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WEED CONTROL IN RADIATA PINE PLANTATIONS

by

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SUMMARY

This Bulletin summarises the results of five years research into the problems of weed control in radiata pine plantations in Western Australia. Several weedicides and several different application techniques are evaluated and the results discussed in relation to the hazards associated with weedicide use. A table of recommendations is presented for the use of weedicides in particular situations.

INTRODUCTION

Plantations of radiata pine (*Pinus radiata* D. Don) in Western Australia are established on two main areas, (1) repurchased farmland and, (2) areas of suitable soil in State Forest cleared of the native eucalypt forest. This Bulletin summarizes the results of five years research on weed control problems in these plantations.

On the grassland sites the pines are subjected to severe competition from the established pasture, particularly in the first year after planting. In seasons of more than usual water stress the grass competition can have a detrimental influence on survival of the pines. Lodging of a heavy sward of oats or rye grass can present a physical obstacle to the pine seedlings. Shrubby weeds and eucalypt coppice are generally not present except on poorly developed farmlands.

On the former forest sites, regrowth of native shrubs and eucalypt coppice is a persistent problem. Not only does the regrowth severely retard the growth of the pines in the early years of the plantation, but it restricts access for cultural operations, thus increasing the cost of the operations or even entirely preventing them. It also creates a serious fire hazard.

The principal shrubby weeds of plantations (hereafter referred to as scrub) are:

netic (*Bossiaea aquifolium* Benth.),
prickly moses (*Acacia pulchella* R.Br.),
and urophylla (*Acacia urophylla* Benth.).

The coppice problem is provided almost entirely by stump suckers, seedlings and lignotubers of jarrah (*E. marginata* Sm.) marri (*E. calophylla* R.Br.) with some W.A. blackbutt (*E. patens* Benth.) on certain sites only. Marri is usually the most frequent eucalypt species.

Removal of competition from any of these sources by hand slashing is a prohibitively expensive and usually useless operation as most of these species resprout and grow again. Furthermore hand operations are labour-intensive, tying up scarce labour for long periods.

Mechanical cultivation, both pre- and post-planting is quite effective on the deep, near-level sandy soils of the coastal plain, but is less efficient on loamy soil types, usually associated with moderate to steep slopes. In the latter instance it has the further disadvantage of promoting erosion and requiring a high standard of clearing. Mechanical slashing is relatively cheap but has the same technical problems as hand slashing and also requires a more expensive job of clearing.

Several years ago these problems in control of weed competition directed attention to the (then) new chemical methods of vegetation control. For some years field trials were carried out by interested operational staff, but in 1965 the research branch commenced systematic investigations of weedicides.

This publication first sets out general considerations in weed control with chemicals, such as type of chemical and spraying techniques, then details results of a number of field trials, and finally discusses the results and gives recommendations for particular situations. Appendices provide information on weedicide mixtures, weedicide properties and a summary of the recommendations.

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GENERAL CONSIDERATIONS

In early pilot trials a number of weedicides were tested, namely:

- 2, 4-D (2, 4-dichlorophenoxyacetic acid)
- 2,4,5-T (2,4,5-trichlorophenoxyacetic acid)
- 2,4,5-TP (2,4,5-trichlorophenoxypropionic acid)
- fenuron (3-phenyl-1, 1-dimethylurea)
- fenatrol (2,3,6-trichlorophenylacetic acid and its sodium salt)
- Tordon 50-D (4-amino—3,5,6-trichloropicolinic acid, or picloram, and 2,4-D)
- and Vorox AA (a mixture of 2-chloro-6-ethylamino-4-isopropylamino-1, 3,5-triazine and 3-amino-1,2,4-triazole).

The 2,4-D and 2,4,5-TP gave uniformly poor results and were discarded. Fenuron and fenatrol gave promising results when used against coppice but appeared to persist in the soil for more than 12 months. As there was therefore a hazard to the newly planted pines, these also were not considered for detailed testing.

Vorox AA was originally used to keep firebreaks clear of grass and associated broadleaf weeds. Once it was determined that the Vorox did not affect radiata pine seedlings at normal application levels, techniques used in firebreak maintenance were applicable directly to control of competition on sites where annual weeds were the problem.

For scrub and coppice control, both 2,4,5-T and Tordon 50-D gave good results, although much remained to be learned about the influence of season of application on efficiency, the optimum concentrations required, the susceptibility of different tree and shrub species and the effect of the chemicals on the pines. The results of these investigations form the bulk of this bulletin.

From the start, it was recognised that a knowledge of the ecology of the various scrub species might be an aid to their control. Prickly moses and urophylla are fireweeds, requiring a hot fire to achieve good germination, although some germination will occur without a fire. Netic regenerates equally well with or without a fire.

Prior to 1966, the usual sequence of plantation development on forested sites was as follows: poles, piles and merchantable timber were removed, generally over a period of some years, thus opening up the forest canopy and encouraging scrub development; the remaining trees were broadcast bulldozed and left to dry out for two years; the area was broadcast-burned and the debris was then burnt away in heaps, usually in the autumn before planting. The pines were planted in June just as scrub and coppice were appearing.

In 1966, there was a general change to clearing by windrowing and since that time there have not been massive germinations of prickly moses or urophylla. Netic is now the main scrub problem in most radiata pine plantations, hence most work on scrub in this publication concerns this species. Urophylla is a problem in restricted areas only.

Weedicides may be applied to coppice either as an overall spray on the foliage or to the stem as a basal bark spray or cut stump swab. The cut stump and weedicide swab technique was not included in these trials because it is slower and more expensive than basal bark treatment and did not prove any more efficient in pilot tests.

There are also two basically different methods of foliar application of the weedicide, viz. large amounts of low-concentration mixture (high-volume method) or relatively small amounts, say 50-100 litres/hectare (5-10 gal/acre) of a concentrated mixture (low-volume). Both have their advantages so work reported here has covered both techniques.

EXPERIMENTAL METHODS

For the earlier field trials involving coppice, square plots of about 0.04 ha (0.1 ac) were used, located to include at least 20 coppice sources. In retrospect, it would have greatly improved the value of the work if equal numbers of coppice had been used for each treatment, but the fixed-area plots reduced field time and were more easily accommodated in operations planning.

Another factor complicating experimental layout was the need to test separately the susceptibility of jarrah and marri to weedicides as pilot trials had indicated probable differences. It proved so difficult to locate the plots to include a minimum of 10 of each species that this requirement was eventually dropped. Representation of each species varied from nil to 100 per cent between plots, thus making a realistic statistical analysis impossible. Nevertheless the information gained is still useful.

Later field trials which used mechanised spraying units covered much larger areas and enabled observations on adequate samples of each species.

Each treatment was evaluated on the basis of two assessments, the first one to three months after spraying and the other 12 months after spraying. The data from the 12 months assessment are referred to in the text as "kill". Coppice sources were counted and labelled individually but scrub kill was judged subjectively and a score allotted in the range 0 to 10, 10 being complete eradication.

Most treatments were replicated at least three times in a growing season to evaluate any influence of stage of plant growth on weedicide efficiency.

All mixture strengths quoted in the results refer to percentage active equivalent (ae) of the particular chemical. In the case of Tordon 50-D the active constituent is taken to be picloram and the 2,4-D content is ignored.

For high-volume foliar treatments the weedicides were applied by hand from either a Rega standard knapsack sprayer or a Kyoritsu hanging type sprayer, and the foliage was wetted to the point of run-off. Results using this equipment were closely related to the results of field-scale treatment with tractor units. For low-volume applications either a Solo mistblower or Agserv Mistrite were used in initial trials. Later, a tractor-mounted Conomist sprayer was used for large-scale experiments. Knapsack or Kyoritsu sprayers were also used for basal sprayers. It should be noted that use of these particular items of equipment does not constitute a recommendation for any of them.

In any weed control operation it is essential to carry out the treatment at the correct stage of weed growth. Clearly, larger weeds will require a greater quantity of weedicide to achieve a kill, so it is more economical to spray smaller plants. On the other hand, weeds at a less-than-optimum size will have insufficient foliage to enable absorption of enough chemical to effect a kill. In these trials coppice was sprayed at an average height of about 1.1 m (4 ft) with a range of 0.7 to 2 m (2-6 ft). Scrub was always in the range of 0.5-1 m (1.5-3 ft) when sprayed.

RESULTS

1. Eucalypt Regrowth

(a) High-volume foliar spraying

The first research field trials using hormone-type weedicides were carried out using the high-volume technique. An extensive series of field trials was designed to investigate the influence of concentration of weedicide, season of application and effect of wetting agents on coppice kill. Results of these trials are presented mainly as summaries, rather than a complex set of tables.

Replicated spraying trials confirmed earlier observations that 2,4,5-T butyl ester gave best results in the period January to April. Treatment in that period, at the optimum concentration, yielded a 70 per cent. kill, compared with less than 20 per cent. in spring (see Table 1).

TABLE 1

Effect of season of treatment on kill of marri coppice with 2, 4, 5-T butyl ester

Treatment	January		April		October	
	No. Sprayed	% Kill	No. Sprayed	% Kill	No. Sprayed	% Kill
0·3% in diesel	51	63	86	73	47	4
0·3% in water	55	84	25	76	66	18
0·5% in water	73	88	16	94	31	3

The optimum concentration of 2,4,5-T varied with the species, 0.3 per cent. being adequate to obtain a 70 per cent. kill in marri during the summer-autumn period, but 0.5 per cent. was required to achieve a comparable kill in jarrah and blackbutt.

For marri, markedly better results were obtained using water as a carrier for 2,4,5-T, compared with diesel distillate. For jarrah coppice, the comparison was inconclusive, neither carrier showing any consistent advantage. In practice, the use of distillate for this purpose is most undesirable as it is unpleasant to work with, it is a pollution hazard and adds to the cost of the operation.

Most weedicides are used with a wetting agent or surfactant which is intended to enhance efficiency through improved foliage penetration. In a series of trials with 2,4,5-T, marri kill was not improved by either "Superior White Oil" or "Plus 50" added at the rate of 0.5 per cent. by volume. However, jarrah did show an improved kill, so a wetting agent of this type should always be used (see Table 2). No difference between these two additives could be detected but it is quite possible other wetting agents could give improved results. This is currently under investigation.

TABLE 2

Effect of two spreader/surfactant additives on efficiency of 2,4,5-T applied to jarrah coppice at 0·5% a.e. in October.

No Additive		"White Oil"		"Plus 50"	
No. Sprayed	% Kill	No. Sprayed	% Kill	No. Sprayed	% Kill
37	19	67	46	44	41

Whereas the 2,4,5-T trials generally yielded clear-cut results, the Tordon 50-D field trials did not. For example, the best marri kill was obtained in spring and summer; autumn spraying gave significantly poorer kills. Jarrah was, however, more susceptible in summer than either spring or autumn.

With regard to concentration, results were again somewhat inconsistent but indicated that, for both jarrah and marri, 0.05 per cent. Tordon 50-D in water will yield a 70 per cent. kill in January, but in October a 0.2 per cent. mixture is required for the same level of control.

The use of wetting agents was not investigated for Tordon, but all trials were conducted using 0.5 per cent. "Plus 50".

A feature of this work was the greater susceptibility of marri to both 2,4,5-T butyl ester and the picloram. This is well shown in Table 3, where the data for all treatments have been grouped for each species and the differences tested on a contingency table.

TABLE 3

Comparison of effect of 2,4,5-T and picloram (Tordon 50-D) on Jarrah and marri coppice

Herbicide	Marri			Jarrah			Chi-Square	
	Spray	Kill	% Kill	Spray	Kill	% Kill	X^2	P
2,4,5-T	1,438	755	53	946	278	37	124	$>0{\cdot}001$
Tordon 50D	660	416	63	627	164	26	178	$>0{\cdot}001$

This difference is presumably due to variation in anatomical characteristics of the leaves.

In addition to trials with the butyl ester of 2,4,5-T in water or distillate carrier, small-scale trials were carried out using the "invert" or oil-in-water emulsions of 2,4,5-T. Comparison of Tables 1 and 4 indicates that no dramatic improvement in performance results from application of the weedicide in this form. Since its price was considerably higher than that of normal 2,4,5-T butyl ester the investigation was not carried any further.

TABLE 4
Kill of marri coppice with "invert" emulsion of 2,4,5-T

January		April		October	
No. Sprayed	% Kill	No. Sprayed	% Kill	No. Sprayed	% Kill
58	72	78	55	16	44

(b) Low-volume foliar spraying

Low-volume techniques introduce further variables to the use of weedicides. In addition to the problems of optimum chemical concentration and time of treatment efficiency is also influenced by quantity of spray mixture applied per unit area. The latter is in turn a function of wind speed, swathe width and sprayer output. Clearly, the most consistent spray coverage will be achieved at a constant strip spacing and in zero wind.

Preliminary field trials were carried out using a knapsack-type mistblower, with the objectives of testing the technique and of gaining experience with it. Only two concentrations of 2,4,5-T were used, 2 and 4 per cent. a.e, with both water and diesel distillate tested as the carrier. Results were most promising (Table 5).

TABLE 5
Effect of concentration of 2,4,5-T butyl ester type of carrier and season of treatment on kill of marri and jarrah coppice from low-volume treatment

Species	Treatment	January		April		October	
		No. Sprayed	% Kill	No. Sprayed	% Kill	No. Sprayed	% Kill
Marri	2% water	95	74	33	58	24	33
	2% diesel	128	54	31	69	15	20
	4% water	152	64	29	59	21	38
	4% diesel	224	44	24	54	20	15
Jarrah	2% water	33	25	3	0	28	32
	2% diesel	16	50	9	56	54	26
	4% water	6	0	10	90	71	72
	4% diesel	34	47	0	0	59	58

Generally, these data supported the results of the high-volume trials that use of diesel as a carrier did not improve the kill in marri and gave inconsistent results in jarrah. For marri a 2 per cent. mixture gave as good a kill as did 4 per cent., but for jarrah there was a trend for the higher concentration to give an improved kill, especially in spring.

These results, together with the possibility of increased productivity, stimulated further work with the low-volume technique. However, it soon became clear the knapsack-type mistblower was unsuitable for broadscale work, so research was concentrated on a tractor-mounted sprayer.

The width of the sprayed swathe has to be determined for the particular sprayer used. For the unit used in this work, the optimum swathe width was found to be about 15 metres (15 yards). Extending the swathe width to as wide as 22 metres (22 yards) generally resulted in poorer coverage, except under windy conditions. It is, of course, pointless to direct the spray into the wind. All low-volume treatment must be done in parallel strips across the prevailing wind and using the wind to carry the mixture.

The efficiency of any treatment also depends on what is required of it, i.e. whether the coppice is required to be killed or merely controlled. This is illustrated by data from the assessment of a low-volume spraying trial, 12 months after treatment. The field experiment was designed to test three levels of 2,4,5-T butyl ester—1.1, 2.2 and 3.3 kg/ha (1, 2 and 3 lb/ac respectively). On fixed area plots, all coppice stems were counted, identified by species and classified as:

A. Dead, no recovery.
B. Weak recovery. Stems dead but weak epicormic shoots appearing. Considered to offer no competition to the pines.
C. Strong recovery. Stems dead but vigorous regrowth apparent. Obviously still competing with the pines.
D. Controlled. Most of foliage dead, but some green leaves still evident. Considered to offer no competition to the pines.
E. No effect. Either no effect at all or bulk of foliage healthy.

The efficiency of the treatment can be described as:

1. Percentage kill—$A/(A+B+C+D+E) \times 100$,
2. Minimum control percent— $(A+B)/(A+B+C+D+E) \times 100$,
3. Maximum control percent—$(A+B+D)/(A+B+C+D+E) \times 100$.

Figure 1 shows the effect of rate of weedicide application on each of these parameters for pure marri coppice and for an "average" mixture of jarrah and marri.

The initial effect of the spraying was very good, spray coverage being in excess of 90 per cent. for all treatments, but the percentage kill of marri after 12 months was only 57 per cent. at the highest application rate. Taking the average coppice regrowth stand, the kill was only 42 per cent. Clearly, if a high percentage kill is required, then a two-stage treatment is essential. Where the clearing is windrowed, the first spray should be done in the period November-December, 10-12 months after clearing and the second in the following autumn before planting.

If the aim is to achieve a temporary control of the weeds (this is generally sufficient to allow the pines to dominate the site), then levels of 2.2 kg (2 lb)

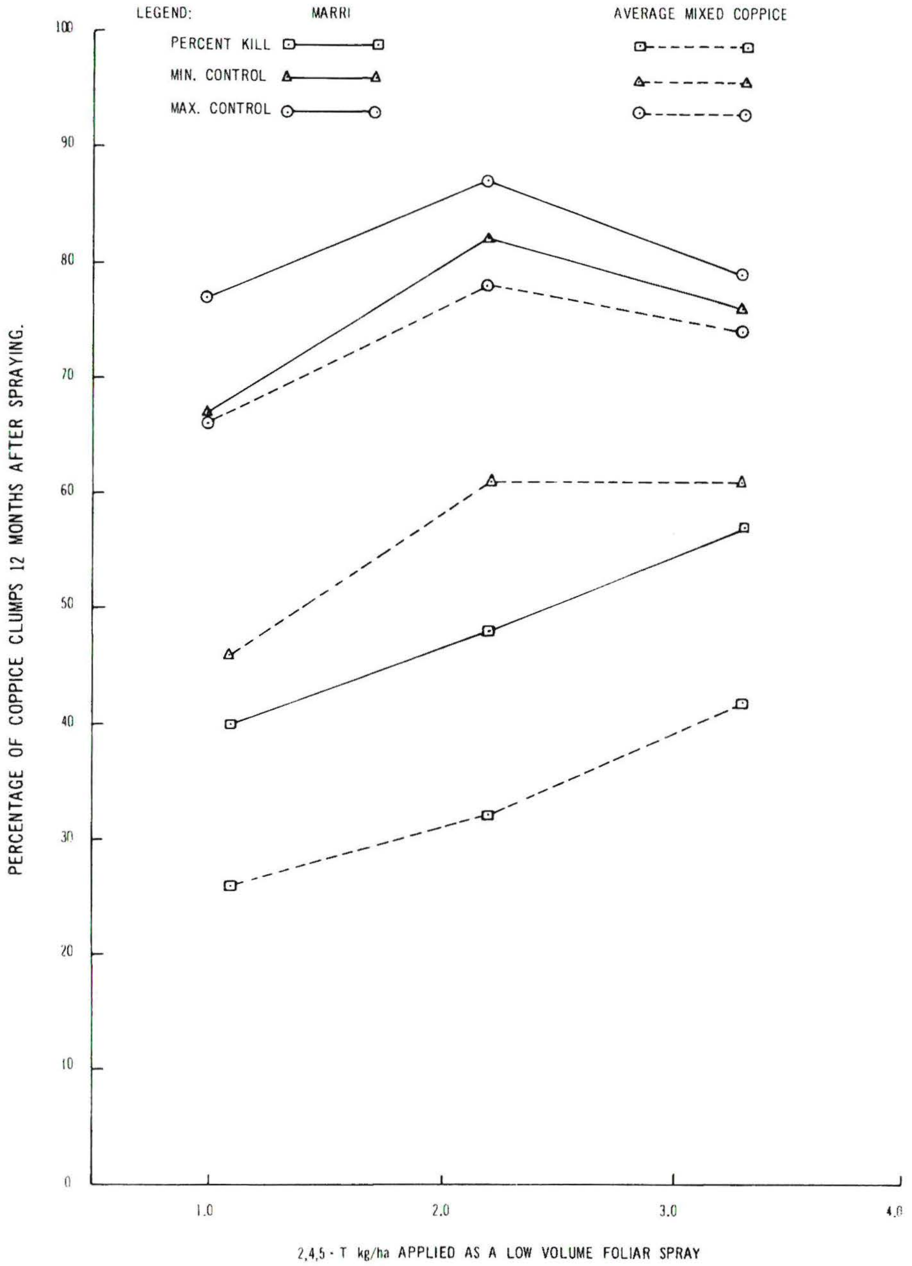

Fig. 1 EFFECT OF LEVEL OF 2,4,5 - T ON PERCENT KILL AND DEGREE OF CONTROL OVER COPPICE.

and above give acceptable results with one treatment. For a coppice crop composed predominantly of marri, even 1.1 kg/ha (1 lb/ac) gave good control, although for routine use, 2.2 kg/ha (2 lb/ac) should be used as it will give more consistent results.

(c) Basal bark spraying

This technique is a very useful, reliable one for killing eucalypt regrowth, and is specially suited to the treatment of coppice which has grown beyond the optimum height for foliar treatment. It is, however, an expensive, slow operation as every coppice stem has to be treated individually. It is generally used to "spot out" relatively small areas missed or recovering from a previous foliar treatment. In even the most careful use of this technique one can usually count on about 10 per cent. of the coppice stems being missed.

The aim of basal bark spraying is to introduce the weedicide into the sap stream in a carrier which is able to penetrate the waxes and gums of the plant bark. Water on its own will not do this, so it is normal to use diesel distillate as a carrier.

The choice of carrier does depend on the particular formulation of 2,4,5-T used. For example, some commercial sources of 2,4,5-T in the 40 per cent. concentration also contain a proportion of kerosene which would enable the weedicide to penetrate bark. Hence water could be used as a carrier in this case. With the 80 per cent. concentrate, distillate is normally used as a carrier, although it is possible water may be suitable if a hydrocarbon such as "white oil" is added at the rate of 5-10 per cent. These aspects are currently being studied.

An extensive experiment was carried out to determine the optimum concentration of 2,4,5-T for effective basal spraying, and to observe whether season of treatment affected the results. Treatments were carried out at two-monthly intervals throughout a year, using concentrations of 1 to 6 per cent. a.e. in diesel distillate. The results are summarised in Table 6 below. Contrary to the results from foliar treatments, there was no difference in response between any of the eucalypt species. As some of the plots carried no jarrah, data for marri only are presented here.

TABLE 6

Percentage kill of marri 12 months after basal spraying treatment

Month of Treatment	Concentration of 2,4,5-T active equivalent				
	1%	2%	3%	4%	6%
August	91	97	97	98	100
October	89	79	93	88	100
December	66	97	86	91	96
February	40	68	89	100	86
April	64	51	83	71	81
June	78	84	87	80	86

In general, the best results were obtained in spring and the poorest in autumn and winter but the differences were not great except at the lowest concentration. Spring treatments require care—when done in ambient temperatures greater than about 24°C (75°F) volatilisation of the 2,4,5-T can cause distortion of pine growing points. The 3 per cent. treatment gave good control all year round and is recommended for field use, with the above proviso.

Basal spraying has been used to kill old scrub plants in established plantations. While it is quite effective for the purpose, it is hardly an economic procedure.

As with any chemical method of vegetation control, the results are entirely dependent on the degree of care taken in application. In basal spraying it is essential the mixture be applied to the lower 30-40 cm (12-15 in) of the stem, all round the stem, to the point of runoff.

2. Scrub Regrowth

(a) High volume foliar spraying

The results detailed below were obtained with stands of scrub about 12-18 months old and 0.3-0.6 m (1-2 ft) in height. Scrub older than this will provide problems in control because far greater quantities of weedicide will be necessary to wet the foliage completely and wetting is physically more difficult because of the dense scrub canopy. When treated at the height mentioned, there appears to be little difference in susceptibility to weedicide of the three main scrub species.

High volume application of 2,4,5-T in water can be used to obtain very good control in spring and early summer (Table 7).

TABLE 7

High volume spraying: effect of concentration of 2,4,5-T and time of spraying on kill of one-year old netic scrub (a)

Concentration of 2,4,5-T	Application Rate kg/ha (b)	Month of Treatment		
		September	November	February
0.1%	0.67	8.2	6.5	0.7
0.2%	1.34	7.5	7.5	2.2
0.3%	2.01	8.8	8.8	2.7
0.4%	2.68	9.9	8.4	6.3

NOTE—(a) Mean rating for three 0.01 ha (0.025 ac) plots. No scrub death rated as 0, complete kill as 10.

(b) 0.67 kg/ha is equivalent to 0.6 lb/ac; other rates in multiples of this.

An acceptable level of control can be obtained in all seasons, using the highest concentration of 2,4,5-T but it is clearly more economic to use the lowest effective concentration at the optimum period of the year.

The spray mixture was applied at the rate of 670 l/ha (60 gal/ac). In practice this meant wetting all the foliage just to the point of runoff. Where the scrub cover is discontinuous the application rate would be less than that used here as there was virtually a complete ground cover of netic on the experimental area.

Tordon 50-D also gives very good control of scrub (Table 8).

TABLE 8

Effect of concentration of Tordon 50-D and season of spraying on kill of netic scrub (spray effect rated as in Table 7)

Concentration of Tordon 50-D	Application Rate kg/ha (a)	Month of Treatment		
		October	January	April
0.01	0.045	1.0	0	1.0
0.05	0.22	2.0	1.0	2.0
0.20	0.88	6.0	6.0	7.0

NOTE—(a) 0.045 kg/ha is equivalent to 0.04 lb/ac. Other levels in multiples of this.

As with 2,4,5-T, high concentrations of Tordon will achieve a good kill of scrub all year round, but the lower concentrations do not seem effective.

(b) Low volume foliar spraying

Spraying of dense scrub regeneration by low-volume techniques needs careful planning to ensure the treatment is carried out at the optimum stage of growth. When scrub exceeds a height of about one metre (3 ft), it develops a very dense canopy which severely restricts penetration of the weedicide mixture. Under these conditions, effective swathe width is reduced to about half that expected and poor results are obtained.

An experiment testing the efficiency of low volume application of 2,4,5-T at three levels at two-monthly intervals through the year, showed a trend similar to that for high volume treatments. Summer treatments were, in general, not as good as early or late spring (Table 9).

TABLE 9

Low volume spraying: effect of quantity of 2,4,5-T applied and month of treatment on kill of netic scrub

Month of Treatment	Rate of 2,4,5-T application kg/ha (a)		
	0.55	1.1	2.2
January	Check only	1	4
March	1	5	5
May	1	5	8
July	Check only	2	8
September	Check only	7	8
November	Check only	5	8

NOTE—(a) 0.55 kg/ha is equivalent to 0.50 lb/ac. Other levels in multiples of this. Kill rated on 0.10 scale on one plot only.

The lowest level of application, 0.55 kg/ha was virtually ineffective, serving only to check scrub growth. One 1.1 kg/ha gave an acceptable kill (a 7 rating) in early spring only, whereas 2.2 kg/ha gave good control in all except mid and late summer.

(c) Economic comparison of picloram and 2,4,5-T.

Picloram (formulated as Tordon 50-D) has been shown in these scrub control studies to give results generally as good as those of 2,4,5-T butyl ester. Although it does have other characteristics which discourage its use on a large scale, e.g. its greater persistence in the soil, the principal factor against picloram is its greater cost.

Prices for both 2,4,5-T and Tordon 50-D have fluctuated since the following comparison was made but the price relativity remains substantially the same. Table 10 lists material costs only for typical high and low-volume applications of each chemical. Costs used for calculation of these data were $2.40/l ($10.90/gal) for 2,4,5-T butyl ester 80 per cent. concentrate and $3.60/l ($16.30/gal) for Tordon 50-D.

TABLE 10

Material costs of Tordon 50-D and 2,4,5-T butyl ester for typical field applications

Method of Application	Cost $ per hectare (acre)	
	Tordon 50-D	2,4,5-T
High volume (a)	32.22 (13.04)	8.08 (3.27)
Low volume (b)	40.28 (16.30)	6.74 (2.73)

NOTES—(a) Tordon 50-D concentration 0.05% a.e., 2,4,5-T concentration 0.3% a.e., both applied at 900 l/ha (80 gal/ac).

(b) Tordon 50-D applied at 0.55 kg/ha (0.5 lb/ac) and 2,4,5-T applied at 2.2 kg/ha (2 lb/ac)

3. Post planting weed control.

It is frequently necessary to carry out a weed control operation after the pines have been planted, either because the pre-planting treatment was ineffective for some reason, or because there has been subsequent germination of scrub.

Where coppice is the main problem, basal spraying with 2,4,5-T in diesel distillate is very effective and reliable, with no problem of damage to pines so long as the operation does not take place in temperatures above 24°C (75°F) in spring. Very hot weather (greater than 29°C (86°F)) in summer should also be avoided as there is a considerable loss of the chemical due to volatilisation.

Control of scrub after planting inevitably involves some foliar spraying technique. The main operational problem is to ensure the pines are either not sprayed directly or can be sprayed with an acceptable degree of damage. If only a small area is involved, the treatment can be done by hand, with a high volume application of 2,4,5-T in water from a pressure-type knapsack sprayer fitted with nozzles which produce a fine spray. The same results could be obtained from a high volume boom spray operation, running the tractor up and down the rows, or even straddling the rows if the pines are still small enough. In this case the nozzles on the boom must be arranged so that the pines are not sprayed directly.

When an overall spraying operation is contemplated, extreme care is necessary as, unlike the southern pine group, *P. radiata* has no true resting stage at any time of the year. Young radiata pine vary in their susceptibility to damage from 2,4,5-T depending on environmental conditions immediately before spraying. If conditions have been favourable for shoot extension, then exposure to 2,4,5-T will result in malformation of the growing tips, death of the leader or, in occasional cases, death of the plant. Relatively little damage will be caused by spraying after a dry period when the shoots are "hardened off."

The significance of any damage varies according to the age of the pines involved. Damage to one-year old pines, even if seemingly severe, is almost invariably ephemeral, whereas damage to pines two years or older results in permanent and important defects. In really severe cases of such damage the malformed top should be pruned off. A new leader, from either a branch or auxiliary shoot, will eventually assume dominance.

An extensive experiment was carried out to observe the problems of post-planting low-volume applications of 2,4,5-T. The weedicide was applied at three rates 0.55, 1.12 and 2.24 kg/ha and at two-monthly intervals beginning in January, 1969. The pines had been planted in June, 1968, for treatments applied from January to May, and in June, 1969, for treatments applied from July to November. This experiment was actually the one for which scrub kill data were given in Table 9. Satisfactory control of scrub was achieved at the higher levels of weedicide, as indicated in that table, but the essential question was whether the damage sustained by the pines was acceptable.

Immediately after spraying, the pine plants gave the impression that disaster was imminent, especially in the September and November treatments. Foliage was burnt, or drooped and turned pale green in colour, leaders were sometimes killed and frequently grossly distorted.

However, recovery was rapid and almost complete. By the third year after treatment there was little evidence of the previous damage. Thus low-volume postplanting operations in recently planted pines are quite feasible even in the spring period, but require careful planning and execution. It should be remembered that any setback to the leaders will result in decreased height growth.

4. Control of grass competition.

Competition from annual grasses and associated broadleaf weeds such as capeweed (*Cryptostemma calendula* (L.) Druce) can be very effectively controlled by treatment with Vorox AA at the rate of 2.2 kg/ha (2 lb/ac). It is usually applied in water from a boom sprayer, mister, or from the air in very steep country. For aerial application it is desirable to increase the rate to 3.3 kg/ha (3 lb/ac) to ensure a minimum of 2.2 kg actually applied over the whole area. It appears that 2.2 kg is the minimum effective level.

Treatment is usually carried out in May-June before planting but Vorox can be applied post-planting at rates up to 4.4 kg/ha (4 lb/ac) without harm to newly-planted *P. radiata*. There is some chlorosis at rates above 4.4 kg/ha. Spraying as late as September is quite effective and gives better grass control in the event of an unusually long spring growing season.

It should be noted Vorox is effective against annual grasses and broadleaf weeds only. Perennial grasses such as Kikuyu (*Pennisetum* Spp.) and paspalum (*Paspalum* Spp.) are much more difficult to control. Suitable techniques for this are under investigation.

DISCUSSION

Method of Application

All of the techniques used here have a place in plantation weed control. Choice of technique will depend on the particular circumstances, but it should always be borne in mind it is preferable to avoid the use of any weedicide if there is an effective and economic alternative.

Basal bark treatment is a reliable, but expensive and unpleasant operation. In steep country small knapsack, or shoulder-strap type sprayers are necessary and the dieseline adds to the discomfort if spillage occurs. Where the terrain permits, it is possible to use a tractor-mounted pump unit. Basal spraying is best used only to "spot out" relatively small areas either inaccessible to foliar spraying units or which have been missed in a previous operation.

High-volume foliar spraying gives good results when carefully used and has the advantages of low capital investment compared with the equipment required for other foliar spraying techniques, and relative insensitivity to changing weather conditions. Its principal disadvantage is the difficulty of maintaining operator efficiency as it is a slow, monotonous operaton. In general, high-volume foliar spraying is cheaper than basal spraying but more expensive than low-volume foliar spraying.

From an administrative point of view, both basal bark and high-volume spraying are relatively labour-intensive. To treat any large area, say 200 hectares (500 acres), will require several men for some weeks. When labour is scarce this is an undesirable feature.

Low-volume spraying, on the other hand, has a low manpower requirement, is more productive, has a low and predictable chemical requirement and simplified logistic problems. However, the technique is more dependent on operator skill than either of the two previous techniques. It is not generally appreciated that good results require a complete spray coverage of the area concerned and that coverage is vitally affected by slight changes in weather conditions. Whereas high-volume spraying can be carried out all through the day on most days when the weather is fine, successful low-volume spraying may be possible only early in the morning or late in the afternoon when the wind speed tends to be least. The ideal situation is calm, dry weather when the mister can make parallel runs across the area at a constant swathe width.

Low-level application of weedicides from aircraft offers the ultimate in low manpower requirement and productivity. However, problems of spray and vapour drift become more important, as explained below. The rate of spray mixture application can be reduced to 55 1/ha (5 gal/ac) and the same quantity of active chemical applied as for ground spraying. For 2,4,5-T spraying, water should be used as a carrier at all times. Diesel distillate, being less dense than water, is much more prone to spray drift. Even a slight puff of wind is sufficient to pick up a cloud of spray and carry it off. The use of dieseline also adds another cost to the operation.

Aerial spraying cannot be regarded as merely another low-volume spraying technique as it has special problems of its own. It is essential each operation is very carefully preplanned. The number of flight lines required must be worked out from an accurate map of the area involved and each line must be clearly marked in the field. To ensure even spray treatment and minimal spray drift the aircraft must fly at a constant speed at a constant height above the ground. Clearly, the latter requirement is impossible to meet in very steep or broken terrain, so aerial spraying will give best results on even topography.

Safety Precautions

It cannot be stressed too strongly that most weedicides are potentially dangerous chemicals if used carelessly or incorrectly. Although some of the dangers are well known, there are others for which we have inadequate information, particularly in respect of long-term effects. It is therefore, a good principle to follow that where there is a satisfactory and economic alternative to the use of weedicides, that alternative should be employed.

With all weedicides, operators should avoid inhalation of fumes or direct contact with the skin or eyes .Protective clothing should be worn where possible and special cabins provided for tractor operators.

Apart from the direct hazard to operators using weedicides there is the hazard to crop trees or other susceptible plants from spray or vapour drift.

Vorox is a wettable powder, so the problem of evaporation of the chemical and subsequent vapour drift does not arise. To ensure there is no hazard from spray drift, aerial application of Vorox should not be undertaken closer than 0.65 km (0.25 miles) from neighbouring pasture. However, boom spraying can be carried out immediately adjacent to susceptible pasture.

Butyl ester of 2,4,5-T on the other hand, is highly volatile and presents a potential hazard from both spray and vapour drift. Spray drift is generally no problem with high-volume foliar spraying or basal spraying but is a very important consideration in planning mister or aerial operations. The principal factor influencing spray drift is wind strength and in the case of aircraft, flying height.

Vapour drift, due to volatilisation of the 2,4,5-T, is much more difficult to detect as it occurs, and it may take place for some days after the spraying operation. The volatility of 2,4,5-T is greatly affected by ambient temperature (see properties of 2,4,5-T formulations listed in Appendix II), and thus can be minimised by spraying only in temperatures below 24°C (75°F). The hazard from vapour drift depends on several factors, such as total quantity of chemical applied, wind strength and direction and temperature conditions for the week following spraying. Clearly, the risk of vapour drift is greatest from an aerial spraying operation, since a large amount of chemical may be deposited in a few hours, and least from high-volume spraying. Consequently, aerial spraying must be confined to periods of reliable cool temperatures, such as April and May.

General

The results presented in this report cover the range of weed control situations likely to be encountered in the pine plantations in southern Western Australia. Although the data in some parts lack statistical proof, there is no doubt the trends identified do exist, as they have been confirmed by field observation.

The results have been summarised into a series of recommendations for various field situations given tabular form in Appendix III. Occasional inconsistencies in the data, e.g. the variation in the effect of 2,4,5-T on jarrah coppice on spring season treatments and in the performance of picloram on coppice generally, indicate the need for more basic information on mode of action of these herbicides and on the influence of immediate environmental conditions on their entry and translocation in coppice.

In conclusion, it should be remembered that successful control of weeds in pine plantations depends on continued observation of the situation. No technique can be regarded as a final, foolproof and universally useful measure. Every weed control situation needs to be considered on its merits and the technique used has to be designed specifically for that situation. No weedicide and no technique can substitute for careful thought.

ACKNOWLEDGEMENTS

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APPENDIX I

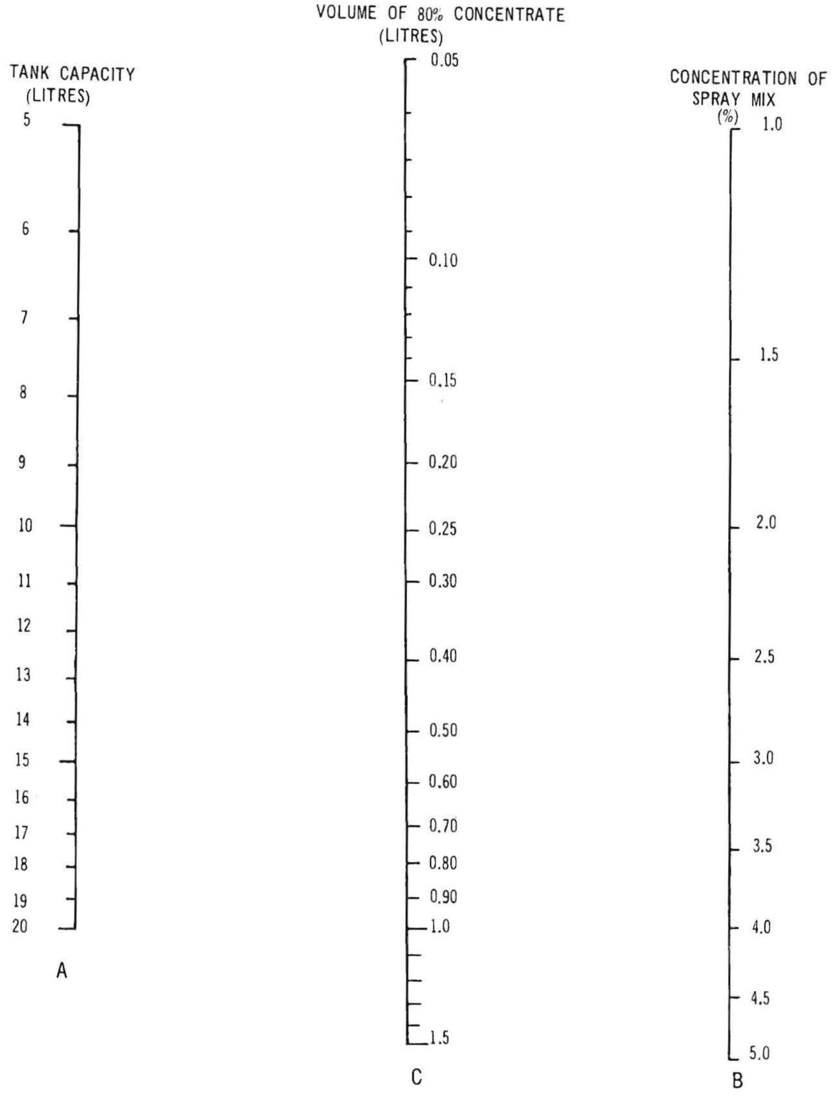
Spray mixture alignment charts for 2,4,5-T.

The two accompanying alignment charts will assist with dilution of 2,4,5-T concentrates to working spray mixtures.

To use, simply place a ruler on the appropriate chart with one end on the required spray mixture concentration (Col. B) and the other on the tank capacity (Col. A). The necessary quantity of 80% 2,4,5-T is then read off Column C where it is intersected by the ruler.

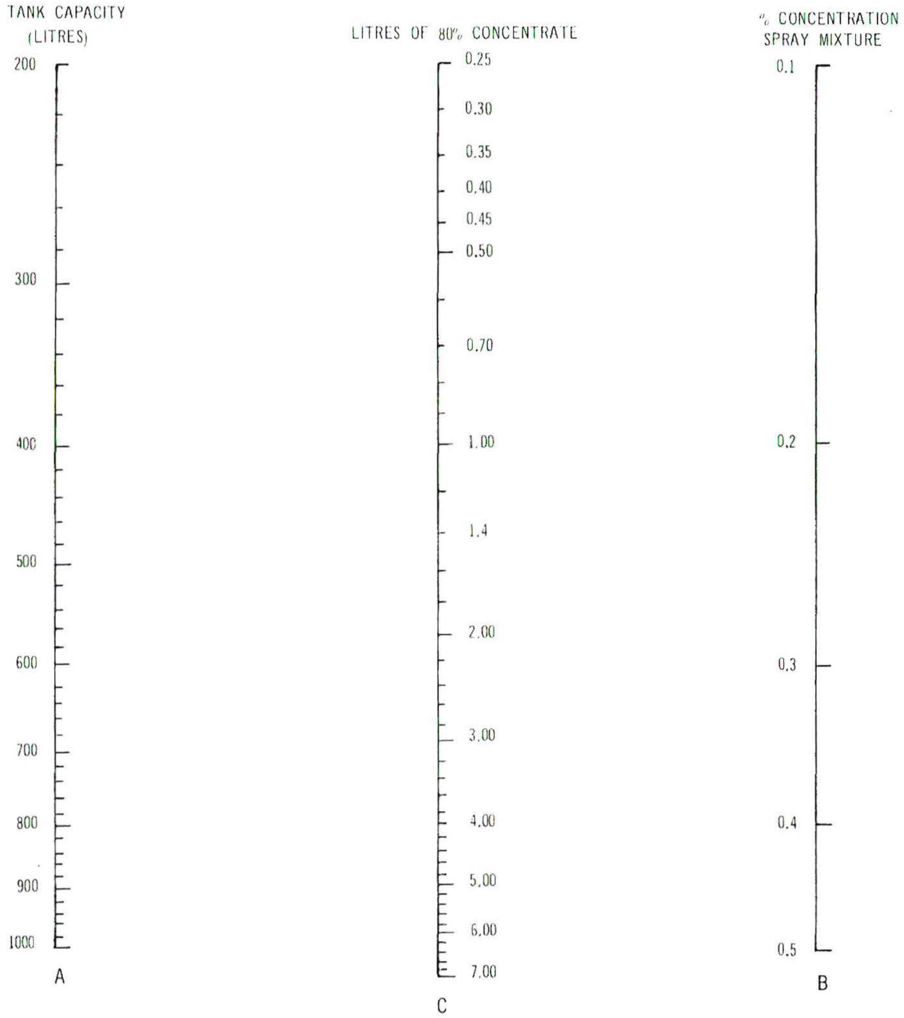
If the 2,4,5-T is available in a concentration other than 80% W/V active equivalent, the required quantity can be calculated by multiplying the figure read off Column C by $\frac{80}{x}$, where x is the chemical concentration as percentage W/V active equivalent.

SPRAY CHART - PORTABLE SPRAYERS



FOR FOLIAR SPRAY SOLUTIONS IN THE RANGE OF 0.1 - 0.5 % DIVIDE COLUMNS B AND C BY 10.
FOR SPRAY VOLUMES 50-200 LITRES MULTIPLY COLUMNS A AND C BY 10.

SPRAY CHART - TRACTOR SPRAYERS



FOR SPRAY VOLUMES OF 20 - 100 LITRES DIVIDE COLUMNS A AND C BY 10.

APPENDIX II

Properties of 2,4,5-T Formulations

1. Effect of temperature on volatility

Temperature °C	Vapour Pressure mgm/m^3
28	—
30	7
40	16
60	85

2. Variation in volatility of various formulations

Formulation	Vapour Pressure mgm/m^3 at 30°C
2,4,5-T butyl ester	7
2,4,5-T butoxyethyl ester	1
2,4,5-T acid	0.1
2,4,5-T amine	—

Note that 2,4-D is generally more volatile than 2,4,5-T. The point should be borne in mind if using Tordon-D as a foliar spray.

3. Sensitivity of test plants

Tomato seedlings are extremely sensitive to small concentrations of 2,4,-D and 2,4,5-T. A marked response is shown at concentrations of hormone vapour above 1 part in 1 x 10^8 parts of air.

APPENDIX III

Summary of Recommendations for Weedicide Use in Radiata Pine Plantations in W.A.

IMPORTANT—2,4,5-T should not be used when the maximum temperature for the day is expected to exceed 24°C (75°F). ALWAYS check for presence of susceptible crops close by.

Situation	Problem	High-Volume Foliar Spray	Low-Volume Overall Spray	Basal Bark Spray
Preplanting	Marri coppice only	0.3% 2,4,5-T in water (a) Jan.-April	2,4,5-T 2.2 kg/ha in water (c) Nov. -April	....
	Mixed coppice	0.4% do.	3.3 kg/ha do.	....
	Jarrah or W.A. Blackbutt coppice	0.5% do.	4.4 kg/ha do.	....
	Scrub	0.3% 2,4,5-T in water (a) or (b) Sept.-Dec.	2.2 kg/ha do.	....
	Annual grasses and capeweed	Vorox A.A 2.2 kg/ha (b) May	Vorox A.A 3.3 kg/ha (d) May	....
Postplanting	Marri coppice only	0.3%, 2,4,5-T in water (a) Jan.-March	2,4,5-T 2.2 kg/ha in water (c) Feb.-March (e)	3% 2,4,5-T in distillate Sept.-May
	Mixed coppice	0.4% do.	do.	do.
	Jarrah or W.A. Blackbutt coppice	0.5% do.	do.	do.
	Scrub	0.2% 2,4,5-T (a) or (b) Aug.-Sept. (e)	2,4,5-T 1.1 kg/ha (c) Sept.-Nov. (e) With **extreme** care	do.
	Annual grasses and capeweed	Vorox A.A 2.2 kg/ha (b) Aug.-Sept.	Vorox 3.3 kg/ha (d) Aug.-Sept.	do.

NOTES—(a) Use tractor spraying unit.
(b) Boom sprayer.
(c) Tractor mounted misting unit.
(d) Aircraft.
(e) For pines in their first year in the field only.

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