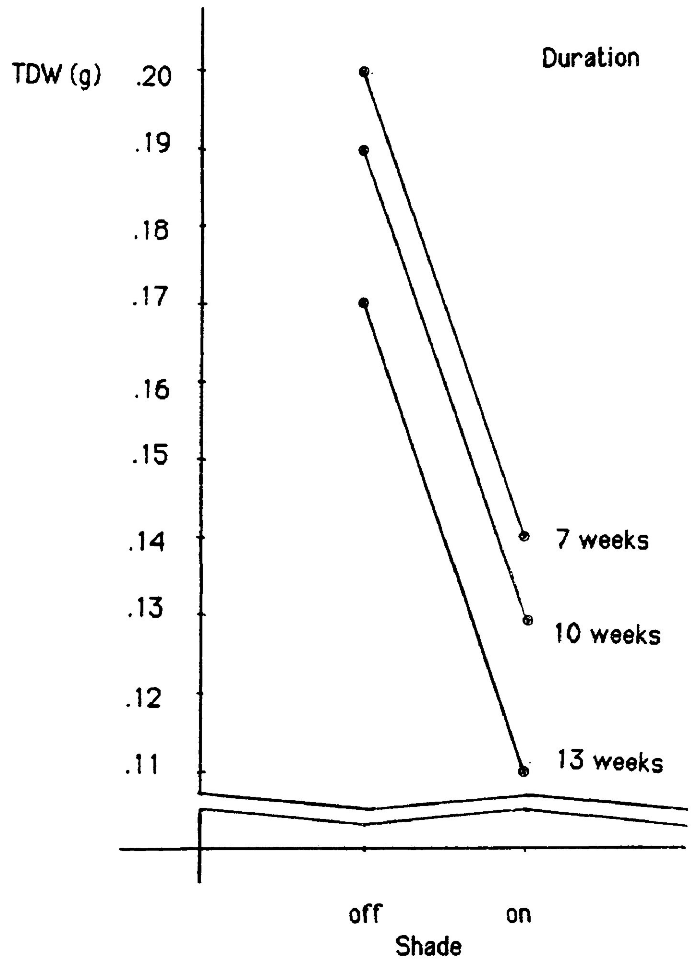


Figure 23. SHADE x DURATION TDW (top dry weight) means.

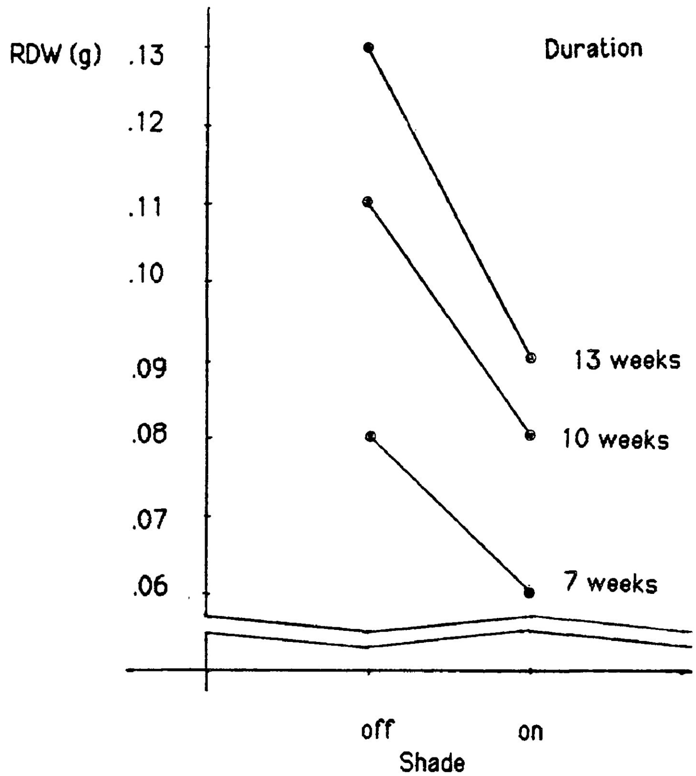


Figure 24. SHADE x DURATION RDW (root dry weight) means.

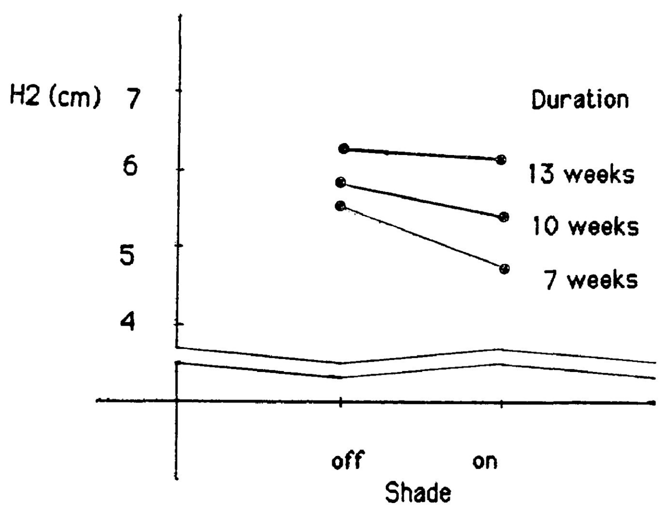


Figure 25. SHADE * DURATION H2 (height at the end of the growing season) means.

Duration x Outplant Date Interaction

The main effect of OUTPLANT DATE is significant in the MANOVA analysis (Table 38), but the differences between means among the 3 levels of the factor on the 5 variables are negligible (Table 42). Therefore, it may not be of practical importance to try to explain the significant effects of the factor for any such interpretation may be misleading.

The 9 centroids of the D x O interaction are significantly different from each other (Figure 11). Of the 5 response variables, the most important variables seem to be RDW, clearly in CVF#1, and TDW, in CVF#2(Table 45). The D x O interaction in the 2-dimensional response space defined by these two variables is illustrated in Figure 26. The figure shows that even when the respon is reduced to just 2 variables, the D x O interaction is complex and difficult to interpret.

The problem with interpreting D x O, or for that matter any interaction effect that involves OUTPLANT DATE, arises from the fact that OUTPLANT DATE has so many uncontrolled sources of variation confounded with it. For example, any environmental event to which the seedlings responded would have affected the 9 crops, represented by the D x O teatment combinations, at 9 different stages of development. Thus, even a single event could have had positive, neutral or negative effects on a crop depending on 1) the D x O combination involved (i.e., on the physiological state of the seedlings when the event occurred), and 2) the response variable involved.

If there is a single, best combination of DURATION and OUTPLANT DATE in my experiment, it was the combination of 10 weeks in the greenhouse with June 11 outplanting date. Figure 27, glyph 5, illustrates that this combination resulted in large, well balanced seedlings. The seedlings in this crop, had a high survival ratio as well (Table 54). One must be cautious, however, about concluding that this particular treatment combination is "best" in any general sense. Because of the complex nature of OUTPLANT DATE effects, there can be no assurance that any D x O combination would have produced the same result in a different year, a different nursery, or even in a different greenhouse at Thunder Bay nursery.

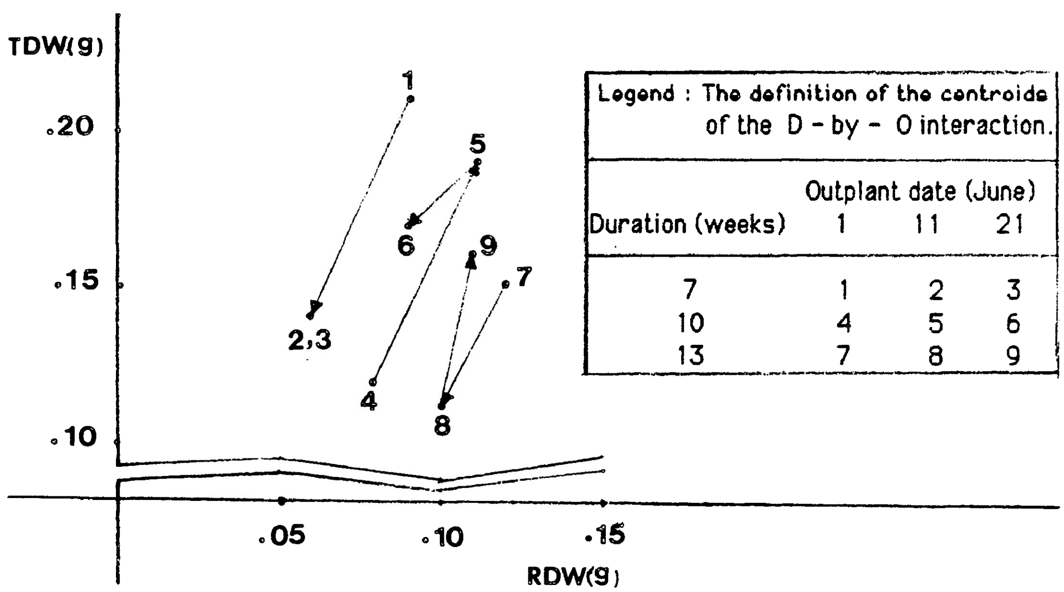
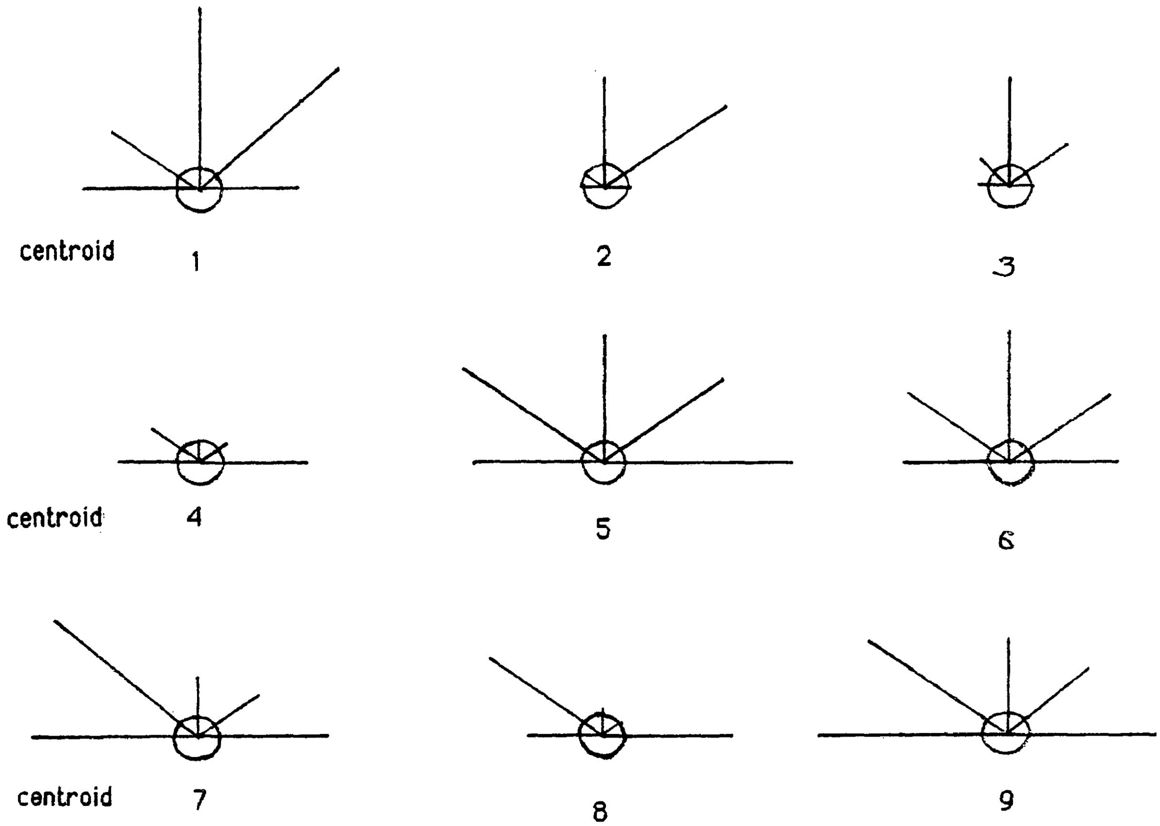


Figure 26. The D x O interaction with respect to variables RDW and TDW.



Legend : The definition of the centroids of the D - by - O interaction.			
	Outplant date (June)		
Duration (weeks)	1	11	21
7	1	2	3
10	4	5	6
13	7	8	9

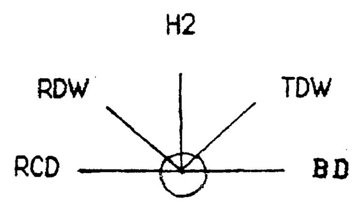


Figure 27. Glyphs (Anderson 1957) of the 9 centroids of the DURATION x OUTPLANT DATE interaction for variables top dry weight, root dry weight, root collar diameter, and height measured at the end of the growing season. The length of each ray is proportional to the value of the corresponding response variable.

Table 54. The DURATION x OUTPLANT DATE interaction table for the corrected survival ratio (CSR) in percent.

Duration (weeks)	Outplant date (June) 1	11	21
7	79.2	82.3	81.3
10	84.2	94.3	87.6
13	83.7	92.9	94.6

The D x O interaction suggests that there is much to learn about the effects of environmental factors on the Castle and Cooke system in both the greenhouse and the transplant bed phases of culture. To do this, it may be useful to study the relationships: 1) between the culture and the physiological condition in the greenhouse phase, and 2) between the seedling physiological condition of the seedlings in the greenhouse phase and the seedling growth following transplanting.

Shade x Acclimatization Interaction

Centroids 1 and 2 of the S x A interaction are overlapped so they are not significantly different at the 5 percent level (Figure 14). The distance between centroids 3 and 4 and centroids 1 and 2 is longer than that between centroids 3 and 4. This suggests that the major effects of the interaction lie between the two levels of SHADE.

The interaction is more important on 4 variables RCD, TDW, H2, and RDW (Table 51). In every case, acclimatization increased the already negative effects of shade in reducing seedling growth (Figures 28, 29, 30, and 31). That is acclimatization and shade had a greater effect on reducing seedling growth than shade did alone. Comparing these figures with Figure 32, it can be seen that bud-set of S x A interaction was negatively related to RCD; this is also true for RDW, TDW and H2 if seedlings were shaded. But this relation was opposite in RDW, TDW and H2 if seedlings were not shaded. I have no interpretation for this result.

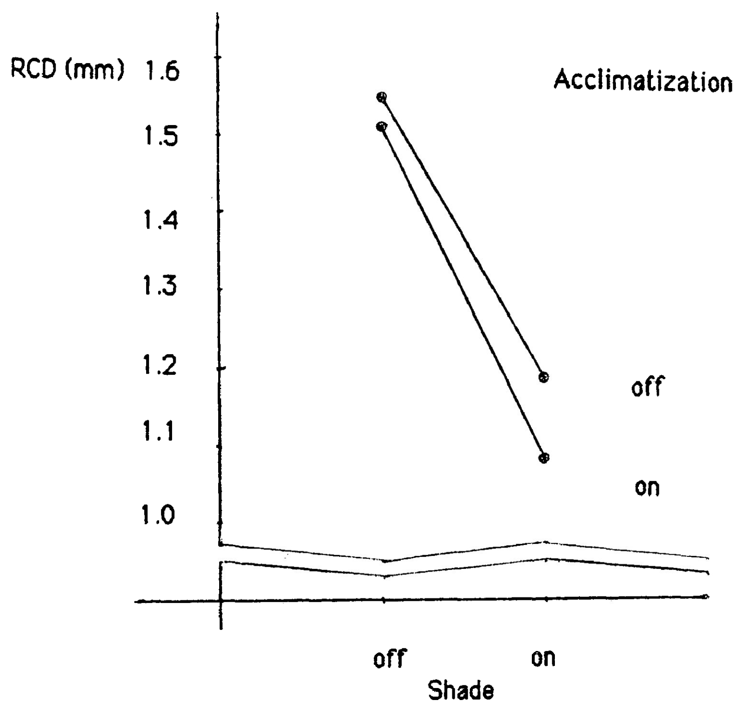


Figure 28. ACCLIMATIZATION x SHADE RCD (root collar diameter) means.

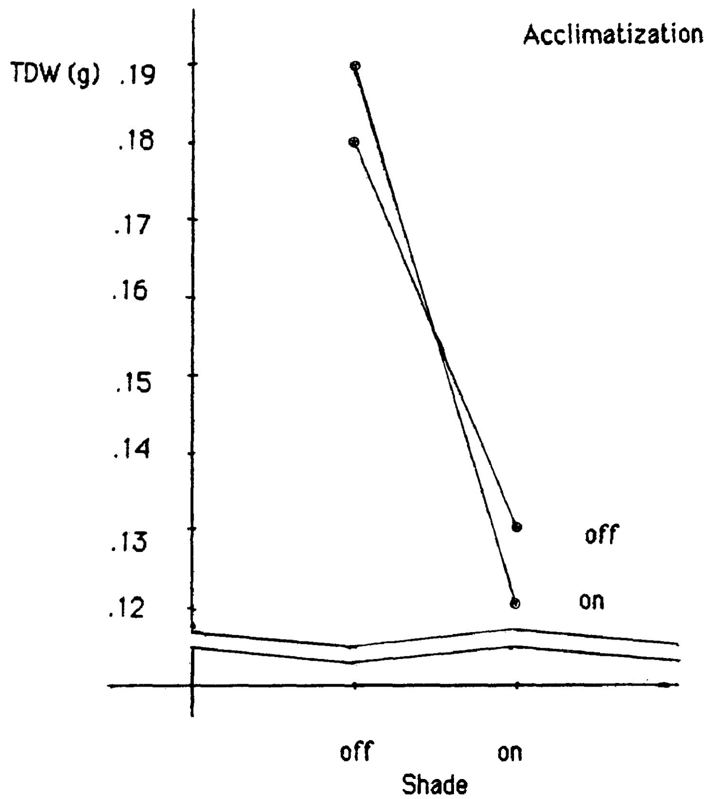


Figure 29. ACCLIMATIZATION x SHADE TDW (top dry weigth) means.

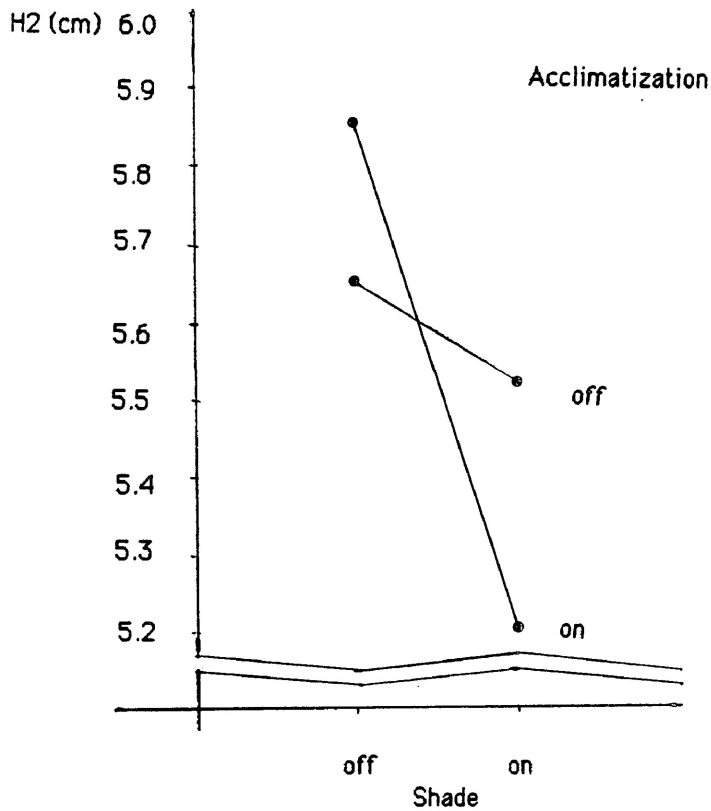


Figure 30. ACCLIMATIZATION x SHADE H2 (height at the end of the growing season) means.

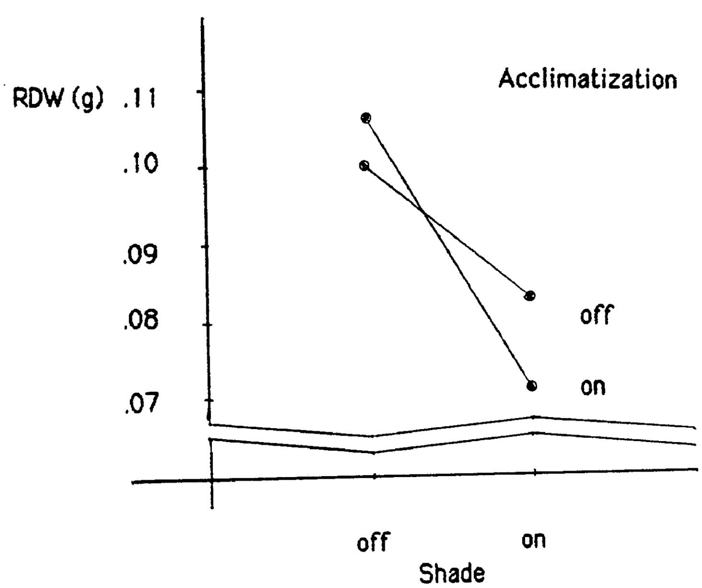


Figure 31. ACCLIMATIZATION x SHADE RDW (root dry weight) means.

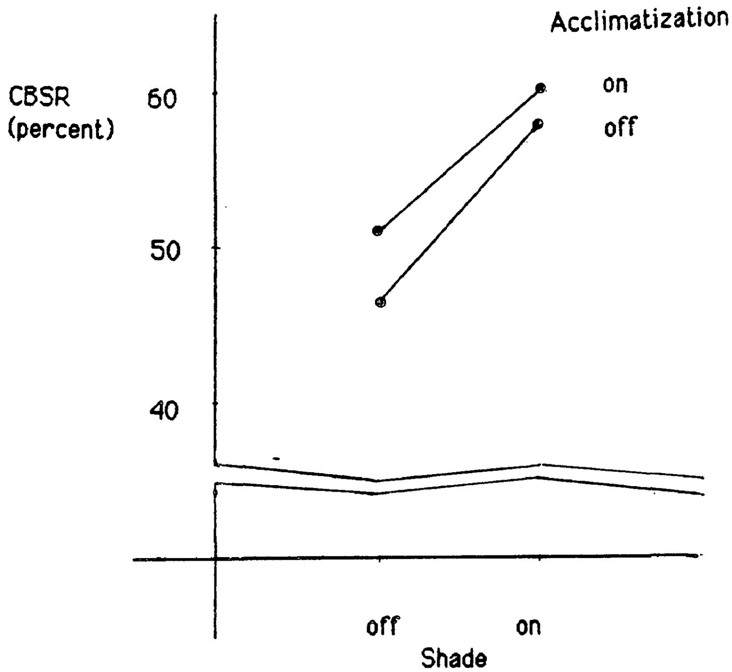


Figure 32. ACCLIMATIZATION x SHADE CBSR (corrected bud-set ratio) means.

CHAPTER 6

GENERAL DISCUSSION

DURATION was the most important factor studied in this experiment. Duration effect influenced both the morphological characteristics of the seedlings and their physiological condition at the end of the greenhouse experiment. The major difference in the seedling growth and development occurred between 7- and 10-week levels of the DURATION (Table 12).

Premature bud-set was highly correlated with the age and size of seedlings at transplanting time. Premature bud-set was negligible if the seedlings were 7 weeks old when transplanted (Tables 12 and 26). The threshold may be coincident with the optimum duration for the seedling growth in the greenhouse phase. It must have to do with the interaction of the physiological conditions of the seedlings at transplanting and the environment which the seedlings experienced in the transplant beds.

Bud dormancy development is controlled both genetically and environmentally. It is a complex physiological and biological process. It is regulated by the relative amounts of the growth-inhibiting substances, such as ABA, to growth-promoting substances, such as GA and IAA (Bidwell 1979). Any environmental conditions unfavorable for growth may promote the production of growth-inhibiting substances, thus inducing cessation of growth and the first stage of dormancy.

In this study the reasons for premature bud-set may be many. First, the seedlings experienced some changed environmental conditions between the greenhouse and transplant bed experiments. These conditions might include lower temperature, shorter photoperiod, lower light intensity, and less favorable moisture and nutrient regimes outside the greenhouse than in the greenhouse. These unfavorable conditions might cause stresses which made seedlings set premature buds. The reasons for the effects of the stresses were more pronounced on larger than on smaller seedlings may be: 1) the larger seedlings outgrew the container before planting; and 2) the longer the period of free growth, the more readily the seedlings set buds (Tinus, R.W. in lett. 15 July 1986).

Second, growth-inhibiting substances are produced by leaves (Wareing and Saunders 1971). As seedlings grew larger in the greenhouse phase, they had more leaves (although not measured) to produce growth-inhibiting substances under an unfavorable environment.

Third, it is possible that the small volume (6 ml) and the close spacing of the container cavity might have pushed the seedling development to a point at which the seedlings were exposed to moisture and/or nutrient stress, so their vigor was reduced.

Finally, the peculiar medium of the container might have some effects, one of which is that it loses water very fast. This may cause high moisture stress on seedlings, especially, when it is hot.

All the above reasons may favor a relative high production of growth-inhibiting substances in the older and larger seedlings after transplanting, thus resulting in the high premature bud-set.

Premature bud-set was an undesirable phenomenon in this study and in practice during the growing season. How the culture in the greenhouse experiment affected the physiological conditions of the seedlings, and how these physiological conditions interacted with the environment in the transplant beds to influence premature bud-set deserves more research.

Seedling age and size at the end of the greenhouse phase (Table 12) were positively correlated with seedling survival (Table 26), and the bud-set ratio in the transplant beds (Table 35). The reason for these results may be as follows. First, after planting, older and larger seedlings with more roots had better contact with soil. Probably, they could absorb more water and nutrients to survive moisture and nutrient stresses. Second, as seedlings grew older and larger, the diameter and the degree of lignification of their stems increased. This in turn increased the sturdiness of the seedlings, and resulted in higher seedling survival. Finally, bud-set may positively affect seedling survival since dormant seedlings are more tolerant to unfavorable conditions. The relationship between the lignification of the seedling stem at outplanting and seedling survival needs more reserach.

Seedling survival increased with successively later outplanting dates (Table 36). The smaller number of roots of 7-week old seedlings may be a possible reason for the significantly low survival of seedlings planted on June 1 (Table 36). Comparing Tables 36, 37, and 53, it is possible to say that the high temperatures and associated high moisture stress following outplanting may be another reason for low survival. The results also show that most seedling mortality took place shortly after planting (Table 22). This suggests that care be taken to improve seedling survival, especially, in the short period immediately following transplanting, or to condition the seedlings better before transplanting.

Premature bud-set greatly influenced seedling growth in the field trials. This effect was more closely related to DURATION than to any other factor (Tables 26 and 40). It could be concluded that premature bud-set did not, or only slightly, reduced the growth of root systems and buds. But, it stopped, or reduced more, the growth of top dry weight and height of the seedlings in the field. As a result of premature budset, the largest seedlings at planting time were the shortest with bigger root systems and buds at the end of the growing season. These seedlings should have higher growth potential than taller seedlings with smaller buds at the end of the growing season, and it is possible that they would overgrow the latter in the next growing season.

Shade increased premature bud-set and survival of the seedlings (Tables 30 and 34). Its positive effect on bud-set may be due to reduced light intensity. Its effets on increasing seedling survival may be due to improved moisture condition. Shade reduced seedling growth (Table 46), possibly because of its increasing premature bud-set and by reducing photosynthesis of the seedlings.

Providing shade is expensive operation. If seedling mortality is not serious, or if there are some other cheaper means to improve seedling survival, especially in a short period of time after transplanting, shade may not be necessary.

Throughout the experiment, the main effect of ACCLIMATIZATION was not significant. Its interactions with DURATION and OUTPLANT DATE did not make much difference on seedling growth in the greenhouse experiment (Tables 9 and 10). The effect patterns of these two interactions on premature bud-set were not conclusive (Tables 27 and 32). The effect of the interaction of ACCLIMATIZATION with SHADE on the end-of-season attributes depends more on SHADE (Figure 14). The reason may be one week was not long enough for any significant effects. Thus, it may not be necessary to acclimatize seedlings for one week before transplanting them under the conditions of this experiment.

The effect of OUTPLANT DATE had to do with the environmental conditions. Any of its interactions with other factors are complex and difficult to interpret. This suggests that there is much to learn about the interaction of the Castle and Cooke system with environmental conditions in influencing black spruce seedling growth.

Seedlings in this study were much smaller at planting than those of Schuessler (1985) and McIntyre (1986) (Table 55) at the same greenhouse durations. The major reason is undoubtedly the fact that the smaller container cavity of the Castle and Cooke system limited seedling growth. At the end of the first growing season, seedlings of McIntyre (1986) were much larger than those in this study (Table 55). One of the major reasons may be the seedlings were smaller at planting in this study (Table 55).

Skeates and Williamson (1979) reported that two-year-old transplants sown up to May 1 were at least comparable to large 2+1 black spruce stock (Armson and Carman 1961). They concluded that for the germinant transplant system to produce the 2-year-old size shown in their study, a plant 3.8 cm tall, 0.9 mm in stem diameter and 0.12 g oven dry weight was required in the first year. The average for height, diameter and oven dry weight of my seedlings are 5.66 cm, 1.33 mm and 0.24 g, respectively. They were greater than those specified by Skeates and Williamson (1979) for the first year plant. Therefore, it is possible that seedlings in my study may be larger than those in Skeates and Williamson's study (1979) after two growing seasons in the nursery beds. Thus, it may be possible to produce shippable seedlings in two growing seasons, by using the Castle and Cooke system.

Table 55. The morphological characters of black spruce seedlings found in the studies of accelerated transplant system.

Reference	Greenhouse phase				Nursery bed phase				
	Age	Ht	RCD	SDW	Plug+x	Ht	RCD	SDW	SR
	wks	cm	mm	g		cm	mm	g	%
1. McIntyre	7	2.3	0.40		p+1	19.0	0.3	2.14	
1986	10	3.4	0.45						
	13	5.1	0.55						
2. Schuess-	7	2.8	0.38	0.01					
ler 1985	10	6.8	0.65	0.09					
	13	9.8	1.07	0.17					
3. Skeates	8				p+1	4.4	1.1	0.14	
etc. 1979	8				p+2	19.4	4.0	2.9	
4. Wang	7	1.6			p+1	6.2	1.2	0.23	81
	10	3.1			p+1	5.6	1.3	0.25	87
	13	3.6			p+1	5.1	1.4	0.25	90

Abbreviations used: Ht=height; RCD=root collar diameter; SDW=seedling dry weight; SR=seedling survival.

1. McIntyre, J.M. Container stock Sb 83-2 A.T.P. Dryden Tree Nursery, Ont. Can. Through personal commulication. The container used was Spencer Lemaire Ferdinand with dimensions 36.8 x 21.5 x 10.2 cm or 40 ml.

2. Schuessler, P.A. Swastika Nursery, Ont. Can. Data was not published. The container used was 408 paperpot system with cavity size 3.8 cm (diameter) x 7.6 cm (depth) or 70 ml. Data was for the winter crop.

3. Means of Skeates etc. were calculated from those of 5 sowing date between March 2nd to May 1st and the planting date was assumed to be June 1st in the study.

4. Author of this thesis. The container used was Castle and Cooke with dimensions diameter 1.3 cm, depth 4.5 cm, and volume 6 ml.

CHAPTER 7

ADDENDUM

During the fall, 1984, and winter, 1984-85, the Thunder Bay nursery experienced wide spread and unusually severe frost heaving. The transplant bed experiment described in this thesis was lost as a result.

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APPENDIX 1

TEMPERATURE RECORDS IN CELSIUS

	In the greenhouse								Outside the greenhouse							
	Month															
	March		April		May		June		May		June		July		Aug.	
Date	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
1	32	18	33	20	30	17			3.9	-2.7	17.0	8.4	29.2	9.4	23.7	14.0
2	33	18	34	17	23	18			8.0	-2.9	24.7	9.0	26.5	15.7	25.0	11.5
3	29	20	33	15	33	14			13.4	-5.2	28.4	6.2	27.3	13.7	27.7	11.3
4	26	22	32	17	36	13			16.0	-4.0	20.5	5.7	23.1	10.6	28.2	10.7
5	26	23			34	13			11.7	0.2	17.6	8.4	21.6	8.2	26.3	13.9
6	29	20	30	15	36	16			13.3	-0.2	16.7	10.4	17.2	7.4	30.9	14.4
7	29	21	32	15	36	16			7.7	5.4	17.8	10.3	24.1	7.1	19.7	15.1
8	29	19	36	16	21	17			9.0	4.3	21.7	10.1	21.1	10.5	29.3	14.8
9	30	22	30	16	25	15	48	9	16.6	0.5	14.4	9.7	23.7	12.6	24.2	13.8
10	33	22	29	17	36	15	32	23	12.8	-1.0	12.8	4.9	27.2	11.1	18.7	13.0
11	30	14	28	18	33	14			19.9	-0.7	22.5	2.6	30.2	12.3	18.8	10.5
12	24	22	32	18	40	14			14.8	1.8	14.7	10.0	26.3	12.0	23.4	8.3
13	31	22	32	19	39	15			14.3	-1.1	19.4	6.4	21.5	13.1	23.0	11.0
14	27	22	21	19	37	15			16.9	-0.2	19.0	2.3	16.3	11.0	23.6	15.9
15	28	23	33	18	35	14			16.5	-1.7	17.2	4.3	23.9	9.7	28.7	13.4
16	27	23	32	22	40	14	38	20	17.8	-1.4	22.0	9.4	25.7	12.8	18.3	10.0
17	31	23	33	17	40	13			27.4	5.7	16.1	9.7	20.3	11.2	19.5	12.2
18	29	23	34	17	39	12			30.5	3.4	27.1	9.9	25.7	10.3	25.0	10.9
19	27	23	33	15	35	14			15.6	7.4	15.9	6.3	27.3	12.3	28.6	8.3
20	33	21	40	16	23	13			10.5	5.4	20.2	3.3	28.2	12.0	26.8	12.4
21	28	25	42	12	23	11			9.3	4.9	18.8	4.7	24.6	9.8	27.8	16.1
22	27	24	31	10	22	12			21.7	7.9	14.7	10.8	31.5	15.0	18.6	8.4
23	38	23	28	10	33	10			21.2	4.7	25.3	11.0	27.1	15.3	21.1	5.1
24	34	20	30	12	32	11			26.0	5.4	20.5	9.1	25.0	10.6	22.7	5.3
25	36	20	37	15	36	10			9.9	3.3	21.8	4.9	26.6	10.7	26.4	8.7
26	36	19	33	16	18	9			14.4	-0.7	23.1	9.7	21.9	11.0	25.7	14.9
27	34	20	28	18	22	8			14.7	0.6	21.2	11.1	21.3	8.4	27.9	15.6
28	30	17	29	16	30	7			16.3	-1.7	20.4	10.2	24.5	6.9	22.5	14.8
29	24	20	27	19	36	6			20.7	0.9	24.9	10.5	29.5	10.9	25.4	11.7
30	32	21	35	16	38	5			23.6	2.2	26.9	9.2	25.7	13.0	22.0	9.3
31									15.0	6.3			27.0	18.2	20.9	6.3

Note : The temperatures in the greenhouse are copied from the Thunder Bay Forest Nursery. The temperatures outside the greenhouse are copied from Monthly Meteorological Summary of Thunder Bay. Environment Canada. 1984.

APPENDIX 2

DAY LENGTH (HOURS)

Date	Month and day length			
	May	June	July	August
1		15:49	16:02	15:03
2		15:51	16:01	15:00
3		15:53	16:00	14:57
4		15:54	15:59	14:54
5		15:55	15:58	14:51
6		15:57	15:57	14:49
7		15:58	15:55	14:46
8		15:59	15:54	14:43
9		16:00	15:53	14:40
10		16:01	15:51	14:37
11		16:02	15:50	14:34
12		16:03	15:48	14:31
13		16:03	15:46	14:27
14		16:04	15:44	14:24
15		16:05	15:43	14:21
16		16:05	15:41	14:18
17		16:06	15:39	14:15
18		16:06	15:37	14:12
19		16:06	15:35	14:08
20		16:06	15:32	14:05
21		16:06	15:30	14:02
22		16:06	15:28	13:59
23		16:06	15:26	13:55
24		16:06	15:23	13:52
25	15:36	16:06	16:21	13:49
26	15:38	16:05	15:18	13:45
27	15:40	16:05	15:16	13:42
28	15:42	16:04	15:13	13:39
29	15:44	16:03	15:11	13:35
30	15:44	16:03	15:08	13:32
31	15:48		15:05	13:29

Note : These records are copied from the weather record office of Environment Canada in the Thunder Bay airport.

APPENDIX 3

DATA MATRIX AT PLANTING

S	A	D	O	B	H1	N	N1	N2	N3	N4	N5
1	1	1	1	1	1.75	2.41	1.58	0.83	0.00	0.00	0.00
1	1	1	1	2	1.47	2.67	2.17	0.50	0.00	0.00	0.00
1	1	1	2	1	1.67	2.00	1.82	0.17	0.00	0.00	0.00
1	1	1	2	2	1.71	2.00	0.92	0.83	0.25	0.00	0.00
1	1	1	3	1	2.08	4.59	3.25	0.92	0.25	0.17	0.00
1	1	1	3	2	1.78	3.99	2.00	1.08	0.75	0.08	0.08
1	1	2	1	1	2.26	9.09	4.17	2.58	1.50	0.67	0.17
1	1	2	1	2	3.71	11.16	5.00	2.08	2.33	1.58	0.17
1	1	2	2	1	3.12	13.59	6.17	2.25	2.50	2.50	0.17
1	1	2	2	2	3.68	17.50	9.33	3.25	2.67	1.75	0.50
1	1	2	3	1	2.99	14.50	5.58	4.00	1.92	2.42	0.58
1	1	2	3	2	2.93	12.00	5.00	2.08	2.00	2.50	0.42
1	1	3	1	1	3.72	11.92	4.58	2.42	2.17	2.25	0.50
1	1	3	1	2	3.23	8.42	4.17	2.25	1.58	0.42	0.00
1	1	3	2	1	3.84	10.50	3.00	2.50	2.67	2.25	0.08
1	1	3	2	2	4.36	14.91	6.50	3.50	2.58	2.00	0.33
1	1	3	3	1	4.26	15.91	6.58	3.17	3.83	1.75	0.58
1	1	3	3	2	3.90	14.00	6.58	3.25	2.00	2.00	0.17
1	2	1	1	1	1.68	4.16	2.50	1.42	0.25	0.00	0.00
1	2	1	1	2	1.58	3.83	3.25	0.50	0.08	0.00	0.00
1	2	1	2	1	1.41	1.67	1.67	0.00	0.00	0.00	0.00
1	2	1	2	2	1.53	2.33	1.75	0.50	0.08	0.00	0.00
1	2	1	3	1	1.39	2.66	2.08	0.50	0.00	0.08	0.00
1	2	1	3	2	1.50	2.38	2.17	0.58	0.08	0.00	0.00
1	2	2	1	1	2.42	6.75	2.67	1.83	1.83	0.42	0.00
1	2	2	1	2	2.99	7.67	3.17	1.75	1.83	0.67	0.25
1	2	2	2	1	3.10	16.42	7.92	4.00	3.08	1.25	0.17
1	2	2	2	2	3.55	17.60	8.17	4.42	2.92	1.92	0.17
1	2	2	3	1	3.09	12.75	5.67	3.08	2.25	1.58	0.17
1	2	2	3	2	3.03	13.17	5.08	2.67	2.50	2.25	0.67
1	2	3	1	1	3.63	12.42	5.92	2.17	2.25	1.83	0.25
1	2	3	1	2	3.30	12.82	5.33	3.58	3.08	0.75	0.08
1	2	3	2	1	3.68	15.34	7.75	2.67	2.67	1.67	0.58
1	2	3	2	2	3.80	16.83	8.50	3.67	2.83	1.83	0.00
1	2	3	3	1	3.09	15.33	6.33	3.83	3.42	1.58	0.17
1	2	3	3	2	3.66	18.91	9.25	4.08	3.00	2.50	0.08
2	1	1	1	1	1.90	4.08	2.50	1.50	0.08	0.00	0.00
2	1	1	1	2	1.80	3.41	2.75	0.58	0.08	0.00	0.00
2	1	1	2	1	1.54	0.92	0.92	0.00	0.00	0.00	0.00
2	1	1	2	2	1.61	1.50	0.92	0.50	0.00	0.08	0.00
2	1	1	3	1	1.78	3.66	2.58	0.75	0.33	0.00	0.00
2	1	1	3	2	1.74	4.84	3.17	1.25	0.42	0.00	0.00
2	1	2	1	1	3.44	10.24	4.50	2.83	2.41	0.50	0.00
2	1	2	1	2	2.23	11.92	5.91	3.33	1.58	0.83	0.33
2	1	2	2	1	3.76	13.91	4.50	3.58	3.33	2.17	0.33
2	1	2	2	2	3.43	14.91	5.33	4.08	2.75	2.33	0.42

S	A	D	O	B	H1	N	N1	N2	N3	N4	N5
2	1	2	3	1	3.46	13.01	5.00	3.50	1.42	2.42	0.67
2	1	2	3	2	3.38	13.92	4.75	3.17	2.25	2.67	1.08
2	1	3	1	1	3.42	11.41	5.08	2.92	2.33	1.08	0.00
2	1	3	1	2	3.81	11.74	5.33	2.50	2.41	1.42	0.08
2	1	3	2	1	3.59	13.91	7.58	3.75	1.58	0.83	0.17
2	1	3	2	2	3.87	12.42	4.50	2.92	2.17	2.58	0.25
2	1	3	3	1	3.84	15.83	5.42	4.08	3.58	2.25	0.50
2	1	3	3	2	3.58	16.34	6.17	4.25	3.83	1.92	0.17
2	2	1	1	1	1.81	2.58	1.58	0.83	0.17	0.00	0.00
2	2	1	1	2	1.65	3.25	2.67	0.58	0.00	0.00	0.00
2	2	1	2	1	1.56	0.83	0.83	0.00	0.00	0.00	0.00
2	2	1	2	2	1.62	2.58	2.08	0.42	0.08	0.00	0.00
2	2	1	3	1	1.45	3.50	2.58	0.67	0.25	0.00	0.00
2	2	1	3	2	1.37	2.50	1.83	0.67	0.00	0.00	0.00
2	2	2	1	1	3.01	10.42	3.83	2.67	2.17	1.75	0.00
2	2	2	1	2	2.33	5.16	2.00	1.50	1.58	0.08	0.00
2	2	2	2	1	2.91	11.42	4.92	2.67	2.17	1.58	0.08
2	2	2	2	2	3.73	17.41	8.33	3.08	2.67	2.83	0.50
2	2	2	3	1	3.07	14.08	6.75	2.50	2.08	2.42	0.33
2	2	2	3	2	2.97	9.84	4.42	2.17	1.75	1.25	0.25
2	2	3	1	1	3.39	7.83	3.25	1.92	2.08	0.50	0.08
2	2	3	1	2	3.08	9.58	4.25	2.17	2.08	1.08	0.00
2	2	3	2	1	3.35	14.66	8.08	3.58	1.67	1.08	0.25
2	2	3	2	2	3.39	14.00	8.50	3.50	1.33	0.67	0.00
2	2	3	3	1	3.03	13.92	6.25	4.00	2.83	0.67	0.17
2	2	3	3	2	3.63	21.01	8.92	5.42	3.17	3.25	0.25

Note : S, A, D, O, and B present factors SHADE, ACCLIMATIZATION, DURATION, OUTPLANT DATE and BLOCK. H1 : height. N : total number of roots; N1, N2, N3, N4, and N5 : the numbers of roots measured in 5 categories : 0-1, 1-2, 2-3, 3-4, >4 cm. Meanings of the numbers in the design matrix are as following.

Factor		levels		
Number		1	2	3
SHADE	(S)	off	on	
ACCLIMATIZATION	(A)	off	on	
DURATION (week)	(D)	7	10	13
OUTPLANT ADTE (June)	(O)	1	11	21

APPENDIX 4

DATA MATRIX OF BUD-SET RATIOS

S	A	D	O	B	BSR1	BSR2	BSR3	BSR4	BSR5	CBSR
1	1	1	1	1	.0000	.0219	.0438	.0662	.2595	.0000
1	1	1	1	2	.0000	.0336	.0336	.0604	.2819	.0000
1	1	1	2	1	.0000	.0000	.0235	.0529	.2118	.0000
1	1	1	2	2	.0000	.0000	.0065	.0327	.3137	.0000
1	1	1	3	1	.0000	.0000	.0603	.0905	.4130	.0000
1	1	1	3	2	.0000	.0000	.0721	.1171	.5837	.0000
1	1	2	1	1	.6793	.6793	.6920	.6920	.7890	.6793
1	1	2	1	2	.7708	.8167	.8243	.8243	.9163	.7708
1	1	2	2	1	.7898	.7970	.7994	.8043	.9448	.7934
1	1	2	2	2	.5630	.6299	.6299	.6299	.8127	.5965
1	1	2	3	1	.2724	.3821	.3821	.3862	.4776	.3821
1	1	2	3	2	.4077	.4344	.4958	.5126	.8034	.4344
1	1	3	1	1	.7741	.8283	.8459	.8459	.9545	.7741
1	1	3	1	2	.5036	.7212	.7444	.7472	.8783	.5036
1	1	3	2	1	.8750	.8785	.8826	.8907	.9187	.8768
1	1	3	2	2	.9151	.9222	.9300	.9300	.9608	.9187
1	1	3	3	1	.4598	.5785	.5856	.5946	.7162	.5785
1	1	3	3	2	.2607	.4069	.4199	.4199	.5714	.4069
1	2	1	1	1	.0385	.0440	.0556	.0556	.7709	.0385
1	2	1	1	2	.0234	.0234	.1235	.1361	.2619	.0234
1	2	1	2	1	.0000	.0000	.0902	.0902	.4511	.0000
1	2	1	2	2	.0000	.0000	.0190	.0316	.2975	.0000
1	2	1	3	1	.0000	.0000	.0304	.0304	.4130	.0000
1	2	1	3	2	.0000	.0000	.0000	.0234	.2749	.0000
1	2	2	1	1	.7359	.7359	.7391	.7478	.9214	.7359
1	2	2	1	2	.4315	.5041	.5041	.5083	.7552	.4315
1	2	2	2	1	.5821	.5994	.6029	.6111	.8240	.5908
1	2	2	2	2	.6556	.6626	.6749	.6749	.8354	.6591
1	2	2	3	1	.2911	.4852	.5277	.5319	.6894	.4852
1	2	2	3	2	.2710	.5708	.5762	.5810	.7816	.5708
1	2	3	1	1	.9398	.9426	.9426	.9426	.9547	.9398
1	2	3	1	2	.8439	.8495	.8495	.8557	.9094	.8439
1	2	3	2	1	.7801	.8340	.8375	.9000	.9580	.8071
1	2	3	2	2	.7773	.7934	.8802	.8802	.9174	.7854
1	2	3	3	1	.8412	.8448	.8696	.8739	.9783	.8448
1	2	3	3	2	.7755	.7901	.7984	.8066	.8971	.7901
2	1	1	1	1	.1327	.1907	.2216	.2680	.6289	.1327
2	1	1	1	2	.2474	.4180	.4444	.4444	.6032	.2474
2	1	1	2	1	.0000	.0000	.0340	.0631	.5388	.0000
2	1	1	2	2	.0000	.0000	.0429	.0714	.2643	.0000
2	1	1	3	1	.0000	.0000	.0279	.0627	.3240	.0000
2	1	1	3	2	.0000	.0115	.0267	.0345	.1544	.0115
2	1	2	1	1	.7778	.8135	.8294	.8526	.9801	.7778
2	1	2	1	2	.8521	.8521	.8599	.8599	.9222	.8521
2	1	2	2	1	.8215	.8527	.8612	.8669	.9292	.8371
2	1	2	2	2	.7101	.7246	.7376	.7376	.8542	.7174

S	A	D	O	B	BSR1	BSR2	BSR3	BSR4	BSR5	CBSR
2	1	2	3	1	.2745	.4824	.5216	.5373	.7804	.4824
2	1	2	3	2	.1600	.6000	.6048	.6048	.8185	.6000
2	1	3	1	1	.8769	.9124	.9124	.9124	.9728	.8769
2	1	3	1	2	.9266	.9294	.9323	.9323	.9631	.9266
2	1	3	2	1	.9488	.9488	.9563	.9563	.9721	.9488
2	1	3	2	2	.9073	.9611	.9611	.9611	.9844	.9342
2	1	3	3	1	.7470	.7470	.7589	.7698	.9203	.7470
2	1	3	3	2	.5205	.7137	.7417	.7417	.9083	.7137
2	2	1	1	1	.0000	.1275	.2010	.2304	.4902	.0000
2	2	1	1	2	.0121	.1030	.1273	.1576	.4000	.0121
2	2	1	2	1	.0055	.0055	.0604	.0934	.3481	.0055
2	2	1	2	2	.0000	.0166	.0333	.0500	.2222	.0083
2	2	1	3	1	.0000	.0000	.0132	.0592	.4139	.0000
2	2	1	3	2	.0000	.0000	.0078	.0078	.1190	.0000
2	2	2	1	1	.8731	.8764	.8985	.8985	.9549	.8731
2	2	2	1	2	.7287	.7287	.7571	.7571	.8537	.7287
2	2	2	2	1	.4986	.7422	.7443	.7528	.8381	.6204
2	2	2	2	2	.5274	.7122	.7164	.7544	.9179	.6198
2	2	2	3	1	.6602	.7305	.7391	.7391	.9286	.7305
2	2	2	3	2	.1735	.2610	.2610	.2610	.9839	.2610
2	2	3	1	1	.9671	.9729	.9729	.9729	.9880	.9671
2	2	3	1	2	.8916	.9398	.9483	.9483	.9787	.8916
2	2	3	2	1	.8016	.8502	.8543	.8543	.9312	.8259
2	2	3	2	2	.8605	.8837	.9105	.9141	.9412	.8721
2	2	3	3	1	.9255	.9255	.9255	.9255	.9529	.9255
2	2	3	3	2	.8992	.9355	.9395	.9476	.9637	.9355

Note : S, A, D, O, and B present factors SHADE, ACCLIMATIZATION, DURATION, OUTPLANT DATE and BLOCK. BSR1, BSR2, BSR3, BSR4, BSR5, and CBSR : budset ratios counted on August 5, 25, September 5, 15, 26, and corrected budset ratio. Meanings of the numbers in the design matrix are as following.

Factor Number		levels 1	2	3
SHADE	(S)	off	on	
ACCLIMATIZATION	(A)	off	on	
DURATION (week)	(D)	7	10	13
OUTPLANT ADTE (June)	(O)	1	11	21

APPENDIX 5

DATA MATRIX OF SURVIVAL RATIOS

S	A	D	O	B	SR1	SR2	SR3	SR4	SR5	SR6	SR7	CSR
1	1	1	1	1	.7766	.7447	.7287	.7287	.7234	.6968	.6968	.7766
1	1	1	1	2	.6638	.6550	.6507	.6507	.6507	.6507	.6507	.6638
1	1	1	2	1	.8421	.8182	.8182	.8134	.8134	.8134	.8086	.8182
1	1	1	2	2	.7477	.7339	.7156	.7018	.7018	.7018	.6972	.7339
1	1	1	3	1	.7760	.7603	.7319	.7319	.7319	.7256	.7256	.7461
1	1	1	3	2	.7588	.7331	.7170	.7138	.7138	.7106	.7106	.7250
1	1	2	1	1	.8095	.8061	.8061	.8061	.8061	.8061	.8027	.8095
1	1	2	1	2	.7973	.7973	.7973	.7974	.7974	.7974	.7874	.7973
1	1	2	2	1	.9199	.9199	.9116	.9088	.9033	.9006	.8978	.9199
1	1	2	2	2	.9368	.9368	.9203	.9203	.9203	.9093	.9066	.9368
1	1	2	3	1	.9283	.9283	.9283	.9283	.9283	.9245	.9245	.9283
1	1	2	3	2	.5349	.5039	.4729	.4612	.4612	.4535	.4496	.4884
1	1	3	1	1	.8557	.8557	.8557	.8531	.8531	.8505	.8505	.8557
1	1	3	1	2	.7482	.7349	.7060	.6982	.6955	.6903	.6850	.7428
1	1	3	2	1	.9101	.8921	.8885	.8885	.8885	.8849	.8849	.8921
1	1	3	2	2	.9422	.9350	.9278	.9278	.9278	.9206	.9206	.9350
1	1	3	3	1	.8858	.8819	.8780	.8740	.8740	.8740	.8740	.8800
1	1	3	3	2	.9180	.9141	.9023	.9023	.9023	.8477	.8242	.9082
1	2	1	1	1	.7811	.7811	.7811	.7725	.7725	.7682	.7682	.7811
1	2	1	1	2	.7875	.7634	.7634	.7589	.7545	.7500	.7366	.7857
1	2	1	2	1	.7228	.7228	.7228	.7228	.7228	.7228	.7228	.7228
1	2	1	2	2	.7718	.7670	.7670	.7670	.7670	.7670	.7670	.7670
1	2	1	3	1	.7803	.7672	.7541	.7541	.7541	.7541	.7541	.7606
1	2	1	3	2	.6107	.6074	.5872	.5805	.5738	.5738	.5738	.5973
1	2	2	1	1	.7966	.7966	.7966	.7931	.7931	.7897	.7862	.7966
1	2	2	1	2	.8294	.8294	.8094	.8094	.8094	.8060	.8060	.8294
1	2	2	2	1	.9457	.9429	.9429	.9375	.9293	.9266	.9239	.9429
1	2	2	2	2	.9003	.8922	.8868	.8706	.8706	.8679	.8679	.8922
1	2	2	3	1	.9717	.9595	.9595	.9514	.9514	.9514	.9514	.9595
1	2	2	3	2	.8340	.8075	.8000	.7925	.7925	.7774	.7774	.8038
1	2	3	1	1	.9151	.9096	.9068	.9068	.9068	.9068	.9068	.9151
1	2	3	1	2	.8211	.8157	.8103	.8103	.8076	.8076	.8049	.8211
1	2	3	2	1	.8705	.8669	.8669	.8633	.8633	.8561	.8525	.8669
1	2	3	2	2	.9231	.9048	.8864	.8864	.8864	.8864	.8864	.9048
1	2	3	3	1	.9255	.9137	.9098	.9020	.9020	.9020	.9020	.9117
1	2	3	3	2	.9725	.9608	.9529	.9529	.9529	.9529	.9490	.9569
2	1	1	1	1	.8485	.8485	.8398	.8398	.8398	.8398	.8398	.8485
2	1	1	1	2	.8520	.8520	.8475	.8475	.8475	.8475	.8475	.8520
2	1	1	2	1	.9409	.9364	.9364	.9364	.9364	.9364	.9364	.9364
2	1	1	2	2	.8075	.8075	.8075	.8000	.8000	.8000	.8000	.8075
2	1	1	3	1	.9796	.9796	.9796	.9762	.9762	.9762	.9762	.9796
2	1	1	3	2	.8990	.8822	.8822	.8822	.8788	.8721	.8687	.8822
2	1	2	1	1	.8400	.8400	.8400	.8400	.8367	.8367	.8333	.8400
2	1	2	1	2	.8614	.8482	.8482	.8482	.8482	.8482	.8482	.8614
2	1	2	2	1	.9620	.9592	.9592	.9592	.9592	.9592	.9592	.9592
2	1	2	2	2	.9718	.9718	.9718	.9662	.9662	.9662	.9662	.9718

S A D O B	SR1	SR2	SR3	SR4	SR5	SR6	SR7	CSR
2 1 2 3 1	.9696	.9696	.9696	.9696	.9696	.9696	.9696	.9696
2 1 2 3 2	.9766	.9766	.9766	.9688	.9688	.9688	.9648	.9766
2 1 3 1 1	.8656	.8605	.8553	.8553	.8553	.8553	.8553	.8656
2 1 3 1 2	.8501	.8450	.8424	.8398	.8398	.8398	.8372	.8501
2 1 3 2 1	.9845	.9845	.9845	.9767	.9767	.9729	.9729	.9845
2 1 3 2 2	.9453	.9453	.9380	.9380	.9380	.9343	.9307	.9453
2 1 3 3 1	.9768	.9768	.9768	.9768	.9730	.9730	.9730	.9768
2 1 3 3 2	.9761	.9721	.9602	.9562	.9562	.9562	.9562	.9602
2 2 1 1 1	.8991	.8947	.8947	.8947	.8947	.8947	.8947	.8991
2 2 1 1 2	.7293	.7205	.7205	.7205	.7205	.7205	.7205	.7293
2 2 1 2 1	.9257	.9010	.9010	.9010	.9010	.8960	.8960	.9010
2 2 1 2 2	.8922	.8922	.8873	.8824	.8824	.8824	.8824	.8922
2 2 1 3 1	.9474	.9684	.9620	.9620	.9620	.9557	.9557	.9652
2 2 1 3 2	.8502	.8502	.8306	.8306	.8306	.8208	.8176	.8504
2 2 2 1 1	.8933	.8933	.8900	.8867	.8867	.8867	.8833	.8933
2 2 2 1 2	.9046	.8728	.8728	.8728	.8728	.8693	.8693	.9046
2 2 2 2 1	.9698	.9698	.9698	.9670	.9670	.9670	.9670	.9698
2 2 2 2 2	.9616	.9507	.9425	.9370	.9370	.9342	.9342	.9507
2 2 2 3 1	.9625	.9588	.9588	.9476	.9476	.9438	.9438	.9588
2 2 2 3 2	.9388	.9228	.9154	.9154	.9154	.9154	.9154	.9191
2 2 3 1 1	.8724	.8698	.8646	.8646	.8646	.8646	.8646	.8724
2 2 3 1 2	.8656	.8579	.8579	.8501	.8501	.8501	.8501	.8656
2 2 3 2 1	.9615	.9500	.9500	.9500	.9500	.9500	.9500	.9500
2 2 3 2 2	.9593	.9556	.9556	.9519	.9481	.9444	.9407	.9556
2 2 3 3 1	.9770	.9770	.9770	.9770	.9770	.9770	.9770	.9770
2 2 3 3 2	.9920	.9920	.9920	.9920	.9920	.9920	.9920	.9920

Note : S, A, D, O, and B present factors SHADE, ACCLIMATIZATION, DURATION, OUTPLANT DATE and BLOCK. SR1, SR2, SR3, SR4, SR5, SR6, SR7 and CSR : survival ratios counted on July 25, August 5, 25, September 5, 15, 26, October 5, and corrected survival ratio. Meanings of the numbers in the design matrix are as following.

Factor Number		levels 1	2	3
SHADE	(S)	off	on	
ACCLIMATIZATION	(A)	off	on	
DURATION (week)	(D)	7	10	13
OUTPLANT DATE (June)	(O)	1	11	21

APPENDIX 6

DATA MATRIX COLLECTED AT HARVESTING

S	A	D	O	B	H2	BC	BD	TDW	RDW
1	1	1	1	1	7.710	1.620	2.160	.26140	.11452
1	1	1	1	2	8.032	1.532	2.244	.30588	.10732
1	1	1	2	1	5.360	1.240	1.710	.14952	.06120
1	1	1	2	2	6.328	1.380	1.980	.20736	.07244
1	1	1	3	1	5.030	1.400	1.880	.16252	.07544
1	1	1	3	2	5.168	1.300	1.848	.13200	.05600
1	1	2	1	1	4.684	1.469	2.068	.12924	.07808
1	1	2	1	2	5.368	1.642	2.294	.14348	.10340
1	1	2	2	1	5.240	1.590	2.150	.15496	.11316
1	1	2	2	2	4.992	1.398	2.404	.15000	.09271
1	1	2	3	1	5.460	1.520	2.080	.16000	.09164
1	1	2	3	2	4.000	1.250	1.936	.11568	.06972
1	1	3	1	1	6.920	1.960	2.520	.25924	.19040
1	1	3	1	2	5.276	1.682	2.202	.16096	.11568
1	1	3	2	1	4.236	1.568	2.371	.10000	.11764
1	1	3	2	2	4.612	1.394	2.250	.11200	.12608
1	1	3	3	1	7.044	2.024	2.465	.26832	.17628
1	1	3	3	2	8.036	1.926	2.438	.27200	.14860
1	2	1	1	1	7.580	1.520	2.410	.24072	.08480
1	2	1	1	2	8.180	2.076	2.150	.34868	.12496
1	2	1	2	1	4.084	1.122	1.760	.08716	.03724
1	2	1	2	2	6.064	1.294	2.130	.16840	.07232
1	2	1	3	1	5.460	1.270	2.360	.13720	.06400
1	2	1	3	2	6.032	1.262	1.882	.17932	.06400
1	2	2	1	1	4.072	1.364	2.126	.10664	.07108
1	2	2	1	2	6.800	1.552	2.470	.23120	.12716
1	2	2	2	1	8.340	1.770	2.670	.33648	.18400
1	2	2	2	2	7.876	1.598	2.508	.30400	.14464
1	2	2	3	1	7.244	1.766	2.214	.26244	.12696
1	2	2	3	2	5.580	1.440	2.080	.15472	.08000
1	2	3	1	1	4.864	1.690	2.406	.13148	.10536
1	2	3	1	2	5.812	1.386	2.276	.16000	.12108
1	2	3	2	1	5.156	1.290	2.382	.12996	.09708
1	2	3	2	2	5.176	1.574	2.404	.18480	.12444
1	2	3	3	1	4.270	1.480	2.170	.10324	.07820
1	2	3	3	2	4.556	1.658	2.158	.11792	.09984
2	1	1	1	1	6.140	1.090	2.220	.14320	.07608
2	1	1	1	2	4.296	0.926	1.918	.08588	.04708
2	1	1	2	1	7.180	1.240	2.280	.15584	.07228
2	1	1	2	2	5.940	0.956	1.936	.10732	.03156
2	1	1	3	1	6.100	1.082	1.812	.15060	.06072
2	1	1	3	2	6.232	0.918	1.972	.12908	.04808
2	1	2	1	1	5.260	1.186	2.228	.13348	.10060
2	1	2	1	2	4.512	1.012	2.062	.09348	.06420
2	1	2	2	1	4.428	1.258	2.296	.10400	.08868
2	1	2	2	2	6.116	1.150	2.230	.16316	.09720

S	A	D	O	B	H2	BC	BD	TDW	RDW
2	1	2	3	1	8.010	1.640	2.570	.21928	.13044
2	1	2	3	2	6.104	1.010	2.060	.13284	.07256
2	1	3	1	1	5.012	1.186	2.200	.13100	.11240
2	1	3	1	2	5.204	1.658	2.212	.14920	.11408
2	1	3	2	1	3.896	1.006	1.950	.07916	.06832
2	1	3	2	2	4.748	1.130	2.122	.10504	.09040
2	1	3	3	1	6.380	1.550	2.620	.18400	.11800
2	1	3	3	2	5.556	1.354	2.194	.13048	.09852
2	2	1	1	1	6.950	1.060	2.060	.14924	.06888
2	2	1	1	2	6.008	1.026	1.866	.13780	.05828
2	2	1	2	1	5.420	0.850	1.710	.08876	.03400
2	2	1	2	2	6.720	1.030	2.044	.14888	.06600
2	2	1	3	1	5.856	0.984	1.800	.12592	.05572
2	2	1	3	2	7.124	1.010	1.958	.11332	.06700
2	2	2	1	1	2.852	1.028	1.974	.05172	.04084
2	2	2	1	2	3.348	0.956	1.972	.06452	.04260
2	2	2	2	1	5.370	1.180	2.400	.13180	.10024
2	2	2	2	2	5.968	1.262	2.250	.14400	.09428
2	2	2	3	1	4.380	0.980	2.080	.08968	.06580
2	2	2	3	2	8.852	1.174	2.190	.22580	.09324
2	2	3	1	1	3.625	0.973	1.821	.06672	.07428
2	2	3	1	2	4.348	1.344	2.032	.10376	.09672
2	2	3	2	1	5.048	1.100	2.132	.11744	.07164
2	2	3	2	2	4.228	1.076	2.138	.08492	.08000
2	2	3	3	1	3.812	1.140	1.936	.07880	.06988
2	2	3	3	2	5.500	1.190	2.062	.14000	.09220

Note : S, A, D, O, and B present factors SHADE, ACCLIMATIZATION, DURATION, OUTPLANT DATE and BLOCK. H2 : height, RCD : root collar diameter, BD : bud diameter, TDW : top dry weight, RDW : root dry weight. Meanings of the numbers in the design matrix are as following.

Factor		levels		
Number		1	2	3
SHADE	(S)	off	on	
ACCLIMATIZATION	(A)	off	on	
DURATION (week)	(D)	7	10	13
OUTPLANT ADTE (June)	(O)	1	11	21

APPENDIX 7

DATA MATRIX FOR THE EXPERIMENTAL ERROR

REP	H2	RCD	BD	TDW	RDW	CSR	CBSR
1	4.830	1.220	2.230	.09676	.09100	.9783	.9538
2	3.869	1.006	1.950	.07916	.06832	.9845	.9488
1	7.230	1.040	2.160	.14720	.05600	.9227	.0000
2	5.420	0.850	1.710	.08876	.03400	.9010	.0055
1	6.470	1.630	2.530	.22431	.12872	.9253	.6486
2	8.340	1.770	2.670	.33648	.18400	.9429	.5908
1	6.300	2.070	2.410	.44200	.17848	.8545	.1787
2	5.460	1.520	2.080	.16000	.09164	.9283	.3293
1	5.220	1.580	2.180	.14464	.10716	.8769	.8904
2	7.044	2.024	2.465	.26832	.17628	.8800	.5785
1	5.348	1.276	2.088	.13940	.08268	.9590	.6615
2	4.380	0.980	2.080	.08968	.06580	.9588	.7305
1	5.964	1.624	2.474	.17676	.09920	.9278	.5519
2	4.072	1.364	2.126	.10664	.07108	.7966	.7359
1	8.772	1.500	2.028	.31364	.10976	.9052	.0383
2	6.140	1.090	2.220	.14320	.07608	.8485	.1327
1	3.774	1.006	1.942	.08080	.05448	.8389	.8400
2	5.260	1.186	2.228	.13348	.10060	.8400	.7778
1	6.060	1.220	2.316	.13664	.09548	.9500	.8151
2	6.116	1.150	2.230	.16316	.09720	.9718	.7290
1	5.671	1.117	1.946	.16875	.06670	.8414	.0000
2	6.328	1.380	1.980	.20736	.07244	.7339	.0000
1	4.064	1.550	2.276	.11184	.08316	.9345	.8067
2	5.176	1.754	2.404	.18480	.12444	.9048	.7854
1	6.740	1.264	1.960	.15172	.06388	.8044	.0302
2	6.232	0.918	1.972	.12908	.04808	.8822	.0115
1	5.452	1.078	2.008	.14548	.04952	.4341	.0000
2	6.032	1.262	1.882	.17932	.06400	.6074	.0000
1	4.852	1.358	2.114	.12800	.09032	.9483	.8704
2	4.556	1.658	2.158	.11792	.09984	.9568	.7901
1	7.640	1.160	2.128	.17504	.07456	.7576	.0172
2	6.008	1.026	1.866	.13780	.95828	.7293	.0121
1	3.988	0.970	2.002	.08000	.07960	.8165	.8686
2	4.348	1.344	2.032	.10376	.09672	.8656	.8862
1	6.568	1.798	2.382	.25168	.18592	.7083	.7232
2	5.276	1.682	2.202	.16096	.11568	.7428	.5036

Note : S, A, D, O, and B present factors SHADE, ACCLIMATIZATION, DURATION, OUTPLANT DATE and BLOCK. H2 : height, RCD : root collar diameter, BD : bud diameter, TDW : top dry weight, RDW : root dry weight, CSR : corrected survival ratio, CBSR : corrected budset ratio.

APPENDIX 8

SUMMARY OF ABBREVIATIONS

Symbol	Definition
A	acclimatization
BD	bud diameter
BSRz	z=1, 2, 3, 4 and 5, corresponding to bud-set ratios counted on 5 and 25 August, 5, 15 and 25 September.
CBSR	corrected bud-set ratio
CSR	corrected survival ratio
CDF	canonical discriminant function
CV	canonical variates
D	duration
H1	seedling height at planting
H2	seedling height at harvest
N	grand mean of roots per seedling at planting
Nx	x=1, 2, 3, 4 and 5, corresponding to the means of seedling roots in ranges 0-1, 1-2, 2-3, 3-4 and 4-5 at planting
O	outplanting date
RCD	root collar diameter
RDW	root dry weight
S	shade
SRy	y=1, 2, 3, 4, 5, 6 and 7, corresponding to the survival ratios counted on 25 July, 5 and 25 August, 5, 15 and 25 September, and 5 October
TCBSR	transformed corrected budset ratio
TCSR	transformed corrected survival ratio
TDW	top dry weight
TRDW	top+root dry weight

APPENDIX 9

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE O - by - D INTERACTION AND VARIABLES H1 AND N

Table A 9-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the O - by - D interaction for variables H1 and N..

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	16.10	95.77	95.77	.97
2	.07	4.23	100.00	.64

Table A 9-2. Dimension reduction analysis of the canonical discriminant function space of the O - by - D interaction for variables H1 and N.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.03	221.110	16	.000	
1	.58	35.159	7	.000	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 3 group centroids is 2.

APPENDIX 10

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE D - by - A INTERACTION AND VARIABLES H1 AND N

Table A 10-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the D - by -A interaction for variables H1 and N.

Function	Eigenvalue	Percent of variance	Cumulative percent	Canonical correlation
1	11.47	98.67	98.67	.95
2	.15	1.33	100.00	.37

Table A 10-2. Dimension reduction analysis of the canonical discriminant function space of the D - by - A interaction for variables H1 and N.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.07	178.67	10	.000	
1	1.00	9.61	4	.048	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 6 group centroids is 2.

APPENDIX 11

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE A - by - O INTERACTION AND VARIABLES H1 AND N

Table A 11-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the A - by - O interaction for variables H1 and N.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	.63	96.67	96.67	.62
2	.02	3.33	100.00	.15

Table A 14-2. Dimension reduction analysis of the canonical discriminant function space of the A - by - O interaction for variables H1 and N.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.60	34.02	10	.000	
1	.98	1.43	4	.849	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 6 group centroids is 1.

APPENDIX 12

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE OUTPLANT DATE FACTOR AND VARIABLES H1 AND N

Table A 12-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the OUTPLANT DATE factor for variables H1 and N.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	.36	99.69	99.69	.51
2	.00	.31	100.00	.03

Table A 12-2. Dimension reduction analysis of the canonical discriminant function space of the OUTPLANT DATE for variables H1 and N.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.74	21.024	4	.000	
1	1.00	.08	1	.783	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 3 group centroids is 1.

APPENDIX 13

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE DUARTION FACTOR AND VARIABLES H1 AND N

Table A 13-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the DURATION factor for variables H1 and N.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	9.26	99.97	99.97	.95
2	.00	.03	100.00	.05

Table A 13-2. Dimension reduction analysis of the canonical discriminant function space of the DURATION factor for variables H1 and N.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.10	159.72	4	.000	
1	1.00	.20	1	.653	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 6 group centroids is 1.

APPENDIX 14

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE DURATION FACTOR AND END-OF-SEASON VARIABLES

Table A 14-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the DURATION factor for variables H1 and N.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	2.97	96.01	96.01	.86
2	.12	3.99	100.00	.33

Table A 14-2. Dimension reduction analysis of the canonical discriminant function space of the DURATION factor for end-of-season variables.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.22	100.13	10	.000	
1	.89	7.80	4	.10	1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 3 group centroids is 1.

APPENDIX 15

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE OUTPLANT DATE FACTOR AND THE END-OF-SEASON VARIABLES

Table A 15-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the OUTPLANT DATE factor for variables TDW, RDW, RCD, H2, and BD.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	.16	80.56	80.58	.37
2	.04	19.42	100.00	.17

Table A 15-2. Dimension reduction analysis of the canonical discriminant function space of the OUTPLANT DATE factor for variables TDW, RDW, RCD, H2, and BD.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance
0	.83	12.52	10	.252 1/
1	.96	2.54	4	.637

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 3 group centroids is zero.

APPENDIX 16

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE D x O INTERCTION AND THE END-OF-SEASSON VARIABLES

Table A 16-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the D x O interaction for variables TDW, RDW, RCD, H2, and BD.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	4.38	84.6	84.6	.90
2	.45	8.7	93.3	.56
3	.23	4.5	97.8	.43
4	.09	1.7	99.5	.28
5	.03	.5	100.0	.17

Table A 16-2. Dimension reduction analysis of the canonical discriminant function space of the D x O interaction for variables TDW, RDW, RCD, H2, and BD.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.093	151.91	40	.000	
1	.501	44.26	28	.026	
2	.726	20.48	18	.306	1/
3	.895	7.13	10	.713	
4	.973	1.78	4	.776	

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 9 group centroids is 2.

APPENDIX 17

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE SHADE FACTOR AND THE END-OF-SEASON VARIABLES

Table A 17-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the SHADE factor for variables TDW, RDW, RCD, H2, and BD.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	1.67	100.00	100.00	.79

Table A 17-2. Dimension reduction analysis of the canonical discriminant function space of the SHADE factor for variables TDW, RDW, RCD, H2, and BD.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance
0	.374	66.37	5	.000 1/

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 2 group centroids is 1.

APPENDIX 18

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE SHADE - BY - DURATION INTERACTION AND THE END-OF-SEASON VARIABLES

Table A 18-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the S - by - D interaction for variables TDW, RDW, RCD, H2, and BD.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	3.79	63.74	63.74	.89
2	1.86	31.29	95.03	.81
3	.21	3.49	98.52	.41
4	.09	1.45	99.97	.28
5	.00	.03	100.00	.04

Table A 18-2. Dimension reduction analysis of the canonical discriminant function space of the S - by - D interaction for variables TDW, RDW, RCD, H2, and BD.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance
0	.06	189.24	25	.000
1	.27	86.68	16	.000
2	.76	17.89	9	.036
3	.92	5.54	4	.236 1/
4	1.00	.13	1	.719

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 6 group centroids is 3.

APPENDIX 19

CANONICAL DISCRIMINANT FUNCTIONS ASSOCIATED WITH THE SHADE - by - ACCLIMATIZATION INTERACTION AND THE END-OF-SEASON VARIABLES

Table A 19-1. Eigenvalues, canonical correlations, and associated statistics of the canonical discriminant functions of the S - by - A interaction for variables TDW, RDW, RCD, H2, and BD.

Function	Eigenvalue	Percent of variance	Cummulative percent	Canonical correlation
1	1.74	89.05	89.05	.80
2	.19	9.69	98.74	.40
3	.02	1.26	100.00	.15

Table A 14-2. Dimension reduction analysis of the canonical discriminant function space of the S - by -A interaction for variables TDW, RDW, RCD, H2, and BD.

Null hypothesis effective dimension is ..	Wilks lambda	Chi-square	df	Significance	
0	.30	80.20	15	.000	
1	.82	13.11	8	.108	1/
2	.98	1.61	3	.657	

1/ Conclusion: accept the null hypothesis that the effective dimension of the subspace occupied by the 4 group centroids is 1.

APPENDIX 20

RADII OF CENTROIDS ASSOCIATED WITH INDIVIDUAL EFFECTS IN THE CANONICAL VARIATES ANALYSIS IN THIS STUDY

Experimental stage and Source of variation	Effective dimension of canonical discriminant function space	Number of centroids	Radius of 95% conf. limit
Greenhouse stage 1/			
DURATION (D)	1	3	0.042
OUTPLANT DATE (O)	1	3	0.042
ACCLIMATIZATION (A) x D	2	6	0.074
ACCLIMATIZATION x O	1	6	0.060
D x O	2	9	0.081
Transplant bed stage 2/			
SHADE (S)	1	2	0.039
D	1	3	0.049
O	0		
A x S	1	4	0.075
S x D	3 3/	6	0.086
D x O	2	9	0.105

1/ Variables used in the analysis are 1/height and total number of roots.

2/ Variables used in the analysis are top dry weight, root dry weight, root collar diameter, height, and bud diameter.

3/ Dimension 2 was used in the calculation since only the first two canonical discriminant functions were used to plot the canonical variates scores of the S x D centroids.

APPENIX 21

AN EXAMPLE SHOWING THE CALCULATION OF THE CENTROID RADIUS IN THE CANONICAL DISCRIMINANT VARIATES PLOT

Formula :

$$R=(X_{0.05,\ m} \times 1/(r \times n))^{1/2}$$

where :

X^2 : Chi-square distribution

m : effective dimensions

0.05 : significant level

r : error degrees of freedom

n : the observations per mean

In the case of factor DURATION in the greenhouse experiment in this study, the parameters in the formula are $m = 1$, $r = 72$, $n = 30$, $X^2 0.05,\ 1 = 3.84$ respectively. Then, the radius is :

$$R = (3.84 \times 1/(72 \times 30))^{1/2} = 0.042 .$$