GROWTH RESPONSE OF PINUS RADIATA TO FERTILISER AND HERBICIDE TREATMENT IN A CLEARFELLED LOGGED AND A CLEARFELLED LOGGED AND BURNED NOTHOFAGUS FOREST

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(Received for publication 9 April 1985; revision 18 October 1985)

ABSTRACT

The growth response of **Pinus radiata** D. Don seedlings was measured for 3 years after the clearfelling and harvesting of a **Nothofagus** spp. forest using the following treatments: podocarp logging only; podocarp logging and burning; logging of all tree species to chipwood standard (10 cm dbh); chipwood logging and burning; with or without fertiliser and/or herbicide treatments. Seedling mortality 3 years after planting exceeded 55% in the unburned treatments but was less than 39% in the burned treatments. Height and diameter growth was better in the burned than the unburned treatments, and in the chipwood rather than with the podocarp logged plots. Fertiliser application produced no measurable effect on seedling growth rates but herbicide application induced a small growth increase. Nutrient levels in the soil and foliage were adequate for the needs of **P. radiata**. Few of the interactions between burning, logging method, fertiliser, and herbicide application were significant.

Keywords: growth response; clearfelling; harvesting; herbicide; fertiliser; burning; seedling mortality; **Pinus radiata**; **Nothofagus menziesii**; **Nothofagus fusca**.

INTRODUCTION

A major objective of exotic forestry in New Zealand is to increase the harvest of *Pinus radiata* in order to reduce the demand for native timber. The low nutrient (phosphorus and nitrogen) status of many West Coast soils suggests that fertiliser applications may be necessary in conjunction with other forest management practices to increase productivity of *P. radiata*.

Beneficial effects from the use of fertilisers have been reported by several workers (e.g., Woollons & Will 1975; Ballard 1978; Mead & Gadgil 1978; Will 1981; Crane 1981, 1982; Hunter 1982; Hunter & Graham 1982; Mead *et al.* 1984). Nitrogen fertilisers significantly accelerated maximum canopy development of *P. radiata*, especially when used together with thinning (Mead & Gadgil 1978; Mead *et al.* 1984). Furthermore, the use of fertilisers at forest establishment has improved growth and survival when applied in conjunction with other silviculture operations, although detrimental effects might result from high nitrogen doses (Sutton 1975; R. Ballard & D. J. Mead unpubl. data; Barker 1978). However, fertiliser applications may also stimulate the growth of competing weeds. The control of weeds by the use of herbicides or intensive cultivation has led to synergistic responses by trees to fertiliser applications (Barker 1978).

The main objectives of this study were (1) to determine the effects of clearfelling and two intensities of logging with or without burning, on the growth of *P. radiata* seedlings, and (2) to determine in each logging treatment the response of *P. radiata* to nitrogen and phosphorus fertiliser with and without herbicide treatment.

MATERIALS AND METHODS

Site Description

The study site was located near Larry's Creek (latitude 42° 50'E), 30 km north of Reefton on the West Coast of the South Island of New Zealand. Main elevation was 200 m with a south-west aspect and slopes averaging 18°. Total rainfall measured at the site was 1482 mm for the first year after burning and 1800 mm for the second year. The study area was located on a terrace remnant that had been truncated and dissected into undulating topography. The terraces were formed through regional tectonic uplift and subsequent river incision. The older terraces were further modified by stream dissection. The parent material consisted of weakly to moderately weathered gravels containing clasts of granite, schist, sandstone, and siltstone. Four major soil-profile classes were identified: yellow-brown earth (Inceptisol), gley soil (Inceptisol), humic gley with thin iron pan (Inceptisol), and podzol (Spodosol). Yellow-brown earth and gley soil constituted the major soils of the experimental area while podsol occurred on one plot and humic gley on two. The pH values of humus layer and topsoil (0–9 cm) ranged from 3.4 to 4.4 and from 4.1 to 4.4, respectively. Other chemical data have been published elsewhere (Phillips 1981; Phillips & Goh 1985).

The forest vegetation consisted primarily of silver beech (*Nothofagus menziesii* (Hook. f.) Oerst.) and red beech (*N. fusca* (Hook. f.) Oerst.). Approximately 5% of the forest cover consisted of podocarp species, predominantly kahikatea (*Dacrycarpus dacrydioides* (A. Rich.) de Laub.), and miro (*Prumnopitys ferruginea* (D. Don) de Laub.), matai (*P. taxifolia* (D. Don) de Laub.), and rimu (*Dacrydium cupressinum* Lamb).

Experimental Design

A completely randomised block design was used consisting of three blocks (replications) arranged across the slope with four plots, each of 0.08 ha (20 × 40 m), per block. Treatments were randomly assigned within the blocks in a line running across the mid-slope, and consisted of high-intensity and low-intensity burning and non-burning treatments. To facilitate high-intensity burns only a small portion of the wood and slash resulting from clearfelling in the PL/B plots was removed from the site. Low-intensity burns were obtained by harvesting to chipwood standard (CL/B). Control non-burning treatments in podocarp logged (PL) and chipwood logged (CL) treatments were separated from the burning treatments by firebreaks several metres wide. Plots were harvested in May 1976 and all designated plots were burned in February 1977.

Within each of the 12 major plots, *P. radiata* seedlings were planted in July 1977. Four treatments were applied in October 1977:

(1) No fertiliser or herbicide (control);

(2) Diammonium phosphate (DAP) fertiliser at 80 g/tree (NP);

(3) Hexazinone herbicide at 4 kg/ha (WC);

(4) Hexazinone at 4 kg/ha and DAP at 80 g/tree (WC and NP).

These treatments formed a 2^2 factorial experiment with four replications of each treatment laid out in a split plot with a latin square design within each major plot. Each treatment contained five seedlings in a line with 1 m between seedlings. However, no two seedlings of different treatments were placed within 3 m of each other.

Field Sampling

Height and root collar diameter measurements were taken in October 1977, June 1978, May 1979, and October 1980, and foliage samples for chemical analysis were taken in February 1979. Within each major plot for each of the fertiliser and herbicide treatments, foliage samples from the four replications were bulked into one composite sample for chemical analysis. Foliage samples were analysed for total nitrogen and phosphorus, calcium, magnesium, and potassium after digestion according to the wet oxidation method described by Parkinson & Allen (1975). Total nitrogen was determined by the indophenol blue colorimetric method, and total phosphorus by the molybdophosphovanadate colorimetric method; calcium and magnesium were determined by atomic absorption spectroscopy, and potassium by atomic emission (Blakemore *et al.* 1977). The moisture content of the humus and soil samples was determined by oven-drying at 105°C for 24 h.

Statistical Computations

Height and diameter data for 1978, 1979, and 1980, were subjected to analysis of variance and the seedling survival percentage in 1980 was analysed. Analysis of height and diameter were based on the means of surviving seedlings within each replication at the time of field assessment. No analysis was done to determine if the error variation was homogeneous between the 12 major plots. Analysis of covariance was done on height and diameter measurements for 1980. The covariates were the corresponding measurements from 1977 of seedlings which survived to the 1980 field assessment. No statistical analysis was done for foliage nutrient concentrations.

RESULTS AND DISCUSSION

Seedling survival in October 1980 was 44.1% in the chipwood logged treatment (CL), 65.1% in the chipwood logged and burned treatment (CL/B), 29.7% in the podocarp logged treatment (PL), and 61.1% in the podocarp logged and burned treatment (PL/B). Analysis of survival data for the major treatments and sub-plot main effects showed that none of the major logging treatments had a statistically significant effect on seedling survival, probably because of large variation within logging treatments. For the sub-plot treatments, only the burning × fertiliser interaction was significant $p \leq 0.05$).

The major effect on seedling survival, although not statistically significant, appears to be related to the kind of logging method and site preparation used. Highest mortalities were in the unburned treatments, reaching a maximum of 70% in the PL treatment, whereas a maximum of 39% was recorded in the burned PL/B treatment. The higher mortality in the two unburned treatments was probably enhanced by the heavy slash, litter, and surface vegetation remaining at the site; this could have reduced the drying of the surface organic horizon compared with that in the burned treatments. Moisture contents of humus layer and soil (0–9 cm) were generally higher in unburned than burned plots (Table 1). Mortality was especially apparent in the PL treatment where only podocarp logs were removed. The clearfelling of the overstorey reduced transpiration from the site and thus soil water content remained high. The soil around roots of the remaining seedlings was high in water content.

Large quantities of slash present in the unburned PL sites in combination with substantial weed competition acted as a physical impediment to seedling growth. Severe damage was also caused by browsing deer, especially in seedlings which exhibited good growth rates.

TABLE 1—Moisture content (% D.W.) of humus layer and soil (0–9 cm) in clearfelled logged and clearfelled logged/burned sites (standard deviations in parentheses)

Date of sampling	Treatment			
	CL	CL/B	PL	PL/B
Humus layer				
24 Feb. 1977	110 (32)	95 (31)	129 (24)	107 (14)
27 Feb. 1977	104 (21)	88 (21)	132 (20)	107 (17)
9 Mar. 1977	125 (57)	134 (70)	201 (61)	122 (43)
20 Mar. 1977	177 (95)	167 (90)	219 (89)	195 (70)
3 Apr. 1977	182 (58)	167 (52)	252 (70)	167 (68)
4 May 1977	184 (66)	226 (85)	281 (86)	212 (72)
5 June 1977	261 (81)	261 (57)	308 (73)	238 (68)
5 July 1977	262 (128)	265 (96)	296 (72)	254 (44)
21 Sep. 1977	181 (93)	155 (44)	211 (80)	159 (55)
29 Oct. 1977	140 (52)	140 (40)	184 (88)	120 (38)
10 Dec. 1977	100 (20)	95 (18)	116 (36)	74 (20)
23 Feb. 1978	62 (24)	56 (11)	87 (32)	44 (8)
Soil (0–9 cm)				
24 Feb. 1977	100 (39)	82 (11)	84 (30)	84 (16)
27 Feb. 1977	78 (13)	80 (10)	79 (20)	70 (9)
9 Mar. 1977	92 (26)	72 (12)	86 (31)	69 (14)
20 Mar. 1977	91 (26)	64 (15)	75 (23)	66 (18)
3 Apr. 1977	87 (29)	68 (15)	67 (17)	66 (18)
4 May 1977	90 (30)	66 (21)	78 (29)	68 (19)
5 June 1977	87 (24)	67 (16)	78 (25)	77 (22)
5 July 1977	87 (23)	75 (20)	76 (26)	70 (18)
21 Sep. 1977	88 (22)	75 (24)	66 (18)	69 (18)
29 Oct. 1977	92 (27)	77 (18)	75 (22)	68 (18)
10 Dec. 1977	76 (16)	66 (9)	68 (7)	60 (7)
23 Feb. 1978	60 (17)	55 (6)	61 (9)	48 (6)

Annual mean height and root collar diameter of seedlings within a logging treatment or logging/burning treatment are shown in Table 2. Levels of statistical significance for the above treatments and their interactions were mostly small (Table 3). Analysis of covariance for the 1980 height and diameter data showed that differences were relatively small. The mean values were not adjusted substantially by covariance.

Diameter growth of *P. radiata* seedlings was better in the burned treatments than in the unburned treatments (Tables 4 and 2). The effect on diameter was highly significant throughout the study (Tables 2 and 3). The effect on height was nearly significant for 1978 ($p \leq 0.08$) and 1979 ($p \leq 0.06$). However, the advantage of marginally greater height in the burned treatments disappeared by 1980 (Table 2). It may be due to the fact that by 1980, most of the smaller seedlings in the unburned treatments had been smothered by weed growth or otherwise killed by excessive moisture, leaving behind taller seedlings. The high mortality in the unburned treatments supports this contention. However, there was no effect due to herbicide in 1980 (Table 2). Herbicide treatment included a small but statistically significant increase in growth of both height and root collar diameter in the first year after planting (Tables 2 and 3). This is to be expected since the herbicide dosage used was low and the hexazinone (being water-soluble) was unlikely to last long at the site as the annual rainfall was more than 1400 mm (Phillips 1981).

Superior height and diameter growth were found in the chipwood logged plots, but the differences were not statistically significant until 1980, i.e., 3 years after planting (Table 2).

TABLE 2—Comparisons of mean annual height and root collar diameter of **P. radiata** seedlings

Main treatments	1978		1979		1980	
	Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Unburned	48	8.6	107	19	214	40
Burned	56	11	128	27	217	48
	ns	**	ns	**	ns	**
Chipwood logged	54	10	124	24	226	48
Podocarp logged	50	9.1	111	21	205	40
	ns	ns	ns	ns	*	**
No herbicide	50	9.2	118	22	214	43
Herbicide	53	10	117	23	217	44
	*	***	ns	ns	ns	ns
No fertiliser	51	9.5	121	23	217	45
Fertiliser	53	9.6	114	22	214	43
	ns	ns	ns	ns	ns	ns

* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
ns = not significant

TABLE 3—Significance levels of some main treatments and their interactions on height and root collar diameter of ***P. radiata*** seedlings

Source of variation*	1978		1979		1980	
	Height	Diameter	Height	Diameter	Height	Diameter
Main logging effects:						
Burn **v.** no burn (B)	0.08	0.008	0.06	0.008	0.06	0.003
Logging method (L)	0.26	0.12	0.22	0.15	0.02	0.004
B × L	0.86	0.08	0.83	0.26	0.66	0.05
Treatment effects:						
WC **v.** no WC (W)	0.03	0.001	0.73	0.27	0.65	0.56
DAP **v.** no DAP (F)	0.28	0.56	0.13	0.17	0.65	0.17
W × F	0.16	0.43	0.03	0.07	0.23	0.11
B × W	0.11	0.52	0.16	0.41	0.22	0.06
L × W	0.53	0.34	0.10	0.06	0.49	0.07
B × F	0.35	0.83	0.70	0.79	0.34	0.42
L × F	0.58	0.56	0.70	0.78	0.74	0.91
B × L × W	0.61	0.83	0.29	0.96	0.008	0.06
B × L × F	1.00	0.44	0.05	0.17	0.41	0.41
B × W × F	0.78	0.33	0.22	0.17	0.55	0.16
L × W × F	0.64	0.69	0.20	0.24	0.44	0.71

* B = burning
L = logging method
W = herbicide (WC = hexazinone at 4 kg/ha)
F = fertiliser (DAP at 80 g/tree)

TABLE 4—Height and root collar diameter of **P. radiata** seedlings in different logging treatments, with and without herbicide and fertiliser

Treatment*		Height (cm)					Diameter (mm)				
		1977	1978	1979	1980	Increment (1977–80)	1977	1978	1979	1980	Increment (1977–80)
CL	Control	22	48	128	223	201	5.1	9.1	24	42	37
	NP	23	51	99	160	137	5.6	9.3	19	30	24
	WC	23	53	122	243	220	5.6	9.9	24	45	39
	WC + NP	23	49	101	223	200	5.6	10	20	44	38
CL/B	Control	24	46	117	188	164	5.9	9.8	25	41	35
	NP	24	53	123	206	182	5.9	11	27	48	42
	WC	24	57	130	229	205	5.8	11	29	51	45
	WC + NP	25	57	107	214	189	6.0	11	24	46	40
PL	Control	25	45	87	168	143	6.3	7.4	13	27	21
	NP	22	46	111	204	182	6.0	7.8	16	32	26
	WC	22	46	103	210	188	5.7	7.7	18	34	28
	WC + NP	25	48	94	178	153	6.1	8.0	15	26	20
PL/B	Control	24	55	126	217	193	5.7	10	24	46	40
	NP	24	58	139	237	213	5.6	9.9	25	49	43
	WC	24	60	144	250	226	5.7	11	30	56	50
	WC + NP	22	61	135	222	200	5.2	11	27	48	43

* Control = no herbicide or fertiliser; NP = DAP at 80 g/tree; WC = hexazinone at 4 kg/ha; WC + NP = hexazinone at 4 kg/ha, DAP at 80 g/tree.

CL = chipwood logged; CL/B = chipwood logged/burned; PL = podocarp logged; PL/B = podocarp logged/burned.

Some indications of interaction effects were found, but few were significant. Significant interactions for height were found for the herbicide × fertiliser and burn × logging method × fertiliser interaction in 1979. Significant interactions were less for root collar diameter than for height. For both height and diameter in 1980 there was a complex burn × logging method × herbicide interaction. The interaction was highly significant for height (Table 3) but less significant ($p \leq 0.06$) for root collar diameter. For full interpretation of these interaction effects, detailed investigations involving more replications or greater seedling survival than that in the present study would be needed.

Concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in the seedling foliage are shown in Table 5. Statistical comparisons were not made because samples were bulked in order to yield sufficient material for chemical analysis. However, nitrogen levels in the burned treatments appeared to be lower than in their related unburned treatments. The reverse was found for potassium concentration. Differences in the phosphorus, calcium, and magnesium levels were minimal.

Foliar concentrations of nitrogen, potassium, and calcium, were substantially higher than the marginal values required for *P. radiata* (Will 1978). The foliage nitrogen levels were higher than those reported elsewhere in New Zealand (Mead *et al.* 1980). It appears that, at least in the short-term, soil levels of nitrogen, potassium, and calcium at this site are more than adequate for *P. radiata.* Adequate levels of nitrogen and phosphorus were present in the control treatments (Table 5) and these, together with poor weed control, probably accounted for the lack of height and root collar diameter response to fertiliser treatment.

CONCLUSIONS

A number of site factors (e.g., aspect, weed competition, moisture, nutrient status) influence the growth rates of *P. radiata* or any other tree species. Results from the present study suggest that high moisture in the humus and soil layers may have limited tree growth, and moisture content may be influenced by the kind of logging treatment. Large accumulations of slash, especially in the podocarp logged plots, prevented adequate drying out of the surface organic layer. This effect is likely to be more pronounced on sites with a south-west aspect which thus receive low insolation throughout most of the year.

Seedling survival in the burned treatments was enhanced by the destruction of much of the surface litter and slash which probably allowed the surface organic layers to dry out to a greater extent than in the unburned treatments. However, burning in both logging treatments was considered to be light to moderate as most of the humus layer was retained (unpubl. data). Therefore, excessive moisture in the organic layers could still have been a factor causing seedling mortality.

These results indicate that, on wet or damp sites, clearfelling and logging without subsequent burning is not a viable means for achieving successful conversion to exotic forests. In these wet areas (annual rainfall in excess of 1400 mm) site amelioration by burning appears to be a necessary forest management practice for successful establishment of *P. radiata.* Substantial mortality in the burned treatments in this study, however,

TABLE 5—Foliage nutrient concentration (%) in **P. radiata** seedlings (February 1979)

Treatment*		N	P	K	Ca	Mg
CL	Control	2.46	0.14	0.99	0.18	0.06
	NP	2.36	0.14	0.82	0.17	0.06
	WC	2.15	0.13	0.90	0.17	0.07
	WC + NP	2.19	0.16	0.98	0.18	0.07
CL/B	Control	2.11	0.14	1.02	0.18	0.06
	NP	2.19	0.13	1.08	0.17	0.07
	WC	2.23	0.15	1.08	0.18	0.06
	WC + NP	2.05	0.14	0.99	0.17	0.06
PL	Control	2.82	0.13	1.05	0.17	0.06
	NP	2.17	0.13	0.98	0.17	0.07
	WC	2.31	0.16	1.00	0.17	0.07
	WC + NP	2.34	0.16	0.99	0.18	0.08
PL/B	Control	2.20	0.16	0.14	0.15	0.06
	NP	2.02	0.14	1.10	0.17	0.06
	WC	1.97	0.14	1.08	0.17	0.06
	WC + NP	2.05	0.14	1.02	0.15	0.06
Threshold levels (from Will 1978)		1.5–1.2	1.15–0.13	0.50–0.35	0.10	0.10–0.08

* See Table 4 for explanation of abbreviations.

suggests that more intensive burning may be necessary to further reduce the humus layer. On the other hand, more intense burning would increase nutrient losses and could necessitate an increase in the levels of fertiliser applied. Some form of artificial drainage (Washbourne 1972) together with the control of weeds by more than a single herbicide treatment would also be essential.

ACKNOWLEDGMENTS

This study could not have taken place without the assistance and co-operation of many people. We wish to thank the Forest Research Institute, New Zealand Forest Service, and the Lincoln College Research Committee for providing research funds and assistance. In particular, we wish to thank Ian Andrew for advice on the statistical analysis of the trial data, and Dr D. J. Mead, Dr G. M. Will, Messrs R. Fitzgerald, G. Oliver, and O. Krygsman, Ms M. A. Mecornis, and Mr C. Davies for their invaluable assistance in the collection of field data and the maintenance of the **P. radiata** fertiliser trial.

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