ASSESSMENT OF SURVIVAL AND GROWTH PROSPECTS OF SEEDLINGS OF DOUGLAS FIR, PSUEDOTSUGA MENZIESII.

by

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ABSTRACT

The object of this work was to study the survival and growth of Douglas fir seedlings in relation to their morphological grade, and in relation to various pruning treatments.

The material used consisted of two-year-old Douglas fir seedlings, grown in the campus nursery at the University of British Columbia under various organic and inorganic fertilizer treatments. These fertilizer treatments produced seedlings which varied in quality, and which were therefore suitable for use in a study of survival and growth in relation to seedling grade.

Experiments were carried out under greenhouse, nursery, and field conditions. Statistical methods of analysis were used to determine the significance of the experimental results.

In all cases, mortality increased directly with decrease in seedling grade. This relationship was not affected by variations of site quality in the field, the percentage of successful establishment increasing with increase in seedling grade on all sites.

Shoot growth, root growth, and growth in diameter under bark were closely related to grade of seedling.

Root pruning retarded bud bursting. Mortality was increased by root pruning in conjunction with top pruning, but not by root pruning alone.

Shoot growth, root growth, and growth in diameter under bark were not affected by root pruning. Shoot growth, and growth in diameter under bark at the root collar were reduced by shoot and root pruning combined.

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INTRODUCTION

The considerations of correct choice of species and provenance of seed are fundamental to the successful establishment of plantations. Beyond this, the production of planting stock capable of high survival and growth is dependent on enlightened nursery management.

It was considered at one time that the poorest looking specimens produced in the nursery would be hardier, and have the greatest chance of survival in the field. This has since been proved to be a fallacy, and during the past century, many studies have been made to determine the optimum nursery management practices for most important tree species. More recently, extensive studies have been made of the soil and nutrient requirements of Douglas fir seedlings in relation to their development, notably by Youngberg (1954) and Schaedle (1959).

Nitrogen has been found to be the most important single element in the development of seedlings of this species, and the latter author has stipulated the optimum rates of nitrogen fertilization for 0-0 and 1-0 seedlings applicable at the Green Timbers Nursery of the B. C. Forest Service.

It is common practice to evaluate the probable survival capacity and growth prospects of nursery stock on the basis of a subjective classification involving size and vigour. Unfortunately, the correlation between the classes of stock so established, and survival and growth after planting has often proved to be poor.

Wakeley (1948) describing experiments with Southern pine seedlings, has reported on variations in the survival capacities of given morphological grades produced in different nurseries. Studies involving more than 122,000 trees, from 1934 to 1941, showed that some unidentified and uncontrolled influence frequently caused greater differences in initial survival than did drastic variations in planting technique. This influence was traced to a lack of coincidence between morphological and true grade. Supposedly inferior stock was found to exhibit higher survival capacity and better growth.

The inference from these studies was that the true, or physiological grades of the stock did not always coincide with the morphological grades. Among the possible causes of differences in physiological grade (with or without corresponding differences in morphological grade), the following were suggested as worthy of attention.

a) Differences in mineral nutrition. Wilde and coworkers (1948) have demonstrated chemical differences in seedlings arising from differences in soil or fertilization.

b) Differences in stored food reserves. These have been discussed by Kopitke (1941).

c) Differences in water tension. Shirley and Meuli (1939) have indicated that control of nursery soil moisture tension may be an important means of controlling physiological grade.

d) Sprays applied at lifting time. Where the incidence of disease or rodent attack necessitates spraying before planting, a modification of physiological grade may result. Shirley and Meuli (1938) have reported on the influence of foliage sprays on the drought resistance of conifers.

The physiological condition of seedlings is also liable to be influenced by the time of year at which they are lifted for transplanting, and by the effects of storage, if this is necessary, between lifting and planting.

Stone and Schubert (1959) have drawn attention to the seasonal periodicity of root initiation and elongation in ponderosa pine seedlings. This phenomenon is symptomatic of the seasonal variation in the physiological condition of the seedlings and of their subsequent response when transplanted.

The conclusion drawn by these workers was that spring planting is likely to give better results than fall planting. Maximum root initiation and elongation was found to take place in the spring, just before bud bursting. Also, seedlings were able to regenerate a new root system at a lower soil temperature in spring than in fall.

Cold storage in general has been found to reduce the amount of root elongation in the first month after transplanting. This reduction was more pronounced the earlier the seedlings were lifted in the fall, and may be closely associated with a failure to achieve "physiological hardening" or "readiness" before being placed in storage.

Bearing in mind the effects of lifting time and storage, it may be possible to improve the correlation between grade and survival by the choice of a better set of characteristics on which to base the classification of the grades.

With this object, Wenger (1955) studied the growth of two-year-old and four-year-old seedlings of <u>Pinus taeda</u>. The conclusion arrived at was that the best indication of growth prospects was given by the previous year's growth, the relation being linear, and independent of seedling height. This correlation was found to be unaffected by gross soil differences, prescribed burning, or seedling age.

The following characteristics were recorded: total height, proportion of the stem bearing branches, proportion of the stem bearing needles, number of branches, needle length, terminal bud length, stem form quotient (ratio mid-height diam. to ground line diam.), and the height-diameter ratio (total height to mid-height diam.).

The number of branches was found to be most satisfactory in predicting seedling growth. Total height was also very satisfactory when age was taken into account.

This study did not consider the possible relation between the character of the root system and growth prospects. Although the type of root growth is not in itself a reliable guide to the survival capacity and growth prospects of the seedling, it is felt that it does merit attention.

It has been suggested that the root collar diameter of seedlings may be used as a measure of their overall physical characteristics (Rutter, 1954, Report on Forest Research, G. B. Forestry Commission, 1958). Root collar diameter has been found to be closely correlated with shoot weight, root weight, and number of roots. The regression of plant survival on root collar diameter was also shown to be significant. This measure may thus give the best indication of survival and growth prospects, and has the advantage that it can be easily determined without disturbing the plant.

It is evident that the practice of grading on the basis of purely morphological characteristics is not a wholly satisfactory procedure. Root collar diameter within certain height limits may be a critical factor in determining survival capacity, but the grading standards for maximum survival will very for different planting sites. There is also no guarantee that seedlings grown to such standards in different nurseries will have equivalent survival and growth prospects.

An indication of unsatisfactory conditions is given by the failure of the root system, or the shoot, or both to develop on transplanting. Lack of shoot development is unlikely to become critical during the first year after planting, whereas the absence of root development might very well be fatal. Hence, the ability of a seedling to initiate new roots reflects the true survival capacity of the seedling, and its subsequent growth prospects.

The severe stagnation of planted Picea abies in northern Sweden has been found by Bjorkman (1953) to be due to failure of the root system to develop and absorb nutrients.

Douglas fir seedlings are particularly sensitive to drought injury, Isaac (1938), this factor being one of the most important causes of mortality in the early stages of establishment of this species. In general, initial survival and height growth depend on an excess of water intake over water loss, and this in turn depends on the formation of new absorbing roots immediately after planting.

Greenhouse studies have been carried out to investigate the capacity of seedlings to initiate new roots, notably by Stone (1955).

The species tested were, Pinus ponderosa, Abies magnifica, Pinus jeffreyi, Abies concolor, and Psuedotsuga menziesii. The seedlings were grown in sandy loam for 60 days, then carefully washed out of this medium in order that their root development might be studied. While all the plants appeared healthy after this period, every species tested showed some root production failures. Douglas fir seedlings had the highest failure with 40 percent. Close examination of seedlings, both those that produced roots and those that failed to do so, did not reveal any morphological differences. After replanting, it appeared that the physiological condition responsible for the inhibition of root development had not altered sufficiently to permit satisfactory growth.

This study was carried out in the first instance with spring transplanted seedlings, and later with fall transplanted seedlings, bringing to light the fact that new root development was much poorer if the seedlings were transplanted in the fall. This fact was investigated further by Stone and Schubert (1959).

It was concluded from this experiment that despite the use of a high morphological grade, a certain proportion of seedlings may be unable to initiate new roots. This proportion of the planting stock would be doomed to die of drought as soon as the soil in contact with their original rooting system dried out.

The effect of root pruning on the development of new roots is also worthy of consideration. The lifting of seedlings for transplanting usually results in a certain amount of injury, and it is often necessary to prune seedling root systems in order to facilitate planting. The effects of root damage on transplanting and of root pruning are generally considered to be beneficial, in that they stimulate the development of adventitious roots, and hence a more fibrous rooting system.

However, Wilcox (1955) on the basis of studies with noble fir, Corsican pine, and ponderosa pine, stated that pruning only stimulates the production of new roots in the immediate vicinity of the cut surface. He also stated that this does not lead to the development of a more fibrous root system, the initiation of new laterals taking place only opposite the xylem poles in the mother roots of seedlings aged from one to three years.

Various authors have claimed that root pruning results in the development of a more compact root system, thus minimizing the danger of damage on lifting for transplanting. No experiments have been reported to substantiate these claims, and it seems possible that if the laterals initiated exhibit a rapid rate of growth, the danger of damage on transplanting may not in fact be lessened.

However, the initial retardation of shoot growth which is likely to be caused by root pruning or transplanting may be beneficial in that it will restrict transpiration and reduce the danger of drought damage.

It is essential that nursery management produce plants which in their first year in the field are capable of producing a root system which can absorb water and nutrients. The optimum top/root ratio of seedlings is determined by the relative transpiration capacity of the crown together with the absorbing capacity of the roots, and it is therefore necessary to produce balanced seedlings, that is, the size of the crowns must not be out of proportion to the size of the root systems.

As has been suggested, the grading of seedlings by a subjective classification of their gross morphological characteristics is not an entirely satisfactory procedure. Ideally, consideration should be given to the physiological condition of the seedlings.

Wilde and Voigt (1949) have investigated the correlation between the degree of succulence of nursery stock and the ratio of the root absorbing surface to the relative transpirational loss. Numerical values of this ratio were obtained by direct measurement of transpiration in a transpiration chamber, and by estimating the total root surface by a method involving titration. The roots were washed to remove soil particles, and then air dried. They were then immersed in a solution of 3N HCl for 15 seconds. After the excess acid was allowed to drain for 5 minutes, the roots were transferred to a beaker containing 250 ml of distilled water. The contents of the beaker were stirred and allowed to stand for 10 minutes. A 10 ml aliquot was titrated with N/3 NaOH, using phenolphthalein as indicator. The total absorbing capacity of the root surface was then expressed in millilitres of titration.

The ratio so obtained was termed the absorption-transpiration (A/T) quotient.

Studies were made with jack pine, shortleaf pine and Norway spruce seedlings which had been raised under various levels of fertility.

The absorption-transpiration quotient was found to be correlated with the degree of succulence of the seedlings. As a measure of the water balance of the plants, this ratio was considered to be related to their relative resistance to drought and frost. This relation was borne out by field observations.

It was suggested that the A/T ratio be incorporated in a system of grading seedlings on a physiological basis. Other factors which might be given consideration are:

a) specific gravity,

b) degree of root respiration,

c) content and ratio of essential nutrients,

d) content of organo-solubles,

e) properties of expressed cell sap.

Such measurements would give some idea of the true or physiological grade of seedlings, and a better indication of their capacity for survival and growth.

Unfortunately, the determination of these factors is laborious and time consuming. To investigate the physiological condition of large numbers of seedlings in this way as a means of controlling planting stock quality is not a practical proposition.

In conclusion, it may be said that unless a relatively simple method of determining the physiological condition of seedlings can be found, we must rely on a system of morphological grading in assessing the quality of planting stock. Such a system must be tested in relation to species, nursery, and planting site.

EXPERIMENTAL MATERIAL

The material used in the following studies consisted of 2-year-old Douglas fir seedlings grown in the campus nursery at the University of British Columbia. These seedlings were grown by W. J. Murison under the direction of Dean G. S. Allen as part of an experiment to determine the effects of various types of organic and inorganic fertiliser on the growth and development of seedlings.

Seedlots

Two seedlots were employed, A(5631c) and B(5632), both supplied by the Forestry Department of MacMillan and Bloedel Ltd. All seed were collected in the vicinity of Nanaimo, B. C., and the two lots showed similar germination percentages. Both received approximately the same pregermination treatment, and they were sown on successive days, June 12 and 13, 1957.

Fertilisation

(i) Organics — Eight types of organic matter were used.

Organic amendments

A.	Duff mull	(young Douglas fir stand)
B.	Raw humus	(young hemlock-Douglas fir stand)
C.	Duff mull	(overmature cedar-hemlock stand)

D.	Black muck	(cedar-sphagnum-skunk cabbage)
E.	Lake Sedge Peat	
F.	Mull	(broadleaf stand)
G.	Sawdust	
H.	Nursery compost	
K.	Control	

These were applied in two concentrations; High - one-third organic matter by volume, and Low - one-tenth organic matter by volume.

Inorganics

The following compounds were used in chemically pure form: triple super-phosphate, calcium nitrate $Ca(NO_3)_2$, potassium chloride KCl, and ammonium nitrate NH_4NO_3.

Inorganic amendments

Low level NH_3PK:	1 gm NH_4NO_3
	1 gm triple super-phosphate
(2)	1 gm KCl
High level NH_3PK:	4 gm NH_4NO_3
	4 gm triple super-phosphate
(1)	4 gm KCl
Low level NO_3PK:	2 gm $Ca(NO_3)_2$
	1 gm triple super-phosphate
(2)	1 gm KCl
High level NO_3PK:	8 gm $Ca(NO_3)_2$
	4 gm triple super-phosphate
(1)	4 gm KCl

Organic and inorganic amendments were made prior to sowing. The high or low level of organic material was first mixed with soil to a total volume of 288 cubic inches. The appropriate level of inorganic fertiliser was then added, and the whole thoroughly remixed.

The treatment code was: organic level-kind of organic-seedlot-inorganic level-kind of inorganic. For example, LG-A-NH_3 meant amendments of low level sawdust and high level NH_3PK using seedlot A. The controls were coded K-A or B - 1 to 8, meaning control-seedlot-number of replicate.

The area was heavily baited and fenced to protect the young growth from mice, and insects such as cutworms and earwigs.

The fertiliser treatments so applied produced seedlings which varied in quality, and which were therefore suitable for use in a study of the survival and growth of nursery stock in relation to seedling grade.

Grading Procedure

The subjective classification of the seedlings involved their division into five distinct grades, ranging from very good to very poor stock. The classification was based on size and apparent vigour.

The relative sturdiness of the seedlings, i.e., their stem diameter and degree of branching, was considered in addition to their absolute height.

Estimations of relative vigour were made on the basis of degree of branching, length of needles, and colour of needles.

Description of methods in greenhouse study.

This experiment was basically a root development study, with the main objectives of relating root regeneration to grade of stock and effect of root pruning. A split-plot randomised block design was used.

The planting medium chosen was a 50 per cent mixture by volume of vermiculite and peat. This mixture, while providing support and retaining moisture for the seedlings, was sufficiently loose to permit lifting of the stock without damage to their root systems. It is easy to handle, clean, and relatively sterile. There were no visible signs of infection by fungal pathogens during the course of the experiment. The peat and vermiculite were mixed in a box measuring 4' by 15' which was raised on a greenhouse bench.

The seedlings were planted at a spacing of 10" by 7".

On lifting, the seedlings were washed from the peat-vermiculite mixture by means of a low pressure hose to avoid damaging the root systems. The excess water drained through the bottom of the box.

Shoot length, tap-root length, and length of longest lateral were measured in centimetres. The total root volume was measured in cubic centimetres by displacement of water in a graduated cylinder. Before the initial measurement, the root systems were carefully washed free of soil, and before the last measurement, washed free of vermiculite and peat.

After lifting, the weights of the old and new roots were determined in grams. The new roots were easily distinguished from the old by their white colour.

Photographs of representative seedlings were taken.

These photographs provide an illustration of the amount and distribution of the regenerated roots, and of the general type of root system characteristic of each grade of stock.

Statistical Analyses

The statistical significance of the experimental results was tested in each case by an analysis of variance. For sources of variation shown to be significant, and where controls had been specified *a priori*, adjacent group means were compared by a j.s.d. (just significant difference) test. Where controls had not been specified, group means were compared by use of a j.s.r. (just significant range) test (Snedecor 1956).

The correlations between certain factors were investigated in the manner described by Snedecor (1956).

The analysis of the split-plot randomised-block experiment was conducted in the manner suggested by Cochrane and Cox (1957).

Summaries of data and all analyses of variance and covariance are appended.

EXPERIMENTS

Experiment No. 1

Location - U. B. C. Greenhouse.

Object - To study the development of Douglas fir seedlings to determine whether shoot and root growth may be related to the morphological grade of the seedlings, or to the fertiliser regimes under which they had been grown. In addition, to study the effect of root pruning on shoot and root development.

Methods - Five grades of stock - very good, good, medium, poor, and very poor were established by the author in a subjective classification involving size and vigour. Replicates within grade of stock were provided by the use of any four of the fertilizer treatments applied to the seedlings in the campus nursery which satisfied the grade requirements. The classes of treatment and grade were:

Grade	Treatments	Grade	Treatments
Very good (VG)	Low C-A-2NO_3	Medium (M)	High B-B
	High F-B-2NH_3		High A-A-2NH_3
	Low C-B-1NH_3		High G-A-1NH_3
	High E-B-2NO_3		Low C-B

Grade	Treatments	Grade	Treatments
Good (G)	High F-B-1NH_3	Poor (P)	Low G-A-1NH_3
	Low E-A-2NH_3		High G-B-1NH_3
	High A-A-2NO_3		Low E-A
	High A-A-1NH_3		High G-B-2NH_3
		Very poor (VP) Controls	K-A-6
			K-A-8
			K-B-3
			K-B-6

All fertilized seedlings were better than the non-fertilized controls.

Further replication was provided by the use of six seedlings within each fertilizer treatment, giving a total of twenty-four seedlings representative of each grade.

The seedlings were lifted from the nursery on February 26th, 1959, and a representative half, i. e., three seedlings from each fertilizer treatment, were root pruned to one-half the original length of their roots.

The seedlings were then planted in a bed of vermiculite and peat in the greenhouse, the design being a split-plot arranged in three randomised blocks, with the sub-plots representing the pruned seedlings.

The seedlings were then allowed a period of sixty-five days for growth, during which time they were given an adequate and uniform supply of water. Times of bud bursting were noted for the individual seedlings.

On lifting, the seedlings were washed from the vermiculite and peat in order to minimize damage to the root systems.

The seedlings were then remeasured.

Results

(a) Time of bud bursting

No influence of grade of stock was apparent.

Bud bursting was significantly delayed by root pruning.

(b) Mortality

Under the favourable conditions obtaining in the greenhouse, only four seedlings died. These were all from the very poor grade of stock.

(c) Shoot growth

The effect of grade on absolute height growth was found to be highly significant.

The average shoot growth in centimetres for each grade was:

VG	G	M	P	VP
10.83	8.86	7.29	3.96	1.40

At the 1 per cent level of confidence, the j.s.d. = 3.16.

At the 5 per cent level of confidence, the j.s.d. = 2.73.

Comparing all grades with the very poor control, the very good, good, and medium grades were highly significantly better, while the poor grade was not significantly better.

Pruning had a significant effect in reducing height growth. The average height growth in centimetres for the unpruned and pruned seedlings was:

Unpruned - 7.29 pruned - 5.64

At the 5 per cent level of confidence, the j.s.d. = 1.5.

Since one might expect a relation between original height and new shoot growth, the regression of shoot growth on original height was removed. Analysis of covariance indicated that the effect of grade on shoot growth remained highly significant.

The interaction of grade and pruning was also found to be highly significant, the reduction in shoot growth due to root pruning being most pronounced in the good and medium classes of stock.

The average height growth of the unpruned and pruned seedlings by grades is given below in centimetres.

Grade	VG	G	M	P	VP
Unpruned	11.4	9.8	9.2	4.5	1.5
Pruned	10.3	8.0	5.3	3.4	1.3
Differences -	1.1	1.8	3.9	1.1	0.2

At the 1 per cent level of confidence, the j.s.d. = 0.84, and at the 5 per cent level of confidence, the j.s.d. = 0.63.

(d) Root growth

The effect of grade of stock on absolute increases in root volume was found to be highly significant.

The average root volume increases by grade in cubic centimetres were:

VG	G	M	P	VP
5.06	3.43	1.33	0.28	0.11

Comparing each grade to the very poor control, the differences are:

VG	G	M	P
4.95 **	3.32 **	1.22	0.17

At the 1 per cent level of confidence, the j.s.d. = 2.66, and at the 5 per cent level of confidence, the j.s.d. = 1.97.

** significant at p 0.01

Hence the better growth exhibited by the very good and good grades is highly significant. The medium and poor grades did not differ significantly from the control.

After removing the regression of root volume increase on original root volume, this characteristic of the two best grades remained highly significant.

The effect of pruning on absolute root volume increase was found to be non-significant. The stimulus to new root development imparted by pruning was apparently sufficient to compensate for the initial reduction in root volume and stored food reserves.

The percentage increases in root volume were closely related to grade of stock, and pruning had a highly significant effect in increasing the percentage volume growth.

To meet the requirements of the analysis of variance, the data were transformed to arcsin values (Snedecor, 1956).

The average percentage root volume increases for the grades were: (data retransformed to percentages)

VG	G	M	P	VP
12.10	13.79	11.06	6.88	3.34

Comparing each grade to the very poor control, the differences are:

VG	G	M	P
8.76 **	10.45 **	7.72 **	3.54

At the 1 per cent level of confidence, the j.s.d. = 5.5, and at the 5 percent level of confidence, the j.s.d. = 4.1.

** significant at p 0.01

Hence the better percentage root growth exhibited by the very good, good, and medium grades was highly significant, while that of the poor grade was not significant.

The average percentage root volume increases of the unpruned and pruned seedlings were: Unpruned - 7.50 and pruned - 11.37. At the 5 per cent level of confidence, the j.s.d. = 2.92. Hence, the average percentage root volume increase of the pruned seedlings was significantly better than that of the unpruned.

The interaction of grade and pruning had a highly significant effect on absolute root volume increase. The better performance of the pruned seedlings in this case can however be explained by the significantly greater initial root volume of one replicate in the very good class of stock.

The effects of individual fertilizer treatments were only reflected in the characteristics of the grades of stock which they had produced. That is, the effects of individual fertilizer treatments within a specific grade were not significantly different.

Discussion

The medium of vermiculite and peat in which the seedlings were planted served to retain moisture, and to support the plants. It may be reasonably assumed that it contained less nutrients than a natural forest soil, and the growth obtained may thus be considered as that which the seedlings would be capable of on transplanting. This growth should therefore indicate their probable chances of successful establishment.

Because of the very favourable growth conditions in the greenhouse, the development of these seedlings was greater than would have been obtained in the field. However the growth obtained probably indicates the relative differences in response to be expected.

From the results given above, it appears that a subjective classification of Douglas fir seedlings on the basis of morphological characteristics gives a fairly accurate indication of the relative shoot and root growth to be expected. It must be noted however that these seedlings had been grown for two years in the nursery without either root pruning or transplanting. In these respects they therefore differed from conventional nursery stock.

The data obtained from the pruned seedlings indicate several possible advantages in the practice of root pruning before planting, apart from the obvious facts that such seedlings are easier to handle and plant.

The delayed bud bursting induced by pruning would be advantageous in reducing the likelihood of damage from late frosts.

The inhibition of shoot growth by pruning in the first months after transplanting would reduce the danger of excessive transpiration and hence of drought damage.

New root development is not reduced by root pruning, and therefore, pruned seedlings do not suffer from the lack of new roots capable of efficient absorption.

Root pruning appears to stimulate new root development in Douglas fir seedlings. The new roots were initiated only in the region immediately behind the cut surface, varied in number from one to six, and developed as laterals rather than as fibrous roots. The final type of root systems developed by the pruned seedlings were rather more compact than those produced by the unpruned seedlings, but were no more fibrous in nature.

It is of interest to note here that examples of a complete failure to initiate new roots were confined to the very poor grade of stock, with the exception of two seedlings in the medium grade. Both of these seedlings were representative of the fertilizer treatment HG-A-1NH_3.

Their failure cannot however be attributed to the fertilizer regime under which they were grown, since all the seedlings from treatment

$HG-B-1NH_3$ in the poor grade successfully produced new roots. Neither can the difference in seed lot explain the failure of roots to develop.

Experiment No. 2a

Location - U. B. C. Research Forest, Haney.

Object - To study the development of Douglas fir seedlings in the field to determine the relationships between growth and grade of stock.

Methods - Five grades of stock, very good, good, medium, poor, and very poor were established as in experiment 1 by Dr. J. H. G. Smith. Replicates within grade were provided by the use of three fertilizer treatments. The classes of treatment and grade were:

Grade	Treatment	Grade	Treatment
VG	Low $A-B-1NH_3$	P	Low E-B
	High $A-B-1NO_3$		High F-A
	High $E-B-1NH_3$		Low $G-A-2NH_3$
G	Low $D-B-2NO_3$	VP	High G-B
	Low $B-A-1NO_3$		K-A-2
	Low $D-A-1NH_3$		High C-A
M	Low F-A		
	High D-A		
	Low $E-B-2NH_3$		

The project was established by Mr. J. Walters in May, 1959, near the spacing trials on the east side of the North Alouette river. The soil was sandy, and completely bare of vegetation.

The field design provided replicates by treatment, and by the use of six seedlings within each treatment, all randomised in a single block.

The project was remeasured by Mr. Walters on Sept. 28th, 1959 and the data were analysed by Dr. Smith.

Results

(a) Mortality

Seedling mortality increased with decrease in seedling grade. No very good, good, or medium grade seedlings died. One poor and four very poor seedlings died during the 1959 growing season.

(b) Growth

Height growth was strongly associated with grade of seedling. With the exception of the poor grade, growth increased directly with stock quality. The better performance of the poor stock could be completely explained by the significantly larger size of one seedling of this grade.

Growth in 1959 was strongly associated with size of stock at time of planting.

No significant influence of original fertilizer treatment in addition to seedling grade was apparent.

Data summary

Averages in feet of approximately 36 seedlings per class

Seedling grade	Planting height	1959 growth	total height end 1959	1959 % growth
Very good VG	0.453	0.171	0.624	37.7
Good G	0.421	0.168	0.589	39.9
Medium M	0.283	0.156	0.439	55.1
Poor P	0.275	0.164	0.439	59.6
Very poor VP	0.232	0.134	0.366	57.8

Remarks

While the absolute growth was better for the better grades of stock, the percentage increases in size were greater for the small stock. However, even if this rate of increase were maintained, which is unlikely, it would take the very poor stock at least three years to catch up with the very good stock in height.

Experiment No. 2b

Location - U. B. C. Research Forest, Haney.

Object - To study the relationships between growth and survival of Douglas fir seedlings and site quality.

Methods - Five plots, ranging in site index at 100 years from 80 to 85, were clearcut, and planted in May, 1959, by Mr. J. Walters with two seedlots of 2-0 Douglas fir. Within each lot, two 36-seedling block of each seedlot were established.

The project was remeasured in Sept., 1959, by Mr. Walters, and the data were analysed by Dr. Smith.

Results

(a) Mortality

The seedlots 5634 and 5621 suffered similar mortality, averaging 6.8 per cent. Blocks A and B within seedlot 5621 were similar but blocks A and B within 5624 differed substantially, averaging 9.4 and 5.0 per cent mortality respectively. No reasons for this difference were apparent. No relation between site quality and mortality was evident in the following tabulation.

Site index	180	160	150	140	85
Mortality per cent	4.9	6.3	11.1	3.5	8.3

(b) Growth

Four randomly chosen seedlings of each seedlot and block were measured on each of the five clearcut plots.

Lot 5621 seedlings were smaller than lot 5634 seedlings on planting, and this difference persisted.

The best growth was on the site 180 plot, and the poorest, relatively and absolutely, on the site 150 plot. This site 150 plot also suffered the most severe mortality.

Data summary

Plot number	1S	5S	7S	8S	4S	
Site index	180	160	150	140	85	
Planting ht.	0.303	0.269	0.344	0.322	0.325	heights in feet
1959 ht. growth	0.203	0.159	0.112	0.153	0.131	
Sept.,1959 ht.	0.506	0.428	0.456	0.475	0.456	
1959 ht. per cent	67.0	59.3	32.7	47.6	40.4	

Remarks

It may be seen that with the exception of plot 7S, absolute and percentage height growth increase with site quality. The atypical results obtained on plot 7S may possibly be explained by the facts that this plot was a little steeper and rockier than the other plots.

Experiment No. 3a

Location - Campus nursery, University of British Columbia.

Object - To study the development of Douglas fir seedlings transplanted in the nursery in relation to their morphological grade, and in relation to various degrees of root and top pruning.

Methods - Five grades of stock were established as in experiment 1 by Dr. J. H. G. Smith. Replicates within grade were provided by the use of three fertilizer treatments and five seedlings within each pre-treatment.
Five pruning treatments were then applied within each pre-treatment according to Dean G. S. Allen's design.

These were:

(a) Control,

(b) Root pruned to height of tops,

(c) Root pruned to one-half height of tops,

(d) Top and roots pruned to one-half original height of tops,

(e) Top and roots pruned to one-quarter original height of tops.

The whole was further replicated in four randomised blocks, A, B, C, D, the experiment being established in April, 1959, by Mrs. M. Lambden, and Mr. M. L. Medveczky.

Seedlings in blocks A and D were lifted in November, 1959, remeasured, and the data analysed by the author.

Results

(a) Mortality

Seedling mortality increased with decrease in seedling grade, and with the intensity of the pruning treatment. Summary of mortality by grades and treatment.

Grade	a	b	c	d	e
VG					1
G					1
M	1	1	1		3
P		2	1	4	4
VP	2	2	8	8	11

(b) Shoot growth

Height growth was found to be closely correlated to grade of seedling.

Averages of shoot growth in centimetres by grades were:

VG	G	M	P	VP
6.54	4.27	3.44	3.27	1.42

Comparing each grade to the VP control, the differences are:

VG	G	M	P
5.12**	2.85**	2.02**	1.85**

At the 1 per cent level of confidence, the j.s.d. = 1.52.

Hence, all grades were highly significantly better than the control.

The effect of treatment was also found to be highly significant. Averages of shoot growth in centimetres by treatments were:

a	b	c	d	e
5.08	4.36	4.18	2.40	3.17

Comparing each treatment to the control, a (no pruning), the differences are:

b	c	d	e
0.72	0.90	2.68**	1.91**

At the 1 per cent level of confidence, the j.s.d. = 1.52, and at the 5 per cent level of confidence, the j.s.d. = 1.15.

Hence, only treatments d and e depressed shoot growth to a significant degree. Thus root pruning alone had no significant effect.

The interaction of treatment and grade had no significant effect.

(c) Root growth

The effect of grade was found to be significant.

Averages of tap root growth in centimetres by grade were:

VG	G	M	P	VP
9.47	11.42	8.80	8.16	2.81

Comparing each grade to the VP control, the differences are:

VG	G	M	P
6.66**	8.61**	5.99*	5.35*

At the 1 per cent level of confidence, the j.s.d. = 6.07.

At the 5 per cent level of confidence, the j.s.d. = 4.57.

Hence, the tap root growth of the very good and good grades was better than the control to a highly significant degree, and the tap root growth of the medium and poor grades was better than the control to a significant degree.

The effect of treatment, and of the interaction of treatment and grade, were found to be non-significant.

(d) Growth in diameter under bark at the root collar.

The growth in diameter under bark at the root collar was found to be closely related to the grade of stock.

Averages of growth in diameter in centimetres by grades were:

VG	G	M	P	VP
0.145	0.104	0.069	0.078	0.030

Comparing each grade to the VP control, the differences are:

VG	G	M	P
0.115**	0.074**	0.039**	0.048**

At the 1 per cent level of confidence, the j.s.d. = 0.029.

Hence, the VG, G, M, and P grades all show a highly significant improvement in diameter growth under bark over the VP control grade.

The effect of treatment on diameter growth under bark at the root collar was also found to be highly significant.

Averages of growth in diameter in centimetres by treatments were:

a	b	c	d	e
0.102	0.098	0.094	0.071	0.060

Comparing each treatment to the control a (no pruning), the differences are:

b	c	d	e
0.004	0.008	0.031**	0.042**

At the 1 per cent level of confidence, the j.s.d. = 0.029, and at the 5 per cent level of confidence, the j.s.d. = 0.222.

Hence, root pruning alone has no significant effect in reducing diameter growth under bark, but this is reduced to a highly significant degree by shoot and root pruning combined.

The influence of the interaction of treatment and grade was found to be non-significant.

Discussion

All grades exhibited significantly better shoot and diameter growth than did the control grade. However, only the very good and good grades showed significantly better root growth.

Contrary to the results of experiment 1, root pruning was found to have no significant effect on shoot growth. This may be explained at least partially by the following facts:

1) The data here represent a complete season's growth, and it is possible that the early shoot growth restriction which was evident in Experiment 1 would not be significant after a longer period of growth.

2) The differences in environment and growth media may also have been partly responsible for the difference in response.

Experiment No. 3b

Using the data collected in the investigation carried out under experiment 3a, a study was made of the relationships between shoot weight and root collar diameter over bark, and between root weight and root collar diameter over bark.

The object of this study was to determine whether the root collar diameter over bark of Douglas fir seedlings can be used as a measure of overall physical characteristics.

Results

A high degree of correlation was found between over bark diameter at the root collar and both shoot and root weight.

Correlation coefficients based on observations are:

1) For collar diameter and shoot weight = 0.916,

2) For collar diameter and root weight = 0.911.

Correlation coefficient at 1 per cent level of significance = 0.230. Hence, both correlations are highly significant. The value of the root collar diameter over bark as a measure of the physical characteristics of the plant is therefore obvious.

Experiment No. 4

Object - To investigate the possibility of using the relative turgidity of Douglas fir seedling needles as a measure of the physiological condition of the plants.

Introduction - The value of the use of relative bark turgidity as an indication of the susceptibility of a tree to infection by facultative parasites has been shown by Bier (1957). In this context, the measure is considered to estimate the physiological condition of the host tree.

Rutter and Sands (1957) have shown that variations in leaf water deficit can be accounted for by changes in soil moisture tension and transpiration rate. Other factors shown to affect this relation were:

(a) age of needles,

(b) time of year,

(c) nitrogen nutrition,

(d) previous soil moisture conditions.

It was suggested, that using one-year-old needles, the water status of stands on various sites might be inferred through comparisons made at the same time of the year. These measurements should be made at sunrise to minimize variations produced by transpiration rates.

It was also suggested that noon values might integrate soil and environmental factors. In such a case, these values would provide an indication of the relative physiological condition of the plants, and in this experiment, all measurements were made from samples collected at midday.

Methods

Samples representative of the five grades of seedlings previously established were taken. One-year-old needles were cut from the plants at approximately two millimetres from the base of the needle, and transferred immediately to weighing bottles which were then stoppered.

After reweighing to obtain the fresh weight, the needles were transferred to water in Petri dishes, the dishes covered, and the needles allowed to soak for a period of twenty-four hours. They were then dried superficially on paper towels, returned to the original weighing bottles, and reweighed to obtain the saturated weight.

The dry weight of each sample was then determined, and the relative turgidity calculated from the formula:

$$\frac{\text{Weight of water in the fresh sample}}{\text{Weight of water required to saturate this sample}}$$

Two separate tests were run, one on graded seedlings which had been planted out, and one on graded seedlings which had remained in the nursery beds. In each case, duplicate samples were taken in order to obtain a water/dry weight percentage unaffected by possible leaching during the soaking period.

Results

Test 1 - The relative turgidity of the needles was found to be related to seedling grade with the exception of the medium grade, which had the highest value of all as follows:

Grade	VG	G	M	P	VP
Rel. turgidity per cent	76	67	87	62	58

No reason was apparent for the higher value obtained for the medium grade.

Test 2 - No relation was found between seedling grade and the relative turgidity of the needles as follows:

Grade	VG	G	M	P	VP
Rel. turgidity per cent	82	82	81	82	83

Discussion

The results of this experiment are contradictory, but it is felt that the possibility of employing this measure to advantage need not be discarded.

The conflicting results obtained in test 1 and test 2 can at least be partially explained. The samples for test 1 were taken from seedlings transplanted for the purposes of experiment 3, and the samples for test 2 were obtained from seedlings in the original nursery beds. The differences between the grades had been accentuated in the case of the transplanted stock, due to the varying ability of the grades to recover and develop after being disturbed. The needles of all grades of seedling used in test 2 were of a relatively uniform green colour, but those of the seedlings used in test 1 showed a variation in colour with grade. Those of the VG, G, and M grades were dark green, and those of the P and VP grades were yellowish-green.

Further sampling will be required before any conclusions can be reached regarding the value of this method. Preferably, measurements should be made in early spring, at weekly intervals, for perhaps a month before the stock is lifted for transplanting. If any differences between grade are then evident, it would then be necessary to trace any reflections of the differences in the relative success of the various grades in the field.

GENERAL DISCUSSION

The overall effects of grade and root pruning observed in the greenhouse study (Experiment 1) were in general substantiated by the nursery and field trials.

The influence of grade of stock:

a) On mortality - All experiments indicated that the relation between mortality and grade of stock was highly significant. Mortality increased directly with decrease in seedling grade. This relationship held true in the greenhouse, nursery, and field experiments, and was not affected by variations in site quality in the field, the percentage of successful establishment increasing with increase in seedling grade on all sites.

b) On growth - Shoot growth, root growth, and growth in diameter under bark, all proved to be related to seedling grade. An increase in grade of stock was in each case followed by improved growth. These effects were not solely due to the initial greater size of the higher grades, since after removal of the regression of growth of each factor on its initial size, the effect of grade remained highly significant. We may therefore infer that the growth conditions responsible for bringing the seedlings to these particular standards have also been responsible for bringing about variations in the physiological condition of stock of different grades. It is these differences in physiological state which are responsible for the superior growth of the better grades of seedling.

The practice of grading Douglas fir nursery stock purely on the basis of gross morphological characters appears to give a fairly satisfactory indication of the survival and growth prospects of the stock when transplanted to the field.

The grading procedure must however take into consideration the general sturdiness of the seedling in addition to shoot length. The diameter of the seedling at its root collar, being closely correlated with shoot and root weight, would seem to be the best characteristic on which to base grading standards. Such grading standards might then be further refined to suit varying planting sites by setting an optimum collar diameter measurement within a given range of shoot height.

The effects of pruning:

a) On bud bursting - Root pruning significantly retarded bud bursting, and since this would reduce the danger of damage from late frosts, root pruning in this context, is deemed to be beneficial.

b) On mortality - The most severe root pruning employed was to one half the shoot height. This, or lighter degrees of pruning did not affect the amount of mortality in the stock so treated. Root pruning in conjunction with top pruning increased mortality.

c) On growth - Considering a complete season's growth, root growth and growth in diameter under bark were not affected by root pruning.

The shoot growth of the seedlings grown in the greenhouse for 65 days was found to be retarded by root pruning. This effect was not apparent at the end of a complete growing season in the pruned seedlings planted in the nursery. No measurements were taken of these nursery seedlings early in the growing season, but it seems probable that the retardation of growth observed in the greenhouse would be initially operative in the field. Such a restriction of shoot growth immediately after transplanting is likely to have a beneficial effect in reducing the possible amount of transpiration while the transplanted root system is becoming re-established.

No significant difference was found between the absolute amount of new roots produced by pruned or unpruned seedlings. The percentage of new roots produced was however significantly greater for pruned seedlings. This is a point of importance, since pruned seedlings will thus possess a higher percentage of new, absorbing roots than will unpruned seedlings, and the efficiency of the root as a nutrient absorbing organism is more important than the root mass *per se*. The determining factor is the number of points at which new roots develop.

It cannot be claimed on the basis of these studies that root pruning of Douglas fir seedlings results in the development of a fibrous type of root system. It does however result in the production of a higher percentage of absorbing roots, and in the development of a more compact root system.

CONCLUSIONS

It appears that the survival and growth prospects of Douglas fir nursery stock may be predicted with reasonable accuracy by means of a subjective classification on the basis of size and vigour. The characteristics of diameter at the root collar and shoot height are the most satisfactory for use in setting grading standards.

The practice of pruning the roots of Douglas fir seedlings, in addition to facilitating planting, produces effects which are generally desirable. The percentage of absorbing roots produced in the first year after planting is increased, and a more compact root system is developed. Bud bursting is delayed, reducing the possibility of damage from late frosts. Shoot growth is initially retarded, reducing the possibility of drought damage through excessive transpiration before the root system is fully re-established. Despite the initial restriction of growth, by the end of the growing season, shoot height and diameter are not significantly lower than those of unpruned transplants.

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Experiment 1 - Data Summary

Average shoot growth in centimetres by grade, pruning, and blocks.

Grade	Treatment	Block I	Block II	Block III	Averages by grade and pruning
VG	Unpruned	11.53	11.63	11.05	11.40
	Pruned	10.25	10.35	10.23	10.28
G	Unpruned	9.55	11.00	8.83	9.79
	Pruned	8.55	7.08	8.18	7.93
M	Unpruned	8.53	9.30	9.63	9.15
	Pruned	4.38	6.13	5.55	5.35
P	Unpruned	4.58	4.45	4.63	4.55
	Pruned	3.50	3.10	3.50	3.37
VP	Unpruned	0.85	2.03	1.65	1.51
	Pruned	1.95	0.68	1.23	1.28

Average root volume increases in mls. by grade, pruning and blocks

Grade	Treatment	Block I	Block II	Block III	Averages by grade and pruning
VG	Unpruned	4.20	4.28	4.90	4.46
	Pruned	3.63	5.58	8.45	5.88
G	Unpruned	2.43	2.90	5.75	3.69
	Pruned	2.08	3.75	3.70	3.18
M	Unpruned	1.30	1.38	1.45	1.38
	Pruned	1.23	1.35	1.25	1.28
P	Unpruned	0.35	0.20	0.38	0.31
	Pruned	0.23	0.28	0.23	0.24
VP	Unpruned	0.18	0.23	0.13	0.18
	Pruned	0.13	0.00	0.10	0.08

Experiment 1 - Analyses of variance tables

a) - Shoot growth

Source of variation	D.F.	Sum of squares	Mean square	F P
Total	119	1510.74		
Full plots	59	1389.39		
grades	4	1379.11	344.78	1723.9 **
blocks	2	0.88	0.44	2.2
error	53	9.40	0.20	
Sub plots	60	1533.64		
pruning	1	80.53	80.53	132.02 **
g x p	4	74.00	18.50	30.33 **
error	55	33.42	0.61	

b) - Root growth (absolute values)

Source of variation	D.F.	Sum of squares	Mean square	F P
Total	119	666.41		
Full plots	59	512.67		
grades	4	456.81	114.20	184.19 **
blocks	2	22.79	11.40	18.39 **
error	53	33.07	0.62	
Sub plots	60	546.00		
pruning	1	0.49	0.49	0.42
g x p	4	88.70	22.18	18.96 **
error	55	64.55	1.17	

Root growth (percentage values) - Data transformed to arcsin values

Source of variation	D.F.	Sum of squares	Mean square	F P
Total	39	8674.3		
grade	4	5210.7	1302.7	20.94 **
pruning	1	1346.7	1346.7	21.65 **
error	34	2116.9	62.2	

** significant at p 0.01

Experiment 1 - Covariance analyses

a) - Shoot growth with influence of original heights removed

Source of variation	D.F.	$[X^2]$	$[XY]$	$[Y^2]$
Total	39	17274.3	7835.8	4940.8
grade	4	16580.5	7820.1	4142.2
error	35	693.8	15.7	798.6

Residuals	D.F.	Sum of squares	Mean square	F	P
Total	38	1386.3			
grade	4	588.1	147.0	6.26	**
error	34	798.2	23.5		

b) - Root growth with influence of original root volumes removed

Source of variation	D.F.	$[X^2]$	$[XY]$	$[Y^2]$
Total	39	2976.0	1151.65	3215.8
grades	4	2706.4	1152.8	2906.5
error	35	269.6	- 1.1	309.3

Residuals	D.F.	Sum of squares	Mean square	F	P
Total	38	2770.1			
grades	4	2460.8	615.2	67.6	**
error	34	309.3	9.1		

** significant at p 0.01

Experiment 3a - Data summary

Average shoot growth in centimetres by grade and treatment

Grade	Treatments a	b	c	d	e	Grade averages
VG	7.45	6.37	5.42	5.48	8.02	6.54
G	5.45	5.32	5.00	2.15	4.62	4.27
M	5.42	4.62	4.60	1.63	0.93	3.44
P	4.70	2.90	5.17	2.15	1.45	3.27
VP	2.37	2.58	0.72	0.58	0.83	1.42
Treatment averages	5.08	4.36	4.18	2.40	3.17	

Average tap root growth in centimetres by grade and treatment

Grade	Treatments a	b	c	d	e	Grade averages
VG	-	6.95	11.67	8.10	11.17	9.47
G	-	11.28	9.98	12.08	12.32	11.42
M	-	7.02	12.95	9.57	5.68	8.80
P	-	5.97	13.40	5.80	7.47	8.16
VP	-	3.85	4.87	1.08	1.43	2.81
Treatment averages	-	7.01	10.57	7.33	7.61	

Average diameter growth (ob) in centimeters

Grade	Treatments a	b	c	d	e	Grade averages
VG	.175	.130	.150	.153	.115	.145
G	.110	.140	.100	.083	.085	.104
M	.075	.090	.088	.050	.043	.069
P	.090	.092	.110	.052	.045	.078
VP	.062	.060	.020	.018	.010	.030
Treatment averages	.102	.098	.094	.071	.060	

Experiment 3a - Analyses of variance tables

a) - Shoot growth

Source of variation	D. F.	Sum of squares	Mean square	F P
Blocks	1	132.37	132.37	26.11 **
treatment	4	209.09	52.27	10.31 **
grade	4	529.78	132.45	26.12 **
t x g	16	19.46	1.22	0.24
error	124	628.47	5.07	
total	149	1519.17		

b) - Root growth

Source of variation	D. F.	Sum of squares	Mean square	F P
Blocks	1	26.89	26.89	0.42
treatment	3	243.87	81.29	1.27
grade	4	993.01	248.25	3.89 *
t x g	12	346.94	28.91	0.45
error	99	6324.17	5.07	
total	119	7934.88		

c) - Diameter growth under bark

Source of variation	D. F.	Sum of squares	Mean square	F P
Blocks	1	0.0220	0.0220	12.2 **
treatment	4	0.0414	0.0104	5.8 **
grades	4	0.2169	0.0542	30.1 **
t x g	16	0.0246	0.0015	0.8
error	124	0.2234	0.0018	
total	149	0.5283		

** significant at p 0.01

* significant at p 0.05

Experiment 3b - Correlation analyses

a) - Diameter at the root collar over bark and shoot weight.

X^2	=	23.9842	XY	=	365.553	Y^2	=	7053.88	N = 123
C	=	22.1192	C	=	295.913	C	=	3958.74	
$[X^2]$	=	1.8650	$[XY]$	=	69.640	$[Y^2]$	=	3095.14	

$$\text{Correlation coefficient } r = \frac{69.64^2}{1.865 \quad 3095.14}$$

$$= \underline{0.916}$$

b) - Diameter at the root collar over bark and root weight.

X^2	=	23.9842	XY	=	321.814	Y^2	=	5402.41	N = 123
C	=	22.1192	C	=	262.199	C	=	3108.09	
$[X^2]$	=	1.8650	$[XY]$	=	59.615	$[Y^2]$	=	2294.32	

$$\text{Correlation coefficient } r = \frac{59.615^2}{1.865 \quad 2294.32}$$

$$= \underline{0.911}$$

Experiment 4 - Test 1 - Data summary

Relative turgidity percentages by grade and pre-treatment

Grade	Treatments a	Treatments c	Treatments e	Grade averages
VG	62	80	85	76
G	66	57	77	67
M	83	89	90	87
P	62	76	47	62
VP	68	41	64	58
Treatment averages	68	69	73	

Water/dry weight percentages by grade and pre-treatment

Grade	Treatments a	Treatments c	Treatments e	Grade averages
VG	88	103	82	91
G	153	118	139	137
M	124	149	88	120
P	116	129	66	104
VP	115	150	84	116
Treatment averages	119	130	92	

Experiment 4 - Test II - Data summary

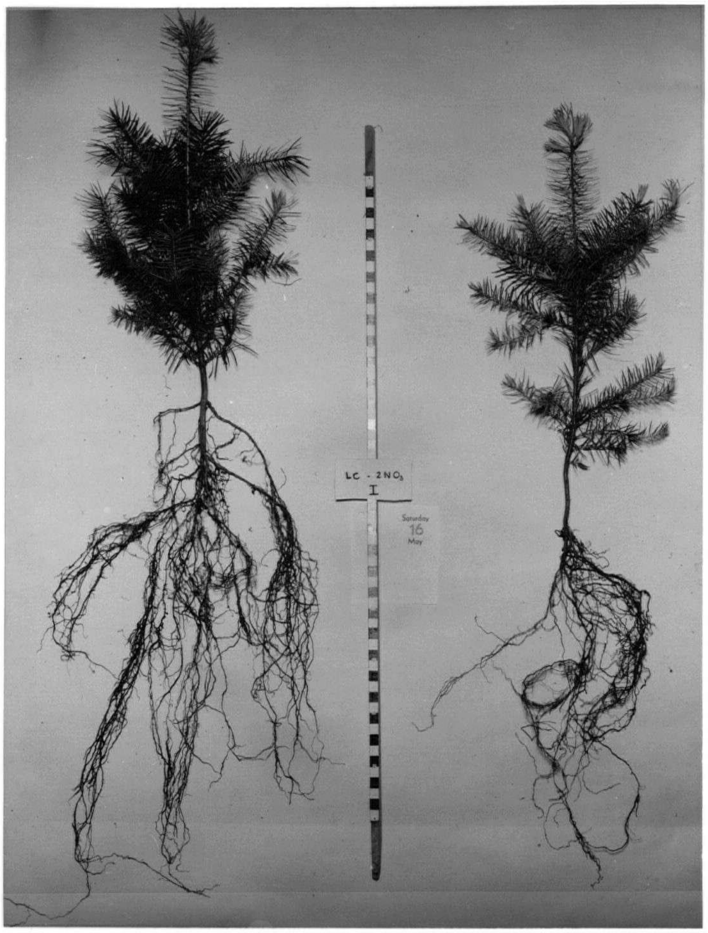
Relative turgidity percentages and water/dry weight percentages by grade.

Grade	Rel. turg. %	Water/dry weight %
VG	82	167
G	82	166
M	81	162
P	82	167
VP	83	157

Grade - Very good (VG)

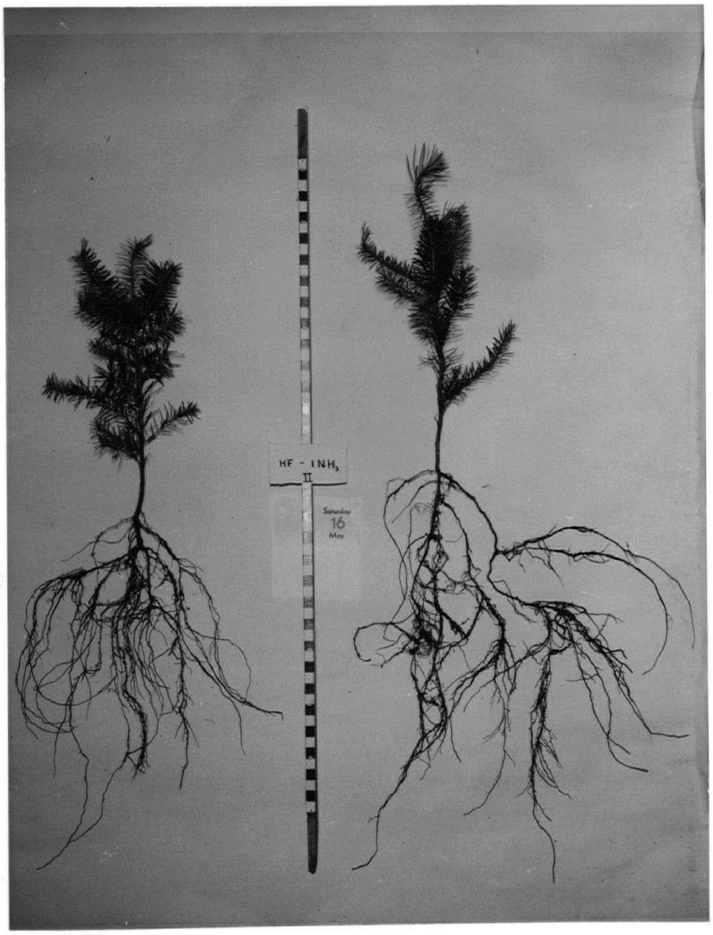
left - pruned
right - unpruned

Scale in centimetres



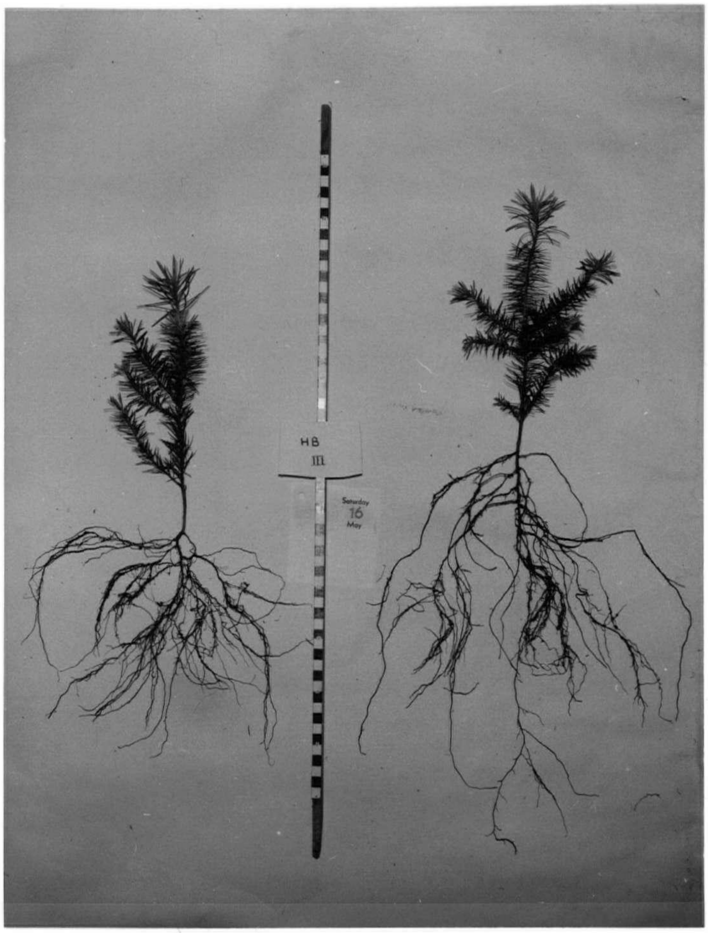
Grade - Good (G)

left - pruned
right - unpruned



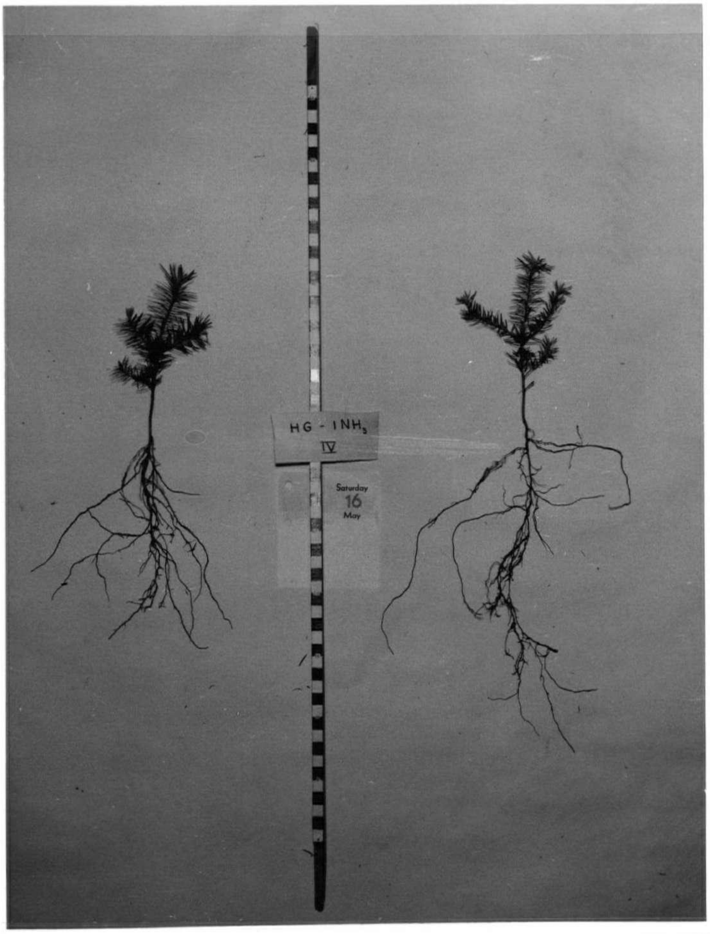
Grade - Medium (M)

left - pruned
right - unpruned



Grade - Poor (P)

left - pruned
right - unpruned



Grade - Very poor (VP)

left - pruned
right - unpruned