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SUMMARY OF NURSERY RESEARCH

1967 - 1976

AUTHOR

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by

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Summary

The Commission's *Pinus radiata* nursery research is summarized with particular emphasis on results of practical use. Highlights include the development of recommendations for:

- (1) maintenance of nursery fertility by a rotational cropping sequence including vigorous ley pastures,
- (2) balanced annual seedbed and foliar fertilizer additions,
- (3) higher seedling yields by modification in seed sowing techniques, by the identification of pathogenic agencies and the use of specific fungicides,
- (4) more effective weed control methods using Propazine-Chlorthal weedicides and tractor-mounted boom sprays,
- (5) improvements in seedling quality by modification and rationalization of crop production techniques to produce large hardy planting stock.

Introduction

In the ten years since the original research working plan was written, research activity has concentrated on *P. radiata* nursery practice. In particular, studies have investigated techniques to maintain and improve

- (1) nursery fertility
- (2) nursery weed control
- (3) planting stock yields
- (4) planting stock quality.

Further work is needed especially in the field of production yields and pathogen control both during the nursery season and to prevent disease transfer on planting stock from nursery to the field.

Research into nursery practices has been subdivided into seven fields for administrative purposes:—

- (a) New nursery investigations.
- (b) Seedling crop development.
- (c) Nursery fertility.
- (d) Nursery pathological and mycorrhizal studies.
- (e) Sowing studies.
- (f) Nursery weed control.
- (g) Planting stock quality.

This report presents a general summary of findings in each field and attempts to integrate these findings with respect to routine nursery practice.

Earlier reports can be located in the experimental files and records maintained by the Research Forester, Bathurst. Details of individual experiments together with photographic records are also located at Bathurst. Other summaries have been published in the appropriate sections of the Forestry Commission's Biennial Research Reports.

New nursery investigations

From 1969, feasibility studies were carried out in the Forbes area to investigate the possibility of establishing a large nursery for *P. radiata* seedling production. Very large succulent seedling crops were raised at the Forbes amenity nursery in two soils from suitable sites and with the aid of supplementary irrigation. Seedling growth was modified by root wrenching to produce very high quality stock which showed high survival and growth rates when planted on severe sites on Vulcan S.F. near Oberon.

These studies indicated that large high quality seedlings could be produced in the Forbes area on flat, sandy and well-drained sites with long growing seasons. However stock quality depended on the judicious use of supplementary irrigation, root wrenching and carefully controlled seedling transport.

In 1973-74, seedling production studies were carried out on a flat sandy site on the outskirts of Bombala township on the banks of the Bombala river. This site was favourable for seedling production provided it was well inoculated with mycorrhizal fungi. NPK fertilizer additions will also be necessary as evident in large seedling crop growth responses.

Seedling crop development

The growth pattern of 1-0 *P. radiata* seedling crops has been determined to help understand factors influencing crop and seedling development. Seedling growth is sigmoidal when parameters such as height (Figure 1a), root collar diameter and dry weight (Figure 1b) are plotted against time. The sigmoidal growth curves indicate that crop growth is exponential with time over most of the growing season. Relative Growth Rate, RGR (Figure 1c), is used to describe the exponential growth phases. It is defined by the equation,

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

where W_1 , W_2 are growth parameters at times T_1 and T_2 respectively. Nursery practice may restrict or encourage development of seedlings and seedling parts by modifying seedbed conditions and seedling morphology and physiology. These practices have a most marked effect in spring and early summer, as mean seedling RGR reaches a peak soon after emergence and then gradually declines over the remainder of the growing season.

Planting stock quality studies indicate that seedling hardiness and size are critical characteristics associated with tree survival and early growth after planting out in N.S.W. highland conditions. A further crop development study was initiated to investigate techniques to modify seedling growth and so produce this high quality planting stock.

Wrenching and fertilization affected shoot growth more than root growth, in dry weight terms, with the former technique inhibiting, and the latter stimulating shoot development. Wrenching cut off a major portion of seedling root systems and seedlings reacted by producing more extensive lateral roots in autumn. A seasonal decline in moisture content was evident right through the growing season in unwrenched seedlings. Moisture content was reduced prematurely by wrenching and remained lower in these plants through into late winter.

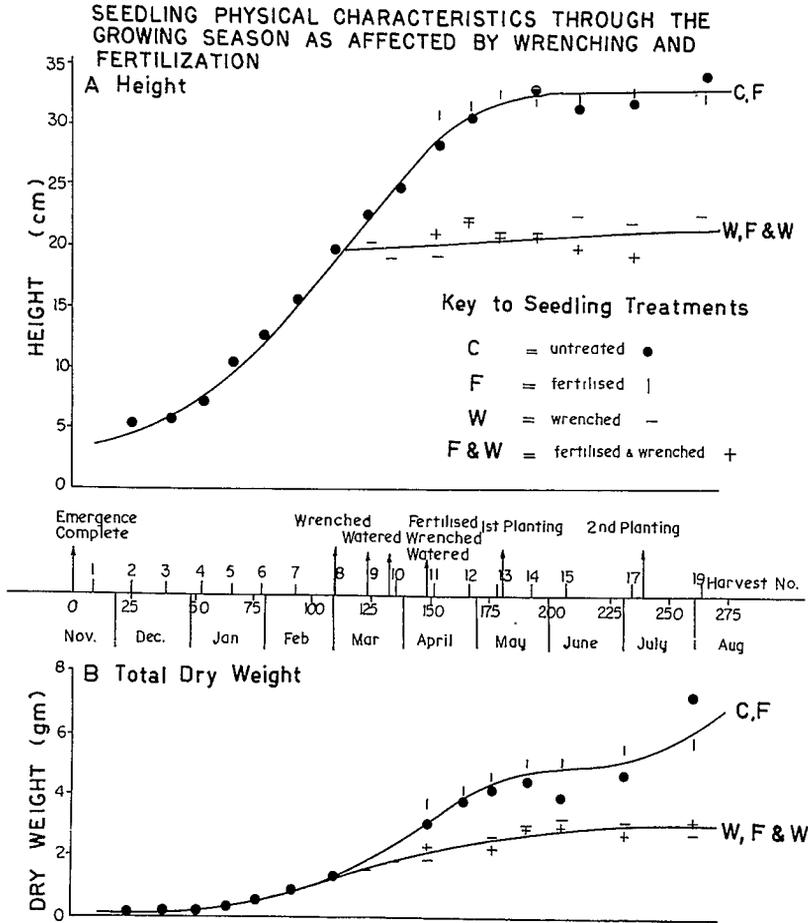


Figure 1a, b

Crop nutrient uptake patterns were also examined in this latter study to gain an understanding of seasonal variations in uptake of various nutrient elements and their re-distribution in the crop. The disruption of these seasonal patterns by wrenching and fertilization was also investigated using chemical tissue analyses on seedlings harvested

throughout the growing season. Further work is required to explain (1) the seasonal variation in needle, stem and root concentrations for each nutrient individually, (2) the inter-relationship of different nutrient concentrations and contents in the various seedling parts and its change with time.

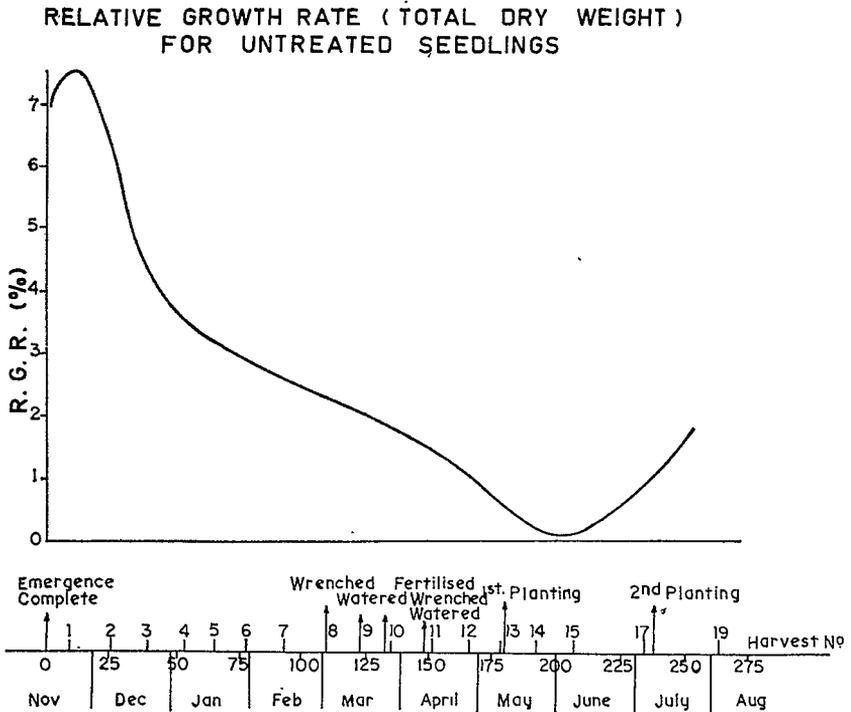


Figure 1c

Seedling nutrient content data with time indicates that nutrient uptake follows a very similar pattern to growth, being sigmoidal in nature. This trend suggests that nutrient availability is not a growth determining factor in the chemically fertile clay loams (basalt derived) common in N.S.W. nurseries. This view is reinforced by the nil responses to individual and complete inorganic fertilizer additions in a number of nursery fertility trials.

Nursery fertility

Maintenance and improvement of nursery fertility is extremely important as open-rooted seedling production places a severe strain on the nurseries' soil and as a considerable investment is spent on the rare sites suitable for large mechanised nurseries.

Nursery fertility studies have included

- (1) soil and foliage chemical analyses to determine the nutrient drain and availability after continued cropping,
- (2) soil texture and structure analyses to assess the degradation of soil structure through continued cropping,
- (3) soil and tissue pathogen surveys to determine the nature and incidence of fungi and nematodes likely to be responsible for complete or partial crop failures and diseased planting stock,
- (4) the development of techniques to counter these causes of nursery fertility decline.

The major nursery soils have considerable reserves of all major nutrients (Table 1) and hence soil chemical analyses have been of little use in monitoring any soil fertility decline. Foliage nutrient concentrations show little correlation with their respective concentrations in matching soil nutrient analyses (Tables 1 and 2). Foliage analyses may be more useful as a warning of incipient or impending nutrient deficiencies. However nursery practices (such as root wrenching) influence foliage nutrient concentrations to such an extent that tissue analyses are only likely to be useful when nursery practices become uniform and consistent from year to year.

Biomass studies have been useful in estimating annual nutrient removals due to cropping (Table 3). Fertilizer recommendations vary slightly with nurseries and current practices but generally the following amounts should be added to N.S.W. nurseries annually:

- 380 kg/ha superphosphate at time of seedbed preparation
- 11 kg/ha complete liquid fertilizer monthly from December to March.

This fertilizer can be added either through a tractor-mounted sprayer or through the irrigation lines. Magnesium levels tend to be low in the clay loam nurseries which would benefit from $MgSO_4$ additions.

The table shows nutrient removal in seedling crops for the five nurseries. These data were obtained from foliage nutrient analysis, and calculated using conversion factors for stem and root concentrations obtained during seasonal uptake studies. It also assumes a yield of 815 430 seedling/ha.

The much lower removals from the Orange and Oberon nurseries are indicative of the more severe wrenching practices carried out in these nurseries.

Soil texture analyses show the very heavy nature of the Commission's major nursery soils (Table 1). Soils with more than 25-25% silt plus clay are generally not suitable for conifer seedling production (Armson and Sadreika, 1974). The high silt plus clay fraction in our soils emphasizes the importance of soil aggregation (i.e. structure) in building up the proportion of sand-sized particles. This aggregation and its

TABLE 1

NURSERY FERTILITY — SOIL FROM PLANTATION NURSERIES RAISING P. RADIATA PLANTS

1. NURSERY SOILS

	Coarse Sand	Particle Size %			Org. Matter %	pH	N Total %	P Total ppm	K	Exchangeable meq. %			
		Fine Sand	Silt	Clay						Ca	Mg	Na	Al
Bondo	20.9	31.2	32.8	15.1	3.5	5.1	0.14	277	0.75	3.04	1.03	0.15	0.66
Helms	12.5	35.6	36.8	15.1	7.2	4.7	0.16	381	1.34	4.45	1.22	0.16	1.36
Bondi						4.6	0.23	577	0.71	2.17	1.10	0.22	1.64
Canobolas	9.6	36.9	39.6	13.8	2.3	5.2		454	1.07	3.41	1.03	0.03	0.28
Norway	51.7	25.0	22.8	0.5	2.1	5.4		169	0.27	1.11	0.20	0.03	0.16
Bombala	65.2	23.3	11.6	0.0	1.9	5.5		174	0.28	1.70	0.46	0.06	0.01

TABLE 2

NURSERY FERTILITY — SEEDLING FOLIAGE FROM PLANTATION NURSERIES RAISING
P. RADIATA PLANTS

2. FOLIAGE CONCENTRATION AND CONTENT OF NUTRIENT ELEMENTS

	N Total	P	K (%)	Ca	Mg	Na	Zn	Mn	Fe (ppm)	Al	S (Inorganic)	B	Sugar (%)	Starch (%)
A. FOLIAGE CONCENTRATIONS														
Bondo	1.57	0.19	1.06	0.23	0.08	84	52	255	531	1285	92	10	1.43	7.09
Helms	1.91	0.18	1.24	0.28	0.08	72	96	423	370	941	221	11	1.25	7.68
Bondi	1.88	0.19	0.93	0.27	0.07	157	71	395	531	1005	216	11	0.42	6.13
Canobolas	1.32	0.15	0.99	0.28	0.07	79	83	349	587	737	240	13	4.36	9.67
Norway	1.36	0.15	0.75	0.39	0.09	117	74	258	150	322	240	12	4.18	10.91
Bombala	1.93	0.23	0.95	0.37	0.09	198	80	211	316	372	270	19	0.81	6.78
Walcha		0.14	1.04	0.68	0.13	120	82	675	11100	995				
B. FOLIAGE CONTENT FOR MEAN SEEDLINGS (mgm)														
Bondo	40	4.2	22	5.0	1.8	0.2	0.1	0.6	1.2	3.1	0.2		43	209
Helms	38	3.0	20	4.8	1.0	0.1	0.1	0.7	0.6	1.6	0.4		27	166
Bondi	28	3.1	14	4.3	1.2	0.3	0.1	0.6	0.7	1.6	0.3		8	116
Canobolas	18	2.6	17	4.7	1.2	0.1	0.1	0.6	0.9	1.2	0.4		52	129
Norway	30	3.3	17	8.5	1.9	0.2	0.2	0.6	0.3	0.6	0.8		57	152
Bombala	13	2.6	12	4.4	1.2	0.2	0.1	0.2	0.4	0.4	0.2		5	44
Walcha		4.2	25	16.4	3.5	0.2	0.2	0.8	8.0	2.5				

TABLE 3. Average element removal in seedling crop (kg/ha)

Nursery	Subdistrict	Foliage dry wt (kg)	N	P	K	Ca	Mg	Mn	Zn
Canobolas	Orange	1085	18	2	16	6	1.3	0.7	0.2
Norway	Oberon	1133	21	3	13	8	1.8	0.4	0.2
Bondo	Tumut	2405	50	8	35	9	3.1	1.0	0.2
Helms	Batlow	1761	50	6	34	8	2.5	1.1	0.2
Bondi	Bombala	1524	39	7	25	9	2.2	1.0	0.2

stability is critical in maintaining adequate soil aeration, minimizing soil surface crusting and allowing the development of extensive fibrous root systems.

Continued cropping decreases soil organic matter levels and when soil humus levels are reduced in these soils, soil aggregation and aggregate stability declines. Seedling yields and quality generally decline in this situation and the nursery has to be abandoned. Soil organic matter levels range from 1.9 to 7.2% in the Commission's nurseries at present (Table 1). Organic matter contents should be maintained between 1.5 and 3.0% with heavier soils requiring contents in the upper end of this range (Armson and Sadreika, 1974; Williams and Hanks, 1976). The Helms value is extremely high probably as a result of the extremely heavy clover pasture on this land previously.

Soil organic levels can be maintained in three ways:—

- (a) annual addition of a large amount (up to 36.5 tonnes/ha) of a suitable organic material,
- (b) crop rotations involving
 - (1) very lush green crops
 - (2) very lush legume-grass pastures.

Suitable organic matter residues are often difficult to obtain in the quantities required and in the N.S.W. context rotations utilizing grass-legume pastures suitable to the various regions, have been recommended. Green crops, such as oats, help to conserve the organic matter levels but are unlikely to prevent a nett decline with time.

Nursery pathological studies

Nursery yields fell from 20-24 000 to 9-13 000 plant/kg seed in 1969 when hand/Mintern sowing was replaced by mechanized sowing with a bank of Stanhay seeders. Trials and observations indicated most of this decrease occurred between sowing and emergence but losses continued throughout the nursery season. These post-emergent losses were particularly heavy during hot humid weather.

Soil sterilization studies have been carried out using "Ditrapex", Methyl Bromide and Formalin. These fumigants did not improve seedling yields appreciably and only sometimes improved seedling growth and

nursery weed control. On this basis the considerable fumigation costs can not be justified.

Post-emergent fungicide spraying is carried out with several fungicides in rotation to prevent a possible resistance build up by the fungal population. "Captan", "Difolitan" and "Thiram" are the chemicals currently in use. Losses continue to occur despite these precautions. More recent research has attempted to determine the fungi responsible for losses at various stages through the growing season and to select chemicals most efficient in controlling these pathogens.

Current pathological studies by the Wood Technology and Forest Research Division include (1) annual surveys of all Commission nurseries to determine potentially pathogenic fungi present both in the soils and on plants, (2) a trial investigating the effectiveness of "Terrazole" and "Mankobunt" as seed dusts in improving seedling emergence rates (i.e. decreasing pre-emergence damping off), (3) a trial investigating the effectiveness of post-emergence spraying of "Difolitan" and "Terrazole" in improving seedling yields (i.e. decreasing post emergence damping off), (4) trials to investigate the possible transfer of these fungi from nursery to the forest.

Sowing studies

Three aspects of sowing techniques have been investigated:

- (a) determining maximum seedbed densities at which high quality seedlings can be produced,
- (b) improving seedling yields by altering sowing methods to minimize seed/seedling losses in the first 10 weeks after sowing,
- (c) improving seedling yields and quality by sowing in both spring and autumn.

Increasing seedbed stocking decreases nursery costs but also decreases seedling quality. Seedbed densities of 200-250 seedlings per sq m are most economical for the production of high quality seedlings. A uniform seedling distribution over the bed minimizes competition and hence improves seedling quality. Broadcast sowing produces the most uniform distribution but sowing rates are difficult to control and makes crops more difficult to cultivate and to keep free of weeds. Drill-sowing techniques should aim at reducing between-drill spacing. Within-drill spacing should also be reduced and made as regular as possible.

In parallel with the pathological studies mentioned previously, sowing methods have been altered to foster more productive, reliable and even emergence and hence seedbed stocking rates. In recent years the number of drills per bed has been increased from six to seven and sowing rates reduced from 52-60 to 40-46 seed per metre of drill. These sowing densities represent about 200 seed/sq m which with improved plant percentages produce seedbed densities of about 140 seedlings/sq m. Seedbed densities should be increased by about 25% to make

most economical use of nursery space and reduce nursery costs. This increase in density should be obtained by increasing plant percentages and by increasing sowing rates slightly.

Soil compaction and crusting over the seed drills restricts the emergence of seedlings and hence pre-disposes them to pathogen attack. These restrictions have been minimized by (1) modifying the "Stanhay" sowing rig to operate through land wheels travelling down the nursery paths. Drill sowers originally operated through their rear wheel and compressed soil over the seed drill after sowing. Dense soil crusts subsequently restricted emergence especially where soil structure was destroyed by heavy rain or irrigation and then allowed to dry out.

(2) sowing in open drills using only the front section of the "Stanhay" sower with the rear wheel lifted off the ground. A sand hopper has been developed to spread sand to cover individual seed drills.

Seedling yields can also be increased by early and adequate seedbed preparation to ensure sowing takes place under most favourable conditions in early Spring. This early sowing permits seedling emergence and development under more favourable conditions so they are sufficiently advanced to resist pathogen attack under hot, humid early summer conditions.

Current studies investigate seed pre-treatment and sowing dates in both Autumn and Spring as techniques to

- (a) increase opportunities for timely and efficient seedbed preparation and sowing
- (b) increase vigour of germination and emergence to minimize the likelihood of pre-emergence pathogen attack
- (c) increase seedling size to allow root wrenchings in mid summer and hence allow seedlings longer to react to these conditioning treatments
- (d) improve opportunities for efficient nursery management by ensuring that two crops are produced each year. These dual crops may increase safety factors (i.e. decrease the need for "insurance" oversowing) in ensuring production goals are attained. The two-tiered cropping system would allow a second sowing to ensure that sufficient stock is available and that both crops are not at the same susceptible growth stage simultaneously (i.e. with respect to losses from hail, cutworms or pathogenic fungi).

Nursery weed control studies

Persistent and vigilant hand weeding can produce virtually weed-free nurseries in which little further weed control is necessary when seedling crops are raised. This degree of nursery hygiene is admirable and desirable but not always economically possible. Usually supplementary weed control is essential to ensure high yields of quality plants.

Weed control is usually divided into three phases

- (a) pre-sowing — before and during seedbed preparation. Many crop weed problems can be minimized in this phase by good nursery hygiene and well timed mowing, ploughing and weedicide applications using contact, non-residual weedicides or fumigants,
- (b) pre-emergence — between seed sowing and seedling emergence. Contact non-residual weedicides are also useful here and if applied just before emergence, can produce a weed free period of up to ten weeks after emergence.
- (c) post-emergence — lasting weed-free conditions can only be created in this phase by the selective killing of only weed species. This selective control can be effected by hand, mechanically, either in cultivation or directed spraying of contact weedicides or by using chemicals which kill only the weed species.

Soil fumigants such as Methyl Bromide, Sodium Metham ("Ditrapex") and Formalin sometimes produce good weed control as well as improved crop growth and high yields of seedlings. However weed infestation often occurs after the fumigants have dissipated sufficiently to allow pine seed sowing. This variable result, and the high cost of fumigation, does not justify the routine use of these fumigants for weed control.

The search for suitable weedicides for use in *Pinus radiata* nurseries commenced in 1951-52 with pre- and post-emergent trials of mainly contact weedicides (Truman, 1970). Mineral spirits with aromatic contents of about 20% showed promise as pre-emergents. Power kerosene is currently used as a pre-emergent at 450 L per ha applied immediately prior to seedling emergence. Paraquat ("Grammoxone") with or without Diquat ("Reglone") are equally effective alternatives at rates of 3.5 L per ha.

Selective post-emergent control can be obtained using commercial dry-cleaning fluid ("White Spirits") when applied as a directed spray to avoid the seedlings. Up to eight sprayings of the seedbeds make this form of weed control relatively expensive when over 450 litres per ha is used at each application.

Between 1961-64 soil residual weedicides (mainly triazines) were tested as pre-emergents in most major *P. radiata* nurseries, initially with very favourable results (Casimir, 1963). Routine applications of Atrazine ("Gesaprim") were recommended and applied at 2.2 kg a.i. per ha at several nurseries, but were responsible for severe crop losses. Subsequent trials showed that the much less soluble Propazine ("Gesamil") at 2.2 kg a.i. per ha was a much safer and effective triazine in our nurseries. In 1967 Chlorthal ("Dacthal") showed promise as a pre-emergent soil residual when applied at 10 kg a.i. per ha especially as it controls grasses not affected by Propazine.

Mixtures of Propazine and Chlorthal have been tested over a number of years and nurseries to check their safety, effectiveness and any build-up of residues. No residue build-up has been evident during this

period and is even less likely where nursery crop rotation is practised. Large scale trials have been used to develop techniques and machinery to ensure that these wettable powders are evenly and uniformly distributed over the seedbeds. Recommended techniques using these chemicals are described in Appendix 1 and have been further verified in routine use over the 1975-76 and 76-77 seasons at Helms nursery.

Planting stock quality

Planting stock quality is monitored and controlled to some extent in most nurseries through grading and culling practices, based on seedling characteristics at time of lifting. Morphological characteristics of size,

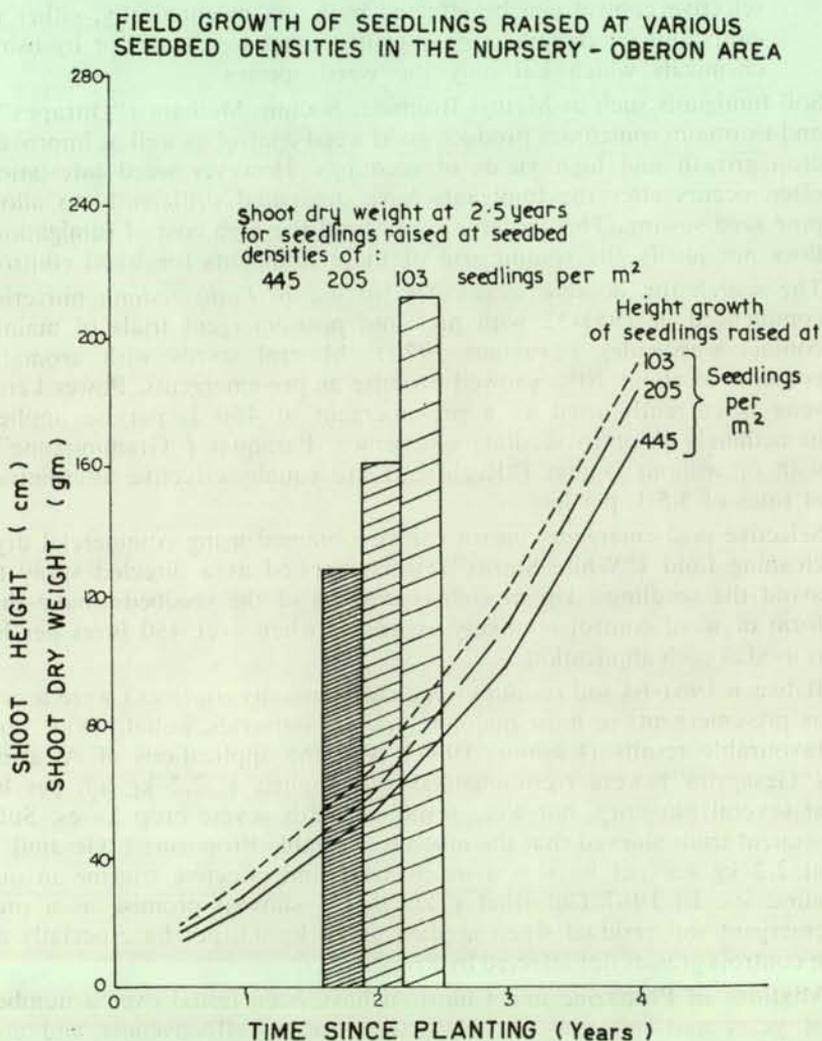


Figure 2

“sturdiness” and “balance” are frequently used but more recently systems based on physiological characteristics, have been developed. However, planting stock quality is ultimately measured by seedling survival and early growth and may vary with conditions under which the seedlings are established and required to grow.

Seedling survival and early growth can dramatically affect plantation productivity and profitability (Woods For. Dep. S. Aust., 1972; Michell, 1971). Improved seedling quality was sought by raising 1-0 crops under a variety of seedbed density, fertilizer, weed control, mycorrhizal and fumigation treatments in most of the Commission’s nurseries. Subsequently the stock was planted out at different stages of the planting

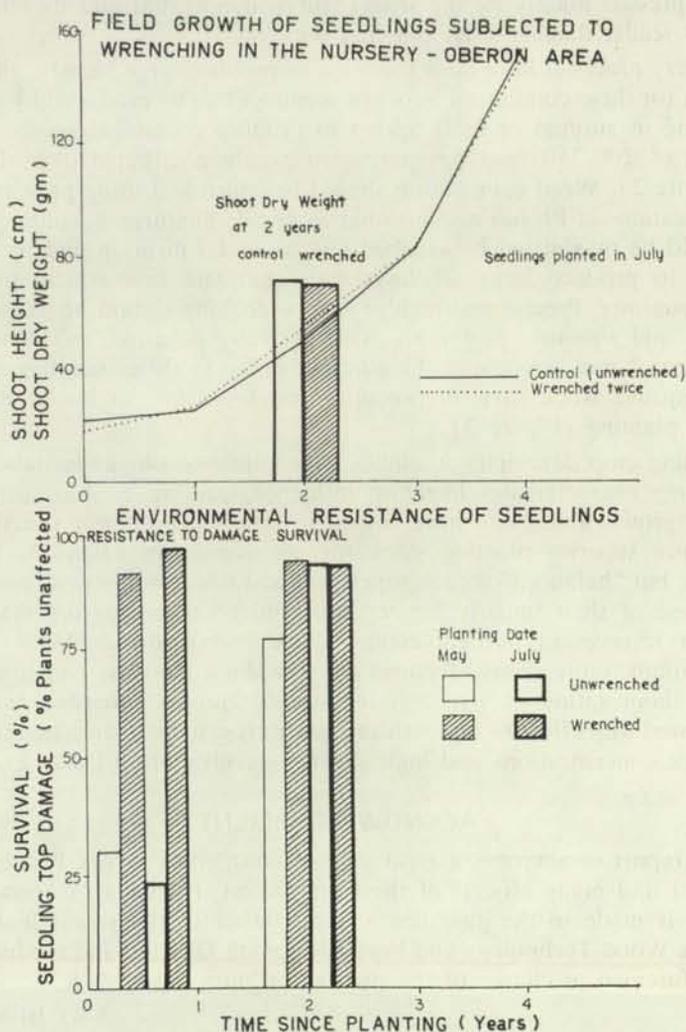


Figure 3

season, in routinely prepared plantation areas in Bathurst and Tumut districts.

P. radiata seedling performance depends mainly on planting stock size and RGR, provided that field conditions are favourable. In these studies, tree size differences at five years after planting depended more on seedling size at planting than to any differences in RGR induced by nursery practices (Figure 2). However most *P. radiata* plantations in N.S.W. are established in Highland regions at 610-1220 m altitude. Bleak winter conditions are common in these areas and plantations are subject to exposed conditions with frequent frosts, drying winds and occasional snow falls. Under these testing conditions, seedling quality is expressed mainly by the stocks' survival potential and its ability to resist leader damage after planting out.

Nursery practices have been modified to produce large "hardy" planting stock for these conditions. Superior seedlings can be produced by careful sowing in autumn or early spring to produce controlled seedbed densities of 200-250 seedlings per sq m evenly distributed over the bed (Figure 2). Weed competition should be controlled using pre-emergent applications of Propazine-Chlorthal weedicide mixtures. Seedling growth should be maximized by seedbed and foliar fertilization and by irrigation, to produce large seedlings with abundant mycorrhizal roots in mid summer. Precise and regular root wrenching should be carried out from mid summer, preferably with correctly adjusted and controlled reciprocal root wrenchers. This latter regime modifies seedling growth to improve stock survival potential and resistance to leader damage after planting (Figure 3).

Seedling crop development studies have improved our understanding of seedling characteristics likely to influence seedling establishment and early growth rates, and have helped to rationalize nursery practices to produce superior planting stock for our conditions (Benson, 1974). Large but "balanced" seedlings perform best under non-stress conditions because of their initially larger shoot and root systems together with larger reserves of nutrient elements and carbohydrates. Under stress conditions, more critical features are low shoot moisture contents, high root/shoot ratios with root systems being fibrous extensive and well endowed with effective mycorrhizae, low nitrogen/high inorganic sulphur foliage concentrations and high sugar concentrations (Table 2).

ACKNOWLEDGEMENT

This report summarizes a great deal of co-operative work between the author and many officers of the Commission. Particular acknowledgement is made to the guidance and assistance of the research officers of the Wood Technology and Forest Research Division and the foresters and foremen in charge of the production nurseries in N.S.W.

A. D. BENSON,
24th January, 1977.

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APPENDIX 1

Pre-emergence weed control with Propazine-Chlorthal weedicide mixtures in *Pinus radiata* nurseries.

1. Weedicide mixture and its application

The weedicide mixture should be applied immediately after sowing, preferably on wet ground and with the assurance that at least 13 mm rain (or irrigation) falls before seedlings begin to emerge.

Material	Amount to make 453 L (100 gal) tank full	Active ingredient	Quantity per hectare
"Gesamil 50"	0.92 kg	Propazine	1.1 kg
"Dacthal W75"	5.5 kg	Chlorthal	10.1 kg
"Plus 50"	1.3 L	Surfactant spray additive	3.2 L
Water	430 L	Water	1120 L
Area to be covered	0.4 ha		

The weedicides are wettable powders and difficult to wet. A slurry should be made with the weedicide mixture before adding it to water. A poorly mixed solution will cause spray blockages and uneven application rates, resulting in seedling deaths in some places and poor weed control in others. Similarly the mixture should be kept well mixed during spraying and output rate kept as uniform as possible.

The mixture has been successfully applied through a 9.5 m long boom spray with 80 degree fan jet nozzles at 50 cm centres.

This boom was operated by a power-take-off pump on an International 434 tractor and connected to a 453 litre fibreglass tank containing the weedicide mixture. This tank was fitted with a Venturi jet agitator to keep the wettable powders fully dispersed.

This spray unit is capable of spraying five seedbeds at a pass while the storage tank contains sufficient weedicide (when filled as in the above table) to cover 22 beds x 100 m long (0.44 ha) at the prescribed rate. The weedicide should be spread as evenly as possible. A more even application can be obtained by making up a half strength mixture and spraying the prescribed area twice.

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Figure 1a, 1b — SC 5133; Figure 1c — SC 5130;

Figure 2 — SC 5132; Figure 3 — SC 5131