CONDITIONING RADIATA PINE SEEDLINGS TO TRANSPLANTING, BY RESTRICTED WATERING

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ABSTRACT

Seedlings of radiata pine (**Pinus radiata** D. Don) growing in a temperature-controlled greenhouse at day/night temperatures of 26°/23°C were pre-conditioned for 6 weeks prior to transplanting, by one of the following watering regimes: D, watered daily; W, weekly; or F, 2-weekly. After transplanting, 24 seedlings of each pre-conditioning treatment were placed into one of the following environments: (a) the pre-transplanting environment, but watered every 8-10 days; (b) artificially-lit cabinet at 23°/20°C (day/night temperatures), and watered every 10-14 days; (c) as (b), but watered every third day.

After transplanting, the D seedlings exhibited high rates of transpiration which fell to about 10% of the original value after 2 days. When the seedlings were actively transpiring, their stomata remained wide open even though the plants were experiencing increasing water deficits. The F and W seedlings on being transplanted, opened their stomata only partly, and thus initially used less water than the D seedlings, and developed smaller water deficits. In the pre-transplanting period D seedlings had significantly higher rates of stomatal and cuticular transpiration than the W plants which in turn had higher rates than the F plants, but 3 weeks after transplanting, this order was reversed. Eighteen days after transplanting, the F seedlings had more new root growth than the W seedlings. The D seedlings had the least new root growth. These differences in root growth had disappeared 40 days after transplanting.

INTRODUCTION

In New Zealand, radiata pine (*P. radiata* D. Don) seedlings must be hardened off to minimise the shock of being transplanted into the field. The normal method of conditioning line-sown seedlings is to undercut and root wrench, with periodic lateral root pruning (van Dorsser and Rook, 1972), and this method gives satisfactory results. However, in other countries alternative methods of conditioning seedlings are used, one of which is to harden off the seedlings by restricted watering (Goor and Barney, 1968). This method would appear to have particular relevance to survival from transplanting, as drought is one of the main factors involved in transplanting shock (Gürth, 1970).

The objective of this study was to examine the water relations and new root growth of seedlings which, prior to being transplanted, had been watered at different frequencies.

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PLANT MATERIAL AND GROWTH CONDITIONS

To reduce genetic variation within treatments, radiata pine seed from one controlled pollination (55 × 121) of the New Zealand Forest Service tree breeding programme was used. The seeds were germinated by the staff at the Duke University Phytotron and the seedlings grown in the greenhouse section there (Kramer *et al.*, 1970) at day/night temperatures of 26°/23°C respectively for 4½ months before any pre-transplanting treatment was imposed. One of the following three pre-transplanting watering regimes was applied for 6 weeks to lots of 90 seedlings — D, watered daily; W, weekly; or F, 2-weekly.

Throughout the experiment the seedlings were grown in a 1 : 1 mixture of vermiculite and gravel in 340-g containers, approximately 7 cm in diameter. The plants were watered alternately with modified Hoagland's solution and demineralised water. At the time of transplanting, the white actively-growing roots were removed so that new growth could be easily assessed, and the seedling was placed in one of the following post-transplanting environments:

(1) G (a temperature-controlled greenhouse at 26°/23°C and watered every 8-10 days)

(2) C1 (an artificially-lit controlled environment cabinet at 23°/20°C and the plants watered every 10-14 days)

(3) C2 (an artificially-lit cabinet 23°/20°C and the plants watered every third day).

The light intensity of the artificially lit cabinets was 40,000-45,000 lux.

Twenty-four plants of each pre-transplanting treatment were assigned to each of the three post-transplanting environments. Nine seedlings of each pre-transplanting treatment were harvested at the time of transplanting to evaluate the effect of the preconditioning treatment on amount and distribution of growth within the seedling (*see* Table 1). The remaining seedlings were not transplanted but left to grow in the temperature-controlled greenhouse and were watered every 8-10 days as in the G post-transplanting environment.

TABLE 1—Effect of restricted watering on growth of seedlings before being transplanted (values given within brackets are standard deviations based on 35 observations for height measurements and nine seedlings for the other measurements)

	Frequency of water		
	Daily (D)	Weekly (W)	2-Weekly (F)
Seedling height (cm)	25.7 (± 2.2)	19.8 (± 2.2)	17.5 (± 2.2)
Foliage o.d. wt (g)	1.531 (± 0.339)	0.985 (± 0.272)	0.729 (± 0.092)
Stem o.d. wt (g)	0.438 (± 0.112)	0.213 (± 0.066)	0.162 (± 0.031)
Root o.d. wt (g)	1.280 (± 0.251)	0.809 (± 0.158)	0.638 (± 0.145)
Root/shoot ratio	0.66 (± 0.10)	0.70 (± 0.14)	0.72 (± 0.16)

METHODS

Rates of transpiration, as weight loss of seedlings growing in sealed pots per unit time which was normally 3 hr, were recorded periodically on three seedlings of each pre- and post-transplanting treatment. Two methods of estimating leaf water potentials were employed—a Richards and Ogata (1958) psychrometer or a pressure chamber

(Scholander *et al.,* 1965; Boyer, 1969). Whole seedlings were used for the pressure chamber measurements, whereas the psychrometer method used parts of needles only. To conserve plant material, the psychrometer method was used whenever possible, but this method could accommodate only a limited number of samples. The pressure chamber method necessitated harvesting one seedling for every water potential reading, but the method is quick and particularly useful where a series of water potential measurements are required over several days. The relationship between these two methods of estimating water stress in radiata pine seedlings is described by the linear regression Y = — 1.799 + 0.976X where Y represents the pressure chamber readings and X the psychrometer readings (Fig. 1). This regression is based on a sample of 50 seedlings ranging in age up to 12 months and growing under a variety of environmental conditions in the phytotron; included in the plants sampled were 20 seedlings of the same material as in the rest of this study. In each of the experiments reported

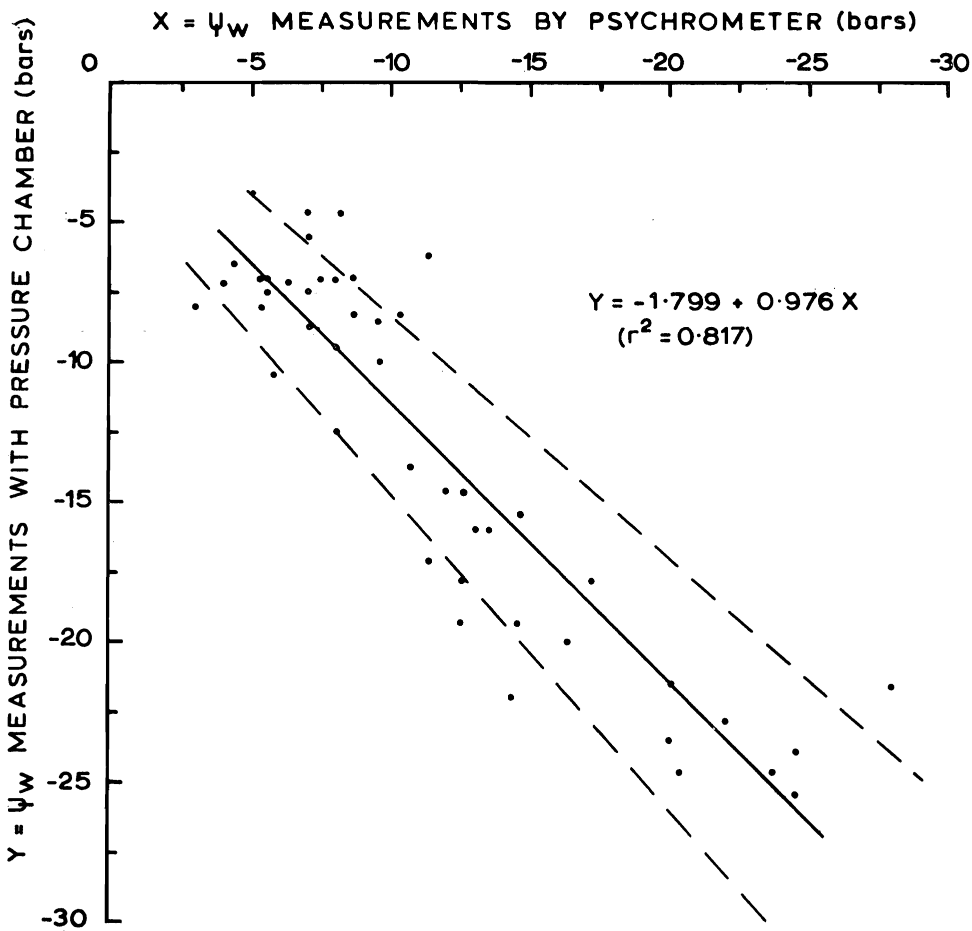


FIG. 1—The relationship between measurements of water potential made by psychrometer and by pressure chamber for 1-yr-old seedlings. The discontinuous lines on either side of the regression line are the 95% confidence limits.

here the pressure chamber method was used for 50% of the readings, but at any one sampling time either the psychrometer or the pressure chamber method was used solely. The pressure chamber readings were converted, via the regression equation, and recorded as psychrometer readings. Four replications were taken with the psychrometer measurements and three with the pressure chamber method.

Estimates of stomatal aperture were made by the alcohol infiltration technique described by Fry and Walker (1967) according to the modifications of Lopushinsky (1969). A 57% ethanol/water solution was used and for any series of measurements two needles were taken from each of three seedlings per treatment. Each needle was examined within 10 min of being detached. Measurements with a modified Wallihan porometer (Byrne *et al.,* 1970) showed no significant changes in stomatal resistance within 10 min of detachment under the conditions of this experiment, but longer periods could not be used without risk of stomatal closure.

Rates of cuticular and stomatal transpiration of excised needle fascicles from seedlings of each pre-conditioning treatment were measured gravimetrically (Hygen, 1953; Bannister, 1964). These measurements were made (1) before transplanting, and (2) 3 weeks after transplanting into the temperature-controlled greenhouse only (G: post-transplanting environment). All plants were well watered in the afternoon prior to taking measurements, and were then placed in a blackened bell jar overnight in a humid atmosphere. The needle fascicles, one from a seedling of each conditioning treatment, were placed side by side on a gauze support at 26°C, approx. 45,000 lux light intensity, and wind speed of 100 cm per sec. Weighings were made every minute at the start, and gradually reduced in frequency to one every 30 min towards the end of the 210-min experiment. There were three replicates of each tratment in a randomised block design. Measurements of water loss were recorded as the leaf relative water content at the time of weighing, i.e., expressed as a percentage of the water content of the leaf at the start of the experiment, when the leaf was assumed to be fully turgid.

Six seedlings of each pre- and post-transplanting treatment were harvested 18 and 40 days after transplanting, when counts of new root growth were made, similar to those of Stone and co-workers for "root regeneration potential" or "regeneration capacity" (Stone and Schubert, 1959; Stone and Jenkinson, 1970). The number of new roots greater than 1 cm long on each plant was recorded, and the length of new growth of these roots measured. The roots were classified into three diameter classes, as judged by eye: the middle class approximately 2 mm in diameter was recorded according to the length measurement, the thinner roots approximately 1 mm in diameter were considered as equivalent to half the standard diameter and counted as only half the measured length, and the thicker roots about 3 mm in diameter were recorded as twice the measured length.

Since root/shoot ratio, whether based on an oven-dried (o.d.) weight or volume basis, is a rather nebulous concept, an estimate of root efficiency was made by measuring the flow of nutrient solution through detopped root systems when placed under a pressure gradient. After growing for 4 weeks after transplanting in the artificially-lit cabinet at 23°/20°C, and being watered every 10-14 days (C1 post-transplanting environment), six seedlings of each pre-conditioning treatment were decapitated and their roots placed in aerated half-strength, modified Hoagland's nutrient solution at 23°C at a pressure of 3.1 bars with the cut stump open to atmospheric pressure. Fine capillaries were used to collect the root exudate. The volume of exudate during the first hour was not measured as differences were generated in setting up the equipment. The volume of exudate from 1 to 3 hr was assumed to be an indicator of the efficiency of the root system.

RESULTS

Rate of Transpiration

Fig. 2 shows the changes in transpiration rate with time of the seedlings transplanted into the C1 environment (artificially-lit cabinet and watered every 8-10 days). Following transplanting, the seedlings of the D (watered daily) pre-conditioning treatment had rates of transpiration more than double those of seedlings of the W (watered weekly)

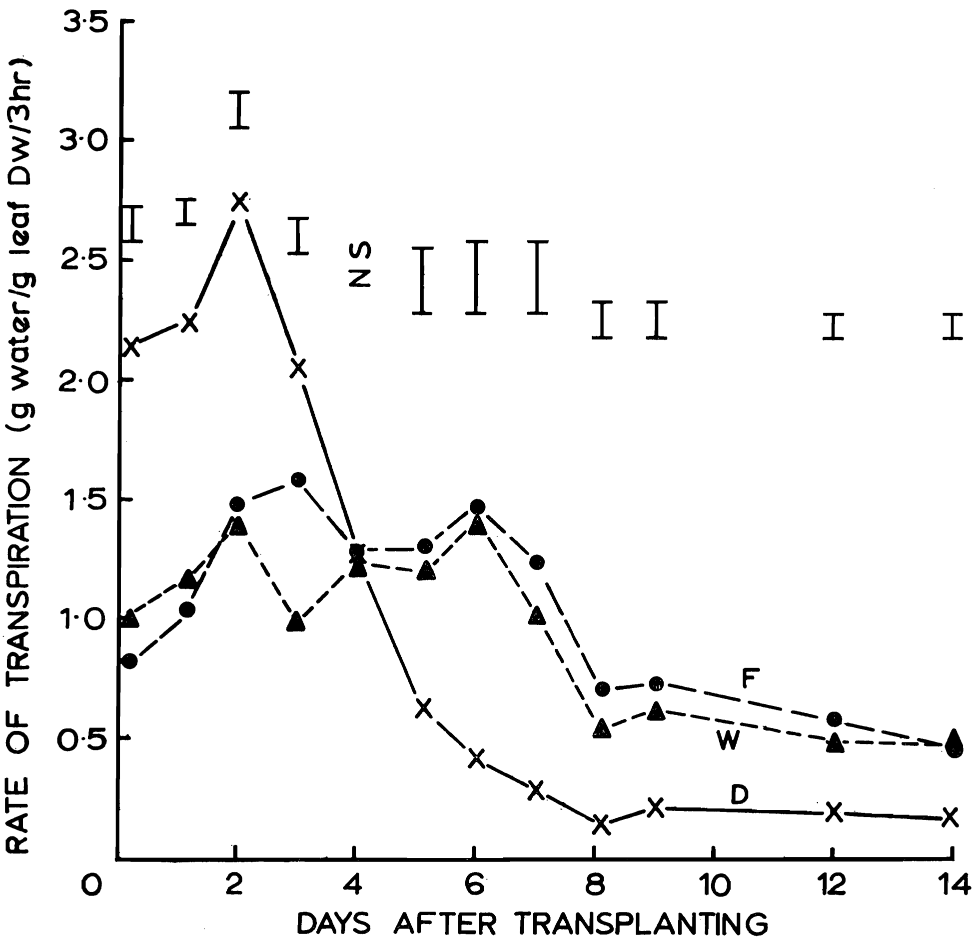


FIG. 2—Time course of changes in rates of transpiration of seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F) then transplanted into an artificially-lit cabinet and watered after 14 days. Vertical lines denote LSD values for the pre-transplanting treatments at the 5% level. NS = not significant.

and F (watered every 2 weeks) pre-conditioning treatments. Within 3 days of being transplanted, however, the rates of transpiration of the D seedlings started to fall drastically, and levelled out about 6 days after being transplanted, at a value 10% of their initial rate. Seedlings of W and F pre-conditioning treatments maintained their initial post-transplanting rates of transpiration for approximately a week. Thereafter these rates fell, but after 2 weeks were double the rate of transpiration of the D seedlings.

Results from the experiment where the seedlings were transplanted in the greenhouse (G post-transplanting environment) were similar to those noted above, except the rates of transpiration were generally much greater under these conditions than in the artificially-lit chambers. Rates of transpiration of the D seedlings for the first 2 days after transplanting in the greenhouse were 3.24 and 3.09 g of water lost per gram of leaf o.d. weight in 3 hr and they then fell by some 90% until they were rewatered 8 days after being transplanted.

Rates of transpiration of a few seedlings, which were left not transplanted in the greenhouse and watered every 8-10 days (G post-transplanting environment), declined considerably more slowly with continued soil moisture stress than transplanted seedlings in the same environment, but otherwise these non-transplanted seedlings showed similar responses to the transplanted seedlings.

Plant Water Status

The internal water stress measurements taken on the day before the seedlings were transplanted in the greenhouse (G post-transplanting environment) showed significant differences in water potential (Fig. 3), as the F seedlings had last been watered 7 days previously, and the W seedlings 3 days previously. On being transplanted into a well-watered soil, all seedlings had high water potential values. On the day after being transplanted, the D seedlings had a water potential value of —15 bars, and they remained obviously very wilted for the rest of that day, which was clear and sunny. The next day was cloudy, which probably accounts for the apparent recovery and the higher water potential measurement of —10.3 bars by the D seedlings. Over the next 6 days all seedlings showed progressive decreases in water potential with the D seedlings having a water potential of —16.8 bars on the eighth day after being transplanted; the seedlings were then rewatered. At this time, the seedlings of W and F pretreatments had water potentials of —11.2 bars.

The seedlings growing in the artificially-lit cabinet and watered every 8-10 days (C1 post-transplanting environment), showed relatively gradual changes in leaf water potentials. The D seedlings had a water potential of —3.2 bars immediately after transplanting, and this decreased uniformly to —15 bars 14 days after they were transplanted. In contrast, the F seedlings had a fairly constant water potential of about —7 bars throughout the experiment, and the W seedlings showed only a slight decrease in water potential with time.

Stomatal Aperture

Fig. 4 shows changes in infiltration pressure, for the seedlings transplanted and kept in the greenhouse (G post-transplanting environment). The stomata were wide open for the first 2 days, but on the third day after transplanting, the seedlings showed an

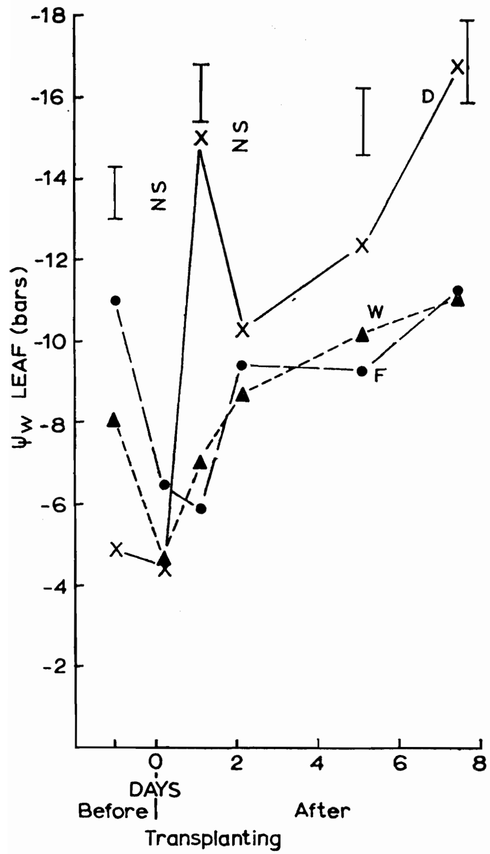
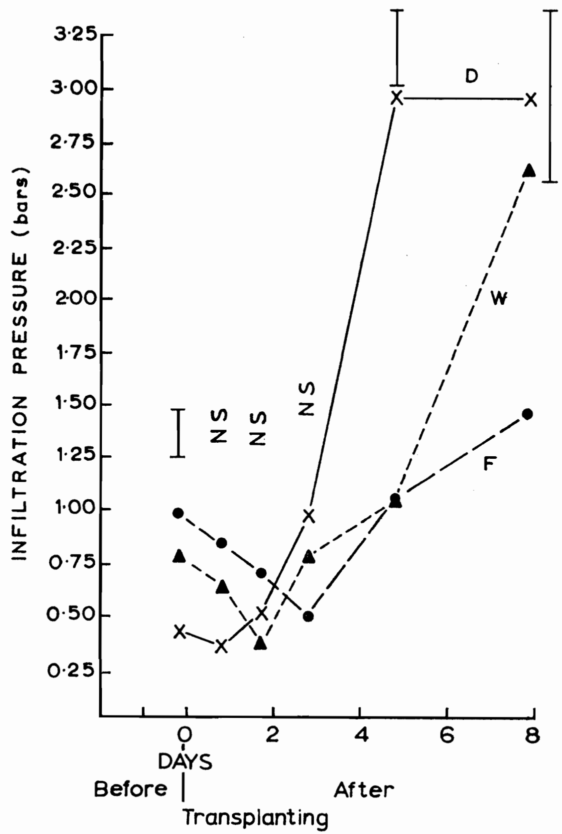


FIG. 3 (left)
Changes in leaf water potential (Ψ) with time for seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F) then transplanted in the greenhouse and watered after 8 days. Vertical lines denote LSD values for the pre-transplanting treatments at the 5% level. NS = not significant.

FIG. 4 (right)
Changes in infiltration pressure with time for seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F) then transplanted in the greenhouse and watered after 8 days. Vertical lines denote LSD values for the pre-transplanting treatments at the 5% level. NS = not significant.



increased, although non-significant, stomatal resistance, and on day 5 the stomata were closed. The stomata of the W and F seedlings were still partly open on day 5.

Since there is a close inverse relationship between rate of transpiration and stomatal resistance, Fig. 2 indicates that the stomata of the seedlings which were watered every 8-10 days in the artificially-lit cabinets (C1 post-transplanting environment) remained virtually fully open until day 2, then started to close until on day 7 the stomata were closed. The stomata remained closed until the seedlings were rewatered. Infiltration pressure measurements also confirmed that the stomata of the W and F seedlings were partly closed throughout the experiment in C1 post-transplanting environment, but showed an increase in resistance from day 8 until the seedlings were rewatered.

Water Loss from Excised Needle Fascicles

Rates of water loss from excised needle fascicles of seedlings growing under the pre-conditioning treatments are shown in Fig. 5; at this stage the seedlings had not been transplanted. The fascicles of each treatment had a period of rapid water loss.

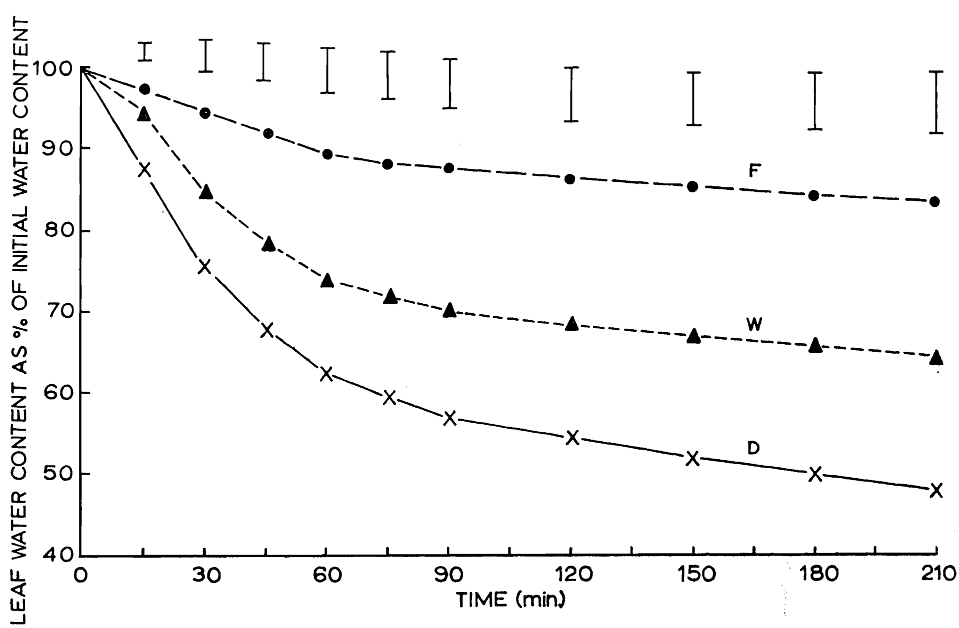


FIG. 5—Loss of water from detached needle fascicles of seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F) before the seedlings were transplanted. Vertical lines denote LSD values at the 5% level for differences due to pre-transplanting treatments.

After approximately 50-90 min, depending on the pre-transplanting treatment, rates of water loss were considerably reduced, presumably from stomatal closure. The low rates of water loss after this time represent rates of cuticular transpiration. Seedlings watered more frequently during this pre-transplanting period of the experiment had higher rates of stomatal and cuticular transpiration. Seedlings watered daily lost about

55% of their initial water 210 min after detachment compared with a 15% drop in water content for seedlings watered once every 2 weeks.

Three weeks after the seedlings were transplanted in the greenhouse (G post-transplanting environment) these measurements of water loss of detached fascicles were repeated, Fig. 6. The period of rapid water loss was generally similar to that of the F and W treatments in Fig. 5, approximately 60 min, but the rates of water loss for the D seedling fascicles in the post-transplanting period were half of those observed in the pre-transplanting period. Similarly, rates of cuticular transpiration were approximately halved in the D seedlings 3 weeks after being transplanted. In contrast, the 8-10 day watering schedule given to the F seedlings in the post-transplanting period, compared with watering every 14th day in the pre-transplanting period, appeared to have induced slightly higher rates of stomatal and cuticular transpiration.

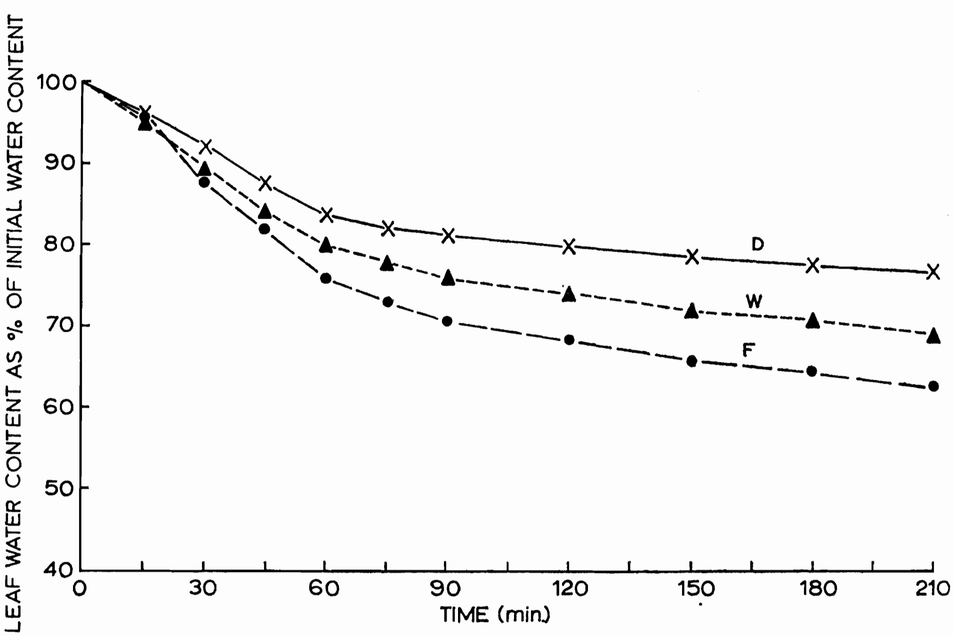


FIG. 6—Loss of water from detached needle fascicles of seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F), then sampled 3 weeks after the seedlings had been transplanted in the greenhouse. Differences between the pre-conditioning treatments were not significant.

New Root Growth

Differences in numbers of new roots produced and in root elongation between treatments (Figs. 7 and 8) were significant generally at the 1% level, for the 18-day harvest, and non-significant for the 40-day harvest. The 18-day harvest showed that the seedlings pre-conditioned by restricted watering (F pre-transplanting treatment in particular) had significantly higher rates of new root growth, both in numbers (Fig. 7) and total length (Fig. 8) than those seedlings watered daily before transplanting. The greater the water stress in the preconditioning period the higher were the rates

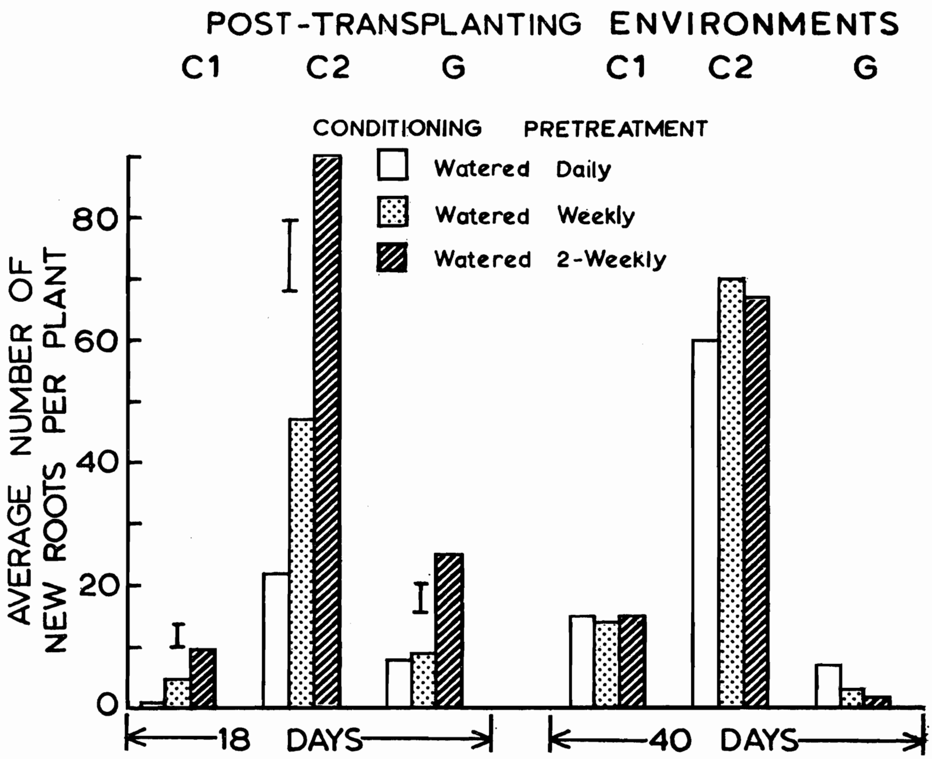


FIG. 7—Numbers of roots formed in seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F), then transplanted into artificially-lit cabinets and watered every 10 to 14 days (C1), or watered every third day (C2) or transplanted in the greenhouse and watered every 8 to 10 days (G). Harvests were made 18 and 40 days after transplanting. The vertical lines denote the LSD values for differences due to pre-conditioning treatments under each of the three post-transplanting environments for the 18-day harvest. Results were not significant for the 40-day harvest.

of new root production, both in numbers of new roots and their lengths. Although the experimental design did not allow direct comparisons between responses to the different post-transplanting environments, it would appear that the availability of soil moisture was one of the main factors determining new root growth following transplanting. Transplanted seedlings which were watered every third day produced nine times the number of roots that seedlings watered every 10-14 days did (C1 post-transplanting environment). Nevertheless, even where soil moisture was not limiting in the post-transplanting phase, i.e., in the artificially-lit cabinet where the seedlings were watered every third day, the same ranking in new root production occurred as in a stressed post-transplanting environment. The F seedlings showed the most new root growth, both in numbers of new roots and in root elongation and the D seedlings least. The results from the greenhouse environment are confusing in that there was apparently less new root growth at 40 days after transplanting than at 18 days. This anomaly

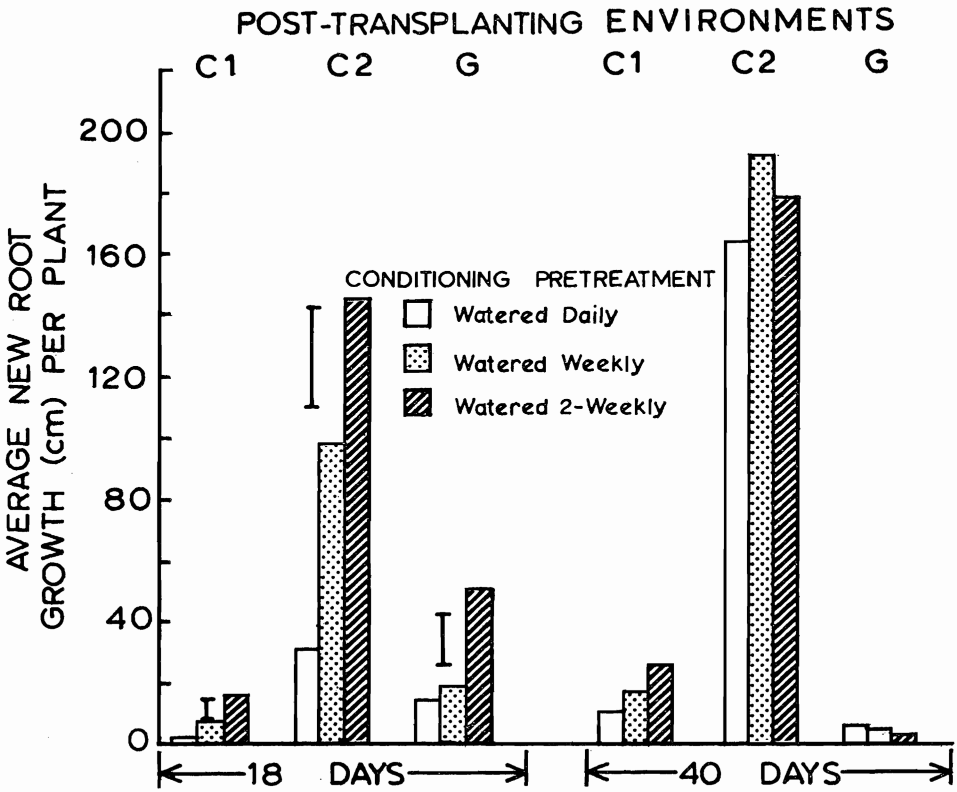


FIG. 8—New root production in seedlings pre-conditioned by being watered daily (D), weekly (W), or 2-weekly (F), then transplanted into artificially-lit cabinets and watered every 10 to 14 days (C1), or watered every third day (C2), or transplanted in the greenhouse and watered every 8 to 10 days (G). Harvests were made 18 and 40 days after transplanting. The vertical lines denote the LSD values for differences due to pre-conditioning treatments under each of the three post-transplanting environments for the 18-day harvest. Results were not significant for the 40-day harvest.

could have resulted from watering the seedlings 14 days prior to the 40-day harvest, and 11 days before the 18-day harvest. The seedlings showed a flush of new root growth a few days after being watered, and this growth gradually decreased in intensity over the 14-day period, presumably with rapid suberisation of the new roots until they were rewatered. Only white, non-suberised roots were included in these counts.

Root Efficiency Measurements

Although there were large differences in the values obtained for root exudation with pre-conditioning treatment, average readings of 0.26, 0.64, and 0.88 ml exudate/g root o.d. weight/hr for seedlings of the D, W, and F pre-transplanting treatments respectively, the variation was such that differences due to pre-transplanting treatment could not be demonstrated at conventional levels of significance. The measurements were made on all the seedlings 4 weeks after they had been transplanted into the artificially-lit cabinet and watered every 10-14 days (C1 post-transplanting environment). These results of root exudation, together with a few additional measurements from other treatments, were plotted against the mass of unsuberised roots present in the root system. Although this relationship appeared best defined as a linear regression, the degree of fit was very poor ($r = 0.31$). The relationship between root exudation and numbers of new roots (longer than 1 cm) was even more variable.

DISCUSSION

Salter and Goode (1967) note that several workers have suggested that drought resistance can be acquired by keeping plants short of water in the early stages of growth. The simplest explanation is provided, as these authors point out, in the general belief that a reduced water supply in the early stages of growth encourages the development of a large, deeply penetrating root system. Even if this effect lasted only a few months it could enhance considerably survival rates of seedlings following transplanting. The data presented in Table 1 indicate that restricted watering drastically reduced growth of the seedlings and root growth was inhibited almost as much as shoot growth. After 6 weeks of restricted watering, i.e., three cycles of being watered once every 14 days, the root/shoot ratios of the F seedlings were not significantly greater than those of the D seedlings. The D seedlings did have slightly lower root/shoot ratios, but this might have been due to their increased size relative to the F seedlings. It is well known (Bray, 1963) that the value of root/shoot ratio decreases with increase in plant size. Zahner (1968) in reviewing the literature observed that the effect of soil moisture on root/shoot ratio is not consistent.

Initially the D seedlings had high rates of transpiration on being transplanted, and maintained these high rates of transpiration with low water potentials of —15 bars. During this period the stomata remained wide open. Whereas the stomata of the D seedlings were slow to respond to increasing water stress, the F seedlings' stomata responded slowly to increased availability of water. This was the first time the D seedlings had been subjected to severe water stress, and their stomata initially were insensitive to decreasing water potentials.

The data from the transpiration experiment generally agree with previous published work that mean daily rates of transpiration decrease in soils of low moisture content. Jarvis and Jarvis (1963b) observed that the rate of transpiration of a plant depended not only on the prevailing soil water potential, but also on the water stress the plant previously experienced. Delayed recovery of transpiration lasting several days after the soil had dried out to wilting point, e.g., F pre-transplanting treatment of this present study, has been reported several times in the literature.

Before transplanting, the D seedlings had higher rates of both cuticular and stomatal transpiration than the W and F seedlings. The stomata of the D seedlings closed at a leaf relative water content of 60% compared with 90% for the F seedlings. A brief examination of needle cross sections of the D and F seedlings with a scanning electron microscope suggested that the leaf cuticle of the F seedlings was considerably thicker than that of the D seedlings (Rook *et al.,* 1971; and unpublished work), although according to Martin and Juniper (1970) the degree of impregnation of the cuticle with wax is more important in controlling water loss than thickness of the cuticle.

Bannister (1964) found that the mean relative water contents at stomatal closure for *Calluna vulgaris* were similar and about 70% under different evaporating conditions. Plants from a dry site gave lower values of relative water contents at stomatal closure (68%) than plants from wet sites (76%), which is contradictory to the above results. Bannister suggested that plants adapted to the drier conditions forgo a degree of stomatal protection for the sake of continued photosynthesis. In the present study with radiata pine the pre-transplanting treatments were probably more sudden and extreme than those of Bannister's experiment, causing the plants to react very differently, and probably preventing the same fine degree of stomatal control in radiata pine that was observed in *Calluna.* Zavitkovski and Ferrell (1968) observed that Douglas fir seedlings from a wet environment were less resistant to dehydration than ecotypes from a dry site. The seedlings from the former environment photosynthesised at lower leaf relative water contents than seedlings from the dry site and, as the authors state, this could erroneously be interpreted as greater efficiency in photosynthesis under drought conditions. When the lowest values of both soil moisture and relative water content were correlated with photosynthetic rates, the seedlings from the dry environment were more efficient. This work with Douglas fir agrees with the present study in indicating that seedlings pre-conditioned to a dry environment make more efficient use of the water available under conditions of water stress, e.g., immediately after transplanting.

The experiments with detached leaf fascicles indicated that the needles of the D seedlings quickly became acclimatised to a restricted water supply. Three weeks after being transplanted the seedlings showed greater stomatal and cuticular control of water loss than the F and W seedlings. Before the D seedlings were transplanted their stomata started to close after 30 min, but closure was not completed until after 90 min (Fig. 5). Following transplanting, stomatal closure occurred after 60 min and appeared to be rapid and effective (Fig. 6). Fig. 4 would suggest that the stomata of D seedlings 3 weeks after transplanting were perhaps not so fully open at the start of the detached needle fascicle experiment before the seedlings were transplanted: this would account for part of the adaptation following transplanting. The stomata of D seedlings 3 weeks after transplanting started to close at a relative water content of 85% compared with 60% in the pre-transplanting period. Jarvis and Jarvis (1963a) state that the leaf water potential at which stomatal closure occurs is not as important to increased tolerance to moisture stress as the rate of attainment of this water potential or its direct effects.

Increased plant hardiness appears to involve several metabolic processes which require food and time to allow the plant to make the necessary metabolic and morphological adjustments (Ferrell and Woodard, 1966; van den Driessche, 1970). The present study indicates that the needles of the D seedlings became more xerophytic during the 3 weeks after transplanting, with resultant greater drought resistance. Other work with radiata pine (Rook, 1969) has shown that seedlings can acclimate in a few days to a warm environment when grown at cool temperatures, and *vice versa.* The ability of this species to adapt quickly to warm or cool temperatures, or from moist sites to dry sites is important to the forester who must harden off seedlings in the nursery before planting them in the field. In Sweden, where much of their planting stock requirements are met as container-grown seedlings (*Picea abies* and *Pinus sylvestris*) raised in plastic greenhouses, the only conditioning treatment given is to leave the seedlings outside for a minimum of 3 weeks before they are taken to the planting site, or placed into cold storage.

Amer and Williams (1958) consider that a temporary increase in growth rate above that of control plants normally occurs when plants are rewatered after short periods of water stress. Stocker (1960) agrees that there is an increase in growth potential during the restitution phase of plants hardened off by water stress. The present study indicated that shoot growth of all seedlings was temporarily inhibited following transplanting, but there was considerable new root production and elongation in the seedlings previously water stressed, particularly in the F pre-transplanting treatment. Seedlings previously severely drought stressed (F pre-transplanting treatments) produced a significantly greater mass of new root growth within 18 days of being transplanted than non-stressed seedlings; these differences had disappeared by the 40-day harvest. This difference could be critical as the rate of new root production could determine survival in some sites. Stone and co-workers (e.g., Stone and Schubert, 1959; Stone and Jenkinson, 1970) measured new root production 28 or 30 days after transplanting the seedling.

Much of the value to afforestation of the technique used by Stone to measure root regenerating capacity depends on the results obtained under artificial conditions of the laboratory being applicable in the field. Stone (1967) recommends closely controlling soil temperature and soil moisture under the test conditions to reduce variation and obtain reproducible results. Stone and Jenkinson (1970) observed that the effect of available soil water on root regenerating capacity in *Pinus ponderosa* transplants varied with season; Stone and Schubert (1959) had previously found a marked seasonal periodicity in root regeneration capacity of *P. ponderosa* in well watered soils. Although Stone and Jenkinson (1970) found that root regeneration capacity was generally depressed as the initial amount of available water was decreased, three of the planting dates actually showed higher root regeneration capacities at 45% and 60% than at 100% available water. In the study reported here, the post-transplanting treatments with less frequent watering produced significantly less new root growth, and the ranking of the seedlings according to pre-conditioning treatment remained the same. The F seedlings always had a higher root growth capacity after 18 days than the D and W seedlings, when the seedlings were transplanted and watered at different frequencies and grown at different temperatures and light intensities. These results help to further substantiate the basic inferences that results obtained by the root regeneration capacity techniques in a laboratory-controlled environment are applicable to a wide range of environments in the field.

The root efficiency results were very variable, but there was a suggestion that the greater the mass of new roots the greater the flow of water through the decapitated root system. This relationship could not be defined precisely, and many of the higher root efficiency values occurred as new root growth was starting rather than when measureable, though relatively little new growth had taken place. Most newly-planted seedlings in the field have few living, unsuberised roots, and the seedling is initially dependent on the ability of its suberised roots to take up soil moisture. Although suberised roots of woody species are less efficient, per unit surface area, than non-suberised roots at absorbing water and nutrients, more than 90% of the total root surface of a tree consists of suberised roots; Kramer and Bullock (1966) concluded from a study with yellow poplar and loblolly pine that most of the water absorption does occur through suberised roots. However, a seedling must produce new roots to explore new soil areas to tap their water and nutrient reserves.

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