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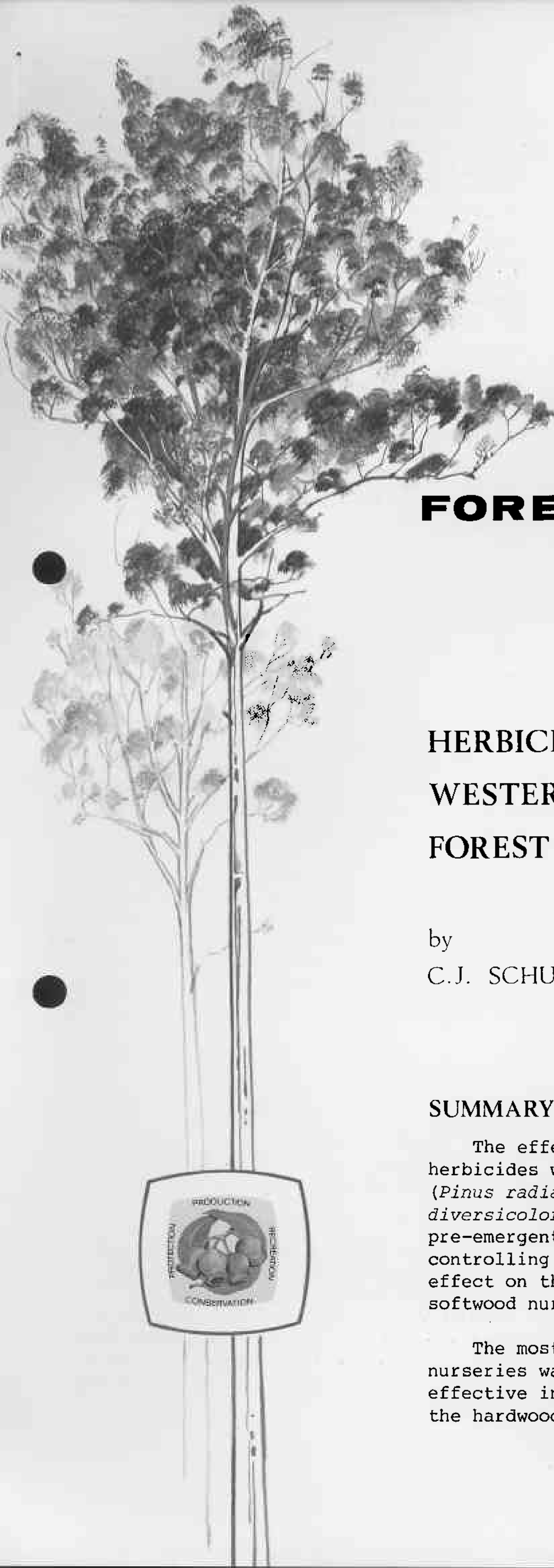

FORESTS DEPARTMENT
OF WESTERN AUSTRALIA

HERBICIDES FOR USE IN WESTERN AUSTRALIAN FOREST NURSERIES

by

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SUMMARY

The effectiveness of several pre- and post-emergent herbicides was tested on nursery beds in softwood (*Pinus radiata* D. Don) and hardwood (*Eucalyptus diversicolor* F. Muell.) nurseries. In both nurseries pre-emergent herbicides were the more effective in controlling weeds. They also had no severe adverse effect on the tree seedlings, especially in the softwood nursery.

The most effective pre-emergent herbicide in both nurseries was nitrofen, whilst propazine was also effective in the softwood nursery and diphenamid in the hardwood nursery.

INTRODUCTION

The Forests Department of Western Australia operates two nurseries in the lower south-west of Western Australia, which produce open-rooted stock for field plantings. One at Nannup raises approximately two million radiata pine (*Pinus radiata* D. Don) seedlings annually, and the other, at Manjimup, raises approximately three million karri (*Eucalyptus diversicolor* F. Muell.) seedlings annually.

In both nurseries weed control measures are necessary. The weed species, if left untreated, compete with the tree seedlings for moisture, nutrients and growing space (Swarbrick, 1976), and this can cause reduced growth, lack of vigour and death. It is also more difficult to lift the seedlings in preparation for planting out.

Different herbicides are effective in controlling different types of weeds. Crop plant tolerance of the various herbicides also varies considerably.

In the hardwood nursery, linuron (0.7 $kg{\cdot}ha^{-1}$ active ingredient, a.i.) is currently used as a pre-emergent herbicide and no post-emergent herbicide is applied. In the softwood nursery, propazine (1.1 $kg{\cdot}ha^{-1}$ a.i.) is used as a pre-emergent herbicide and nitrofen (9.0 $kg{\cdot}ha^{-1}$ a.i.) as a post-emergent herbicide. (Simazine was formerly used as a pre-emergent herbicide in the softwood nursery but its use has been discontinued. Its long residual life in the soil (Swain, 1970) has been detrimental to pines, and the weed population now consists of species that tolerate it.) In both nurseries the pre-emergent herbicides are applied immediately after seeding.

Many researchers have studied the effects of herbicides in both softwood and hardwood forest nurseries with the aim of clarifying crop plant and weed responses so that effective herbicide regimes can be prescribed.

Kurth and Van Dorsser (1969), for example, studying three pre-emergent herbicides, found that propazine and chlorthal were effective for use with *P. radiata*, and that the tree seedlings could tolerate very high application rates (3.4 $kg{\cdot}ha^{-1}$ a.i.). However, neither could be used on *E. delegatensis* R.T. Bak.; only linuron was satisfactory with this species. Propazine was most effectively used to control broad-leaved weeds, while annual grasses were better controlled with the use of chlorthal.

Van Dorsser (1971) observed that lodgepole pine (*P. contorta* Dougl. var. *latifolia* Wats.) was susceptible to applications of pre-emergent herbicides, with the exception of chlorthal. Chloramben (5.6 $kg{\cdot}ha^{-1}$ a.i.) and nitrofen (5.0 $kg{\cdot}ha^{-1}$ a.i.) showed potential for use as post-emergent herbicides with Douglas fir (*Pseudotseuga menziesii* (Mirbel) Franco), whilst nitrofen was the only post-emergent herbicide amongst those tested that did not affect lodgepole pine seedlings adversely.

The residual effects of herbicides could determine their future use in forest nurseries. However, irrigation and cultivation before and after crop removal increase the activity of soil micro-organisms, the most important deactivating agents for herbicides, by increasing soil moisture and aeration (Swain, 1970). They could therefore be useful in minimizing the residual effect of herbicides.

The trials reported here examined the weed control properties and the effect on tree seedlings of a wide range of pre- and post-emergent herbicides. Many had not been used before in Western Australian forest nurseries. Recommendations for future prescriptions are presented.

1. SOFTWOOD NURSERY

METHOD

Trial plots were 30 m long and 1.2 m wide (the normal width of a nursery bed). Each contained six rows of *P. radiata* seedlings.

The pre-emergent herbicides tested in the softwood nursery were nitrofen (trade name "Tok E-25"), diphenamid ("Enide 50") and propazine ("Gesamil"). The post-emergent herbicides tested were nitrofen, glyphosate ("Round-up") and a mixture of terbuthylazine and terbumeton ("Caragard").

The herbicides were applied with a logarithmic sprayer (Fig. 1). This machine applies a continually decreasing amount of herbicide across a plot so that a wide range of application rates can be tested. Using a known initial application rate, the effective application rate at any place within the plot can then be calculated. The logarithmic sprayer was used in these trials because it obviates the necessity for a great number of replications.

The logarithmic sprayer applied 138 $l{\cdot}ha^{-1}$ of herbicide per plot through "T jet" nozzles, at a travelling speed of 60 $m{\cdot}min^{-1}$. The travelling speed was timed by pacing one-metre steps along a marked tape, to a one-second pulse.

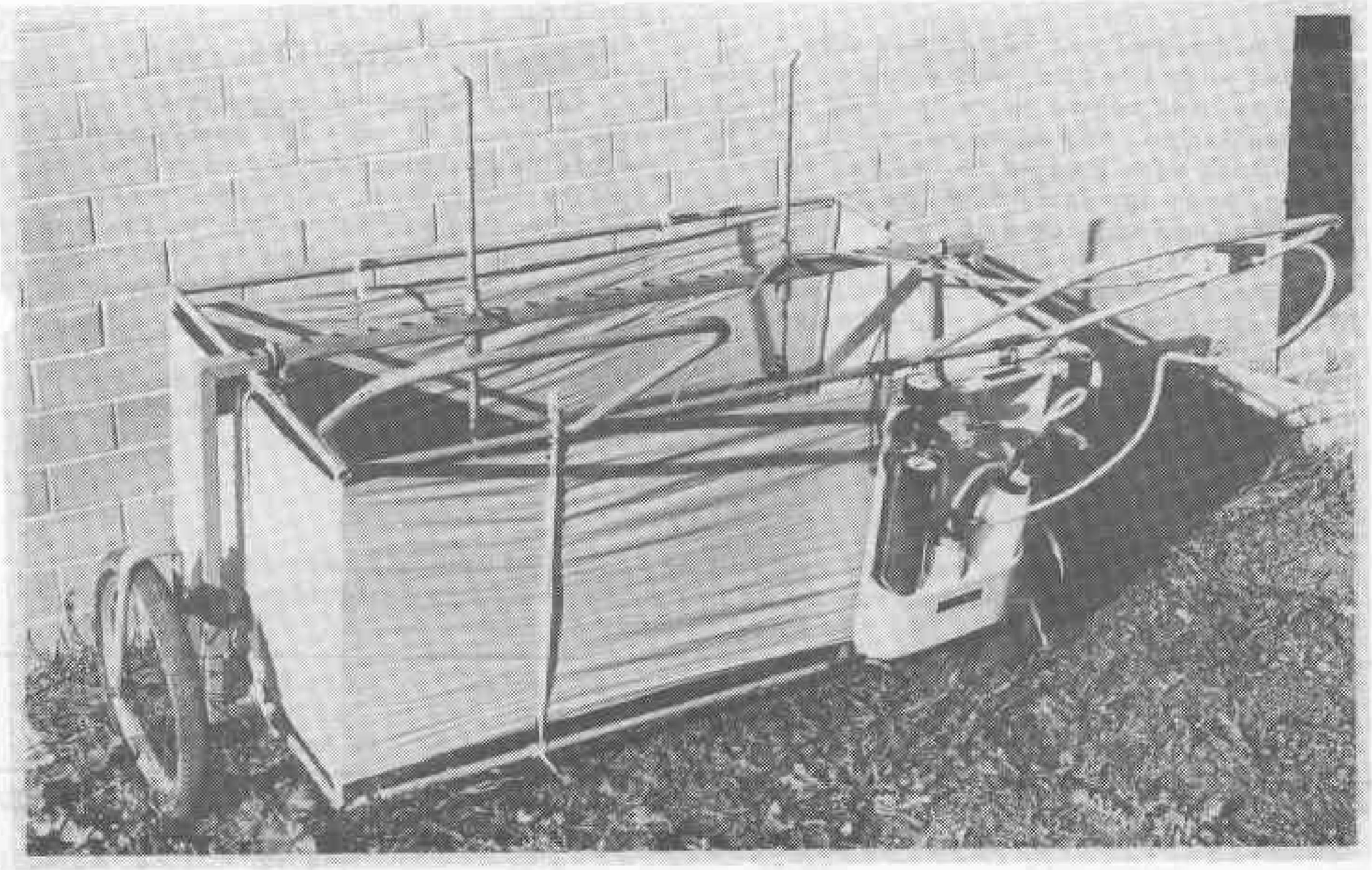

FIGURE 1: The logarithmic sprayer used to apply a consistently decreasing amount of herbicide across the trial plots

TABLE 1

Application rates ($kg{\cdot}ha^{-1}$ a.i.) of herbicides applied to softwood nursery plots

Herbicide		% a.i.	Initial rate	Final rate
Pre-emergent	Nitrofen	25	10.91	1.90
	Diphenamid	50	10.26	1.30
	Propazine	50	3.73	0.09
Post-emergent	Nitrofen	25	16.78	2.18
	Glyphosate	36	0.67	0.09
	Terbuthylazine-terbumeton	50	3.73	0.09

There were two replications for each pre-emergent herbicide and one replication for each post-emergent herbicide. Table 1 shows the initial and final application rates across the plot for each herbicide. Some preliminary screening was carried out to determine the most likely range of effective application rates for each herbicide. There were no control plots because some degree of weed suppression is considered necessary.

The pre-emergent herbicides were applied when the pine seed was sown in mid-October, nine months prior to planting out the seedlings. The post-emergent herbicides were applied 55 days after sowing, when germination of the pine seedlings was completed.

Effectiveness was assessed 101 days after application for the pre-emergent herbicides and 52 days after application for the post-emergents. From the initiation point of each plot, where application rates were highest, the distance to where each weed species was no longer controlled was measured. This was generally taken as the point at which competition became adverse to the pines. The application rate of the herbicide at this point was then calculated for each weed species.

Since none of the herbicides damaged the pine seedlings, no assessment of the seedlings was undertaken.

RESULTS

Table 2 shows the comparative effectiveness of pre- and post-emergent herbicides, indicating for each the application rate at which weed control was effective without damage to the pine seedlings. Also included is a cost per hectare (chemicals only) for spraying at these rates in 1979.

Nitrofen and propazine were the two most successful pre-emergent herbicides.

TABLE 2

Effective rates of application, cost and effectiveness in controlling weeds for pre- and post-emergent herbicides in the softwood nursery trial

	Herbicide	Initial rate ($kg \cdot ha^{-1}$ a.i.)	Effective rate ($kg \cdot ha^{-1}$ a.i.)	Cost/ha 1979 ($ Aust.)	Weeds not controlled
Pre-emergent	Nitrofen	10.91	3.86	96.95	1*, 8, 11, 12
	Diphenamid	10.26	4.46	118.13	1, 4, 5, 8, 11, 12
	Propazine	3.73	0.09	5.80	1, 11, 13
Post-emergent	Nitrofen	16.78	10.50	264.20	6, 7, 8, 9, 10
	Glyphosate	0.67	0.24	12.25	6, 7, 8, 9, 11
	Terbuthylazine-terbumeton	3.73	1.86	22.20	2

*Key to weed species

1. *Cynodon dactylon*
2. *Convolvulus arvensis*
3. *Arctotheca calendula*
4. *Solanum nigrum*
5. *Trichocline spathulatum*
6. *Anagallis arvensis*
7. *Rumex acetosella*
8. *Sonchus oleraceus*
9. *Lotus minor*
10. *Conzya bonariensis*
11. *Echinochloa crusgalli*
12. *Trifolium subterraneum*
13. *Digitaria sanguinalis*

Neither affected the germination and growth of pine seedlings, even at their highest rates of application. While propazine is much cheaper to apply for satisfactory weed control, it was not effective in controlling *Echinochloa crusgalli*, *Cynodon dactylon* and *Digitaria sanguinalis*, all summer-growing grass species. Nitrofen, however, was capable of effectively controlling *D. sanguinalis*, and gave limited control over the other species.

Of the post-emergent herbicides, terbuthylazine-terbumeton and nitrofen proved to be the most effective. Glyphosate was not totally effective within the range of applications tested, but to increase the application rate would probably result in damage to the pine seedlings (increased application rates f glyphosate had been observed to damage *P. radiata* seedlings in preliminary trials).

Nitrofen destroyed *E. crusgalli* at all application rates across the plot. Terbuthylazine-terbumeton was the most effective in controlling the broad spectrum of weeds; however, it can control *E. crusgalli* effectively only if it is sprayed immediately after emergence. It was observed to cause some damage to pine seedlings at 8 kg·ha^{-1} a.i. in preliminary field trials.

2. HARDWOOD NURSERY

METHOD

Trial plots were the same size as chose in the softwood nursery (30 x 1.2 m), and each contained six rows of *E. diversicolor* seedlings.

The pre-emergent herbicides tested were nitrofen ("Tok E-25"), diphenamid ("Enide 50"), propazine ("Gesamil") and chlorthal ("Dacthal"). They were applied at the time of sowing in January (mid-summer). The post-emergent herbicides used were nitrofen, glyphosate ("Round-up"), a mixture of terbuthylazine and terbumeton ("Caragard"), and monosodium methylarsonate (MSMA) ("Daconate 8"). They were applied 30 days after the pre-emergent herbicides, when the karri seedlings were at the six-leaf stage (approximately 5 cm tall); this is because eucalypts are more prone than pine seedlings (Swarbrick, 1976) to damage by the herbicides used in this trial, which are largely for the control of broad-leaved weed species.

There were two replications for each herbicide and control treatment. The logarithmic sprayer was used, as in the softwood nursery, to distribute the herbicide at a steadily decreasing rate across the plots. Table 3 shows the initial and final application rates for each herbicide.

The assessment techniques differed from those used for the pines because, while weed control was regarded as the prime objective in the softwood nursery, the effect of the herbicides on the tree species was the most important factor in the hardwood nursery. Here, seedling counts were regarded as a better indication of treatment success than a visual assessment of weed or tree

TABLE 3

Application rates (kg·ha^{-1} a.i.) of herbicides applied to hardwood nursery plots

Herbicide		% a.i.	Initial rate	Final rate
Pre-emergent	Nitrofen	25	14.91	1.90
	Diphenamid	50	10.26	1.30
	Propazine	50	3.73	0.09
	Chlorthal	75	14.78	1.79
Post-emergent	Nitrofen	25	16.78	2.18
	Glyphosate	36	0.67	0.09
	Terbuthylazine-terbumeton	50	3.73	0.09
	MSMA	80	3.73	0.09

seedling growth.

Each 30 m plot had seven 1 m sub-plots located along it at a 5 m spacing from the beginning of the plot. In each sub-plot the number of tree seedlings per row and their top height (assessed as the mean dominant height) were recorded two months after the application of the pre-emergent herbicides and one month after the application of the post-emergent herbicides. In addition, the presence and abundance of weed species were recorded on a subjective scale of ground cover ranging from 0 (nil cover, i.e. total weed control) to 5 (total weed cover), a value of 1 (2 weeds per row, slight occurrence) being regarded as effective weed control. This figure is the equivalent of 30 small weeds per square metre of nursery bed. At this density of weed growth karri development and growth are not seriously inhibited. Each weed species was identified, and a point in the plot where control ceased to be effective was assessed (i.e. where weed cover exceeded 1 on the subjective scale).

Height was once more assessed three months after treatment in the plots treated with the two most effective pre-emergent herbicides. This was necessary because some differences in height growth had become obvious between the treatments.

RESULTS

Karri survival, compared with the optimum stocking for karri nursery beds (23 seedlings per metre), is shown for pre- and post-emergent herbicides in Figures 2A and 2B respectively. (The figures show mean results for the two replications.)

Of the pre-emergents, only propazine significantly reduced karri seedling germination and survival. Only at application rates below 0.5 kg·ha^{-1} a.i. did propazine allow an adequate karri stocking; all other pre-emergent herbicides tested gave acceptable karri survival rates.

The poor stocking in sections of the control (untreated) plot was caused by extreme competition from *Rumex acetosella* and *Chenopodium pumilo*, both of which create a dense ground cover.

Of the post-emergent herbicides, terbuthylazine-terbumeton gave unsatisfactory karri survival. The anomalous survival figure for the first sub-plot (0-1 m along the plot) was caused by complete survival in an outside row of the bed; the other five rows in the plot contained very few seedlings. This may have been due to a sprayer malfunction or to a light wind, causing the herbicide to drift despite the plastic shield surrounding the spray.

Glyphosate produced acceptable karri survival only below an application rate of 0.12 kg·ha^{-1} a.i. Nitrofen had only minimal effects on karri survival at application rates above 8.91 kg·ha^{-1} a.i., and MSMA produced only marginal survival above an application rate of 0.98 kg·ha^{-1} a.i.

Tables 4A and 4B contain karri height growth data for both pre- and post-emergent herbicide treatments.

It appears that the pre-emergent herbicides, while producing higher karri survival rates (Figs 2A and 2B), also tend to produce taller seedlings. Of the pre-emergent herbicides nitrofen seems to allow the greatest height growth at most rates of application. When used as a post-emergent, however, it seems to have an inhibiting effect on height growth, although not to the same extent as glyphosate or terbuthylazine-terbumeton.

The small size of the seedlings in sections of the control treatment is due to weed competition.

The two herbicides to show greatest promise for weed control were nitrofen (used as a pre-emergent) and diphenamid. The results of the second height growth assessment, carried out on these plots three months after spraying, are given in Table 5 (data for the two replications have been averaged).

Diphenamid inhibited karri height growth significantly three months after application. At three of the application rates there were significant growth differences ($p < 0.05$) between the two herbicide treatments. At all other application rates, the mean dominant heights in the nitrofen treatment exceeded those in the diphenamid treatments.

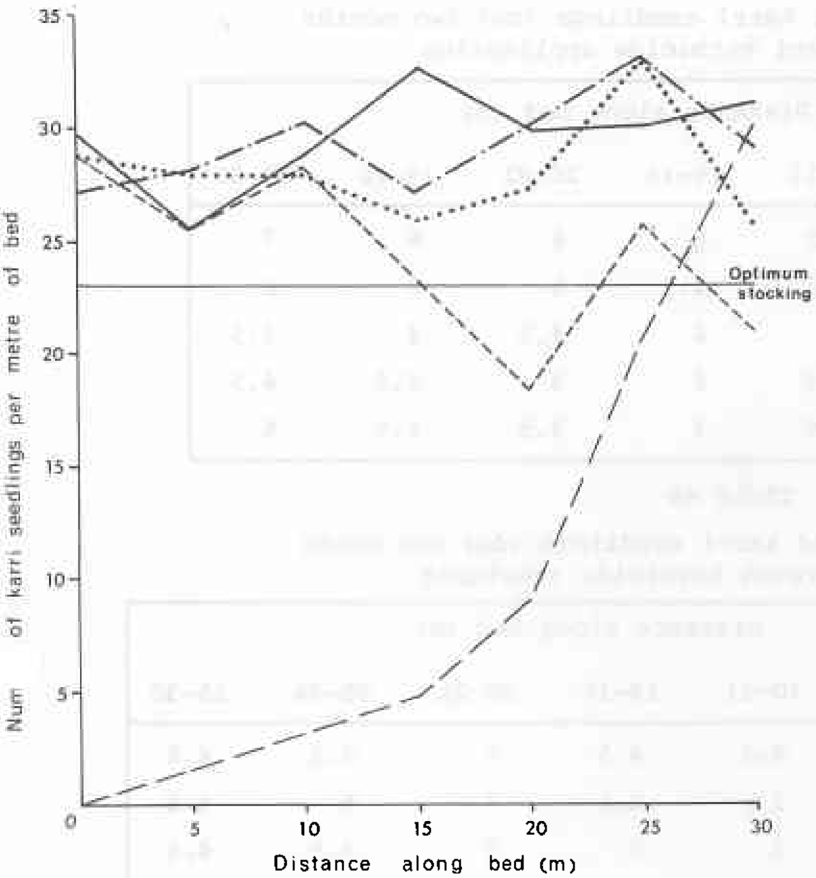

FIGURE 2A: Karri seedling survival 8 weeks after treatment with pre-emergent herbicides

KEY:

Nitrofen ————

Diphenamid — · — · —

Propazine — — — —

Chlorthal ....

Control ----------

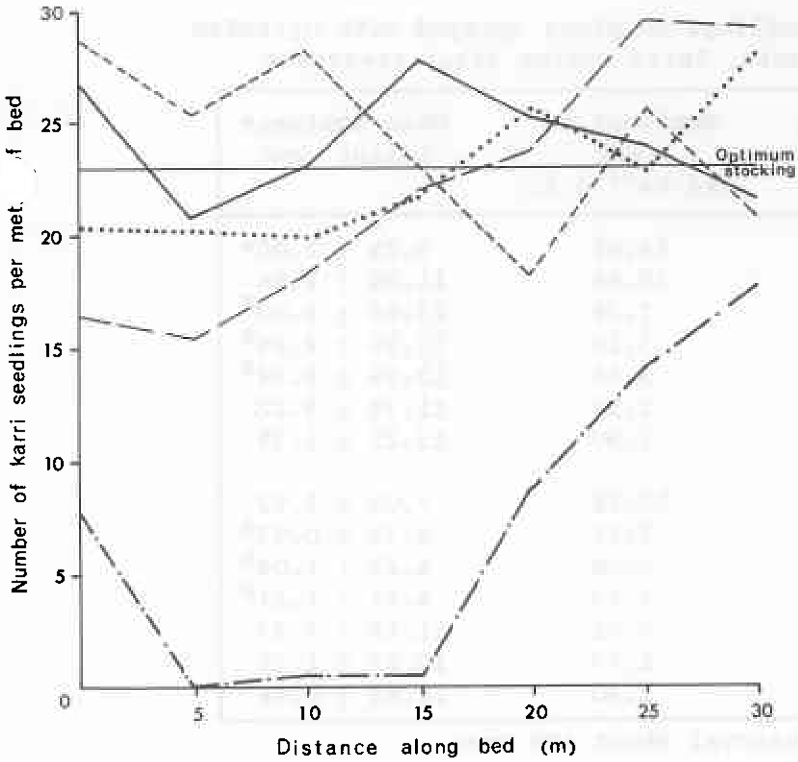

FIGURE 2B: Karri seedling survival 4 weeks after treatment with post-emergent herbicides

KEY:

Nitrofen ————

Glyphosate — — — —

Terbuthylazine-terbumeton — · — · —

MSMA ....

Control ----------

TABLE 4A

Mean dominant height of karri seedlings (cm) two months after pre-emergent herbicide application

Herbicide	Distance along bed (m)						
	0-1	5-6	10-11	15-16	20-21	25-26	29-30
Nitrofen	4.5	5.5	5.5	6	6	6	7
Diphenamid	4.5	4	4.5	4.5	5	5	6
Propazine	-	4.5	4	4	4.5	4	4.5
Chlorthal	4	-	3.5	4	4	4.5	4.5
Control	5	3.5	4.5	3	3.5	4.5	5

TABLE 4B

Mean dominant height of karri seedlings (cm) one month after post-emergent herbicide treatment

Herbicide	Distance along bed (m)						
	0-1	5-6	10-11	15-16	20-21	25-26	29-30
Nitrofen	4.5	3	4.5	4.5	6	5.5	4.5
Glyphosate	2	2	2	2.5	4	4	4.5
Terbuthylazine-terbumeton	3	1	3	3	3	3.5	4.5
MSMA	2.5	3	3.5	3.5	4	4	4.5
Control	5	3.5	4.5	3	3.5	4.5	5

TABLE 5

Mean height growth of karri seedlings on plots sprayed with nitrofen (pre-emergent) and diphenamid, three months after treatment

Herbicide	Distance along bed (m)	Application rate ($kg \cdot ha^{-1}$ a.i.)	Mean dominant height (cm)
Nitrofen	0-1	14.91	9.29 ± 2.05*
	5-6	10.49	11.08 ± 2.86
	10-11	7.39	13.95 ± 3.00[a]
	15-16	5.19	13.98 ± 2.95[a]
	20-21	3.65	13.96 ± 3.74[a]
	25-26	2.57	11.74 ± 3.22
	29-30	1.90	13.21 ± 1.79
Diphenamid	0-1	10.26	7.08 ± 1.92
	5-6	7.21	5.73 ± 0.97[a]
	10-11	5.08	6.25 ± 1.09[a]
	15-16	3.57	6.21 ± 1.21[a]
	20-21	2.51	11.15 ± 2.93
	25-26	1.77	10.23 ± 1.58
	29-30	1.30	11.69 ± 0.66

* indicates 95% confidence interval about the mean

[a] indicates a significant difference at $p < 0.05$ between karri height growth after treatment with herbicides at comparable rates of application

The results of the assessment of weed control effectiveness, based on the subjective assessment scale of 1 to 5, are given in Figures 3A (pre-emergent herbicides) and 3B (post-emergent herbicides).

When compared to the control (untreated) plots, all the pre-emergent herbicides offered a good degree of weed control. Propazine was the most effective of the pre-emergents as it gave satisfactory weed control at an application rate of 0.9 kg·ha^{-1} a.i. (approximately $11.50 per hectare, 1979); however, it caused severe karri mortality (Fig. 2A). Chlorthal was

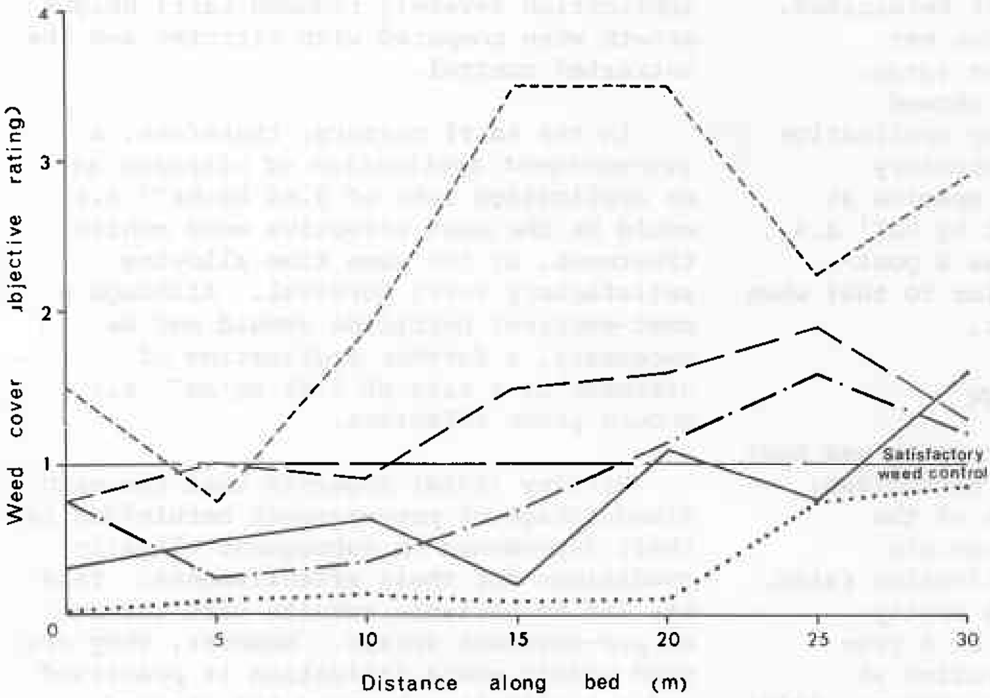

FIGURE 3A: Pre-emergent herbicide weed control in the hardwood nursery.

KEY:

Nitrofen

Diphenamid

Propazine

Chlorthal

Control

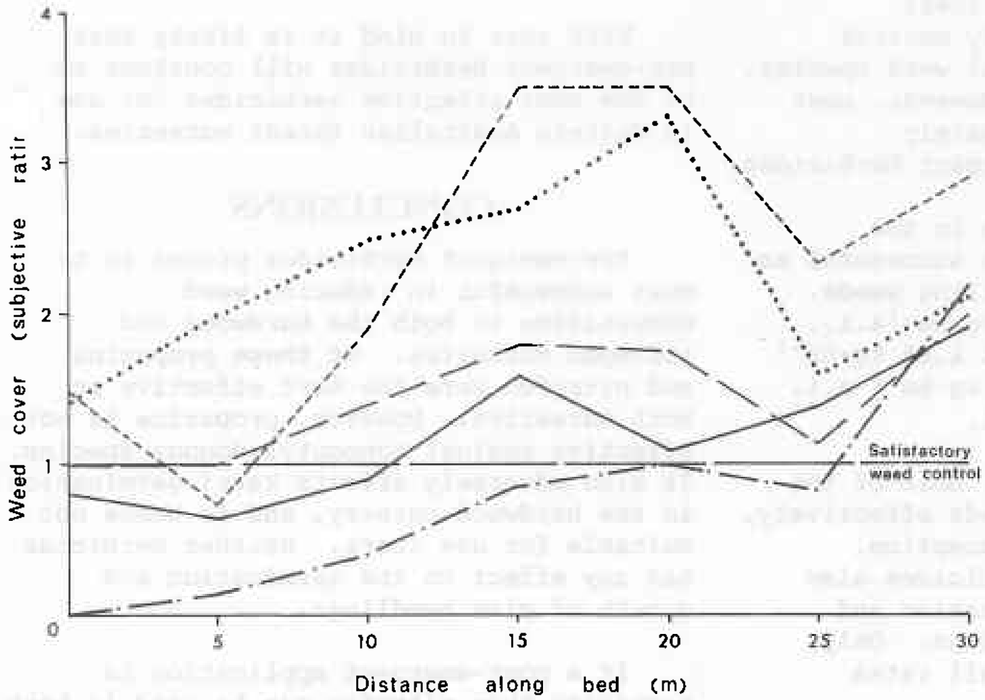

FIGURE 3B: Post-emergent herbicide weed control in the hardwood nursery

KEY:

Nitrofen

Glyphosate

Terbuthylazine-terbumeton

MSMA

Control

only satisfactory at application rates higher than 7.3 kg·ha^{-1} a.i., while diphenamid was satisfactory at application rates above 2.7 kg·ha^{-1} a.i. Both of these herbicides appeared to have no detrimental effects on karri germination and survival.

Generally, the post-emergent herbicides gave less effective weed control than the pre-emergent herbicides. Only terbuthylazine-turbumeton was effective at most application rates; neither MSMA nor glyphosate showed effective weed control at any application rate. Nitrofen showed satisfactory control of monocotyledonous species at application rates above 2.11 kg·ha^{-1} a.i., although its effectiveness as a post-emergent herbicide is inferior to that when it is used as a pre-emergent.

DISCUSSION

Weed control in both nurseries was best achieved using pre-emergent herbicides. In the softwood nursery none of the herbicides affected the *P. radiata* seedlings at any of the application rates. The most effective and least costly herbicide application would be a pre-emergent application of propazine at 0.49 kg·ha^{-1} a.i. ($6.80 per hectare, 1979). Alternatively, nitrofen at a rate of 3.86 kg·ha^{-1} a.i. could be used, but this would be much more expensive ($96.95 per hectare, 1979). Neither of these prescriptions will completely control *Cynodon dactylon,* a perennial weed species, or *Echinochloa crusgalli.* However, most other weed species are adequately controlled by these pre-emergent herbicides.

Post-emergent herbicides in the softwood nursery were not as successful as the pre-emergents in controlling weeds. However, glyphosate at 0.2 kg·ha^{-1}a.i., terbuthylazine-terbumeton at 1.86 kg·ha^{-1} a.i., and nitrofen at 10.50 kg·ha^{-1} a.i. provide partial weed control.

In the hardwood nursery, most of the pre-emergents controlled weeds effectively, *Lotus minor* being a major exception. However, several of the herbicides also severely affected the germination and survival of the karri seedlings. Only nitrofen and diphenamid at all rates tested did not affect karri.

Except for nitrofen, the post-emergent herbicides decreased karri survival below the required nursery stocking level. Furthermore, they achieved weed control only at high rates of application.

Of the two pre-emergent herbicides that gave both satisfactory weed control and satisfactory karri survival rates, diphenamid at the appropriate rates of application severely reduced karri height growth when compared with nitrofen and the untreated control.

In the karri nursery, therefore, a pre-emergent application of nitrofen at an application rate of 3.65 kg·ha^{-1} a.i. would be the most effective weed control treatment, at the same time allowing satisfactory karri survival. Although a post-emergent herbicide should not be necessary, a further application of nitrofen at a rate of 8.91 kg·ha^{-1} a.i. should prove effective.

Hartley (1964) suggests that the main disadvantage of pre-emergent herbicides is their dependence on subsequent climatic conditions for their effectiveness. This has led to variable results with the use of pre-emergent sprays. However, they are used widely where irrigation is practised and are effective because the assured supply of moisture decreases the importance of the general climatic conditions.

With this in mind it is likely that pre-emergent herbicides will continue to be the most effective herbicides for use in Western Australian forest nurseries.

CONCLUSIONS

Pre-emergent herbicides proved to be most successful in reducing weed competition in both the hardwood and softwood nurseries. Of these propazine and nitrofen were the most effective in both nurseries. However, propazine is not effective against monocotyledonous species. It also adversely affects karri germination in the hardwood nursery, and is hence not suitable for use there. Neither herbicide has any effect on the germination and growth of pine seedlings.

If a post-emergent application is necessary then nitrofen can be used in both nurseries, although it is not effective against dicotyledonous species. Terbuthylazine-terbumeton can also be used in the softwood nursery, where it does not affect the tree seedlings.

NOTE

Since the trials were carried out, nitrofen has been withdrawn from the market in Australia.

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