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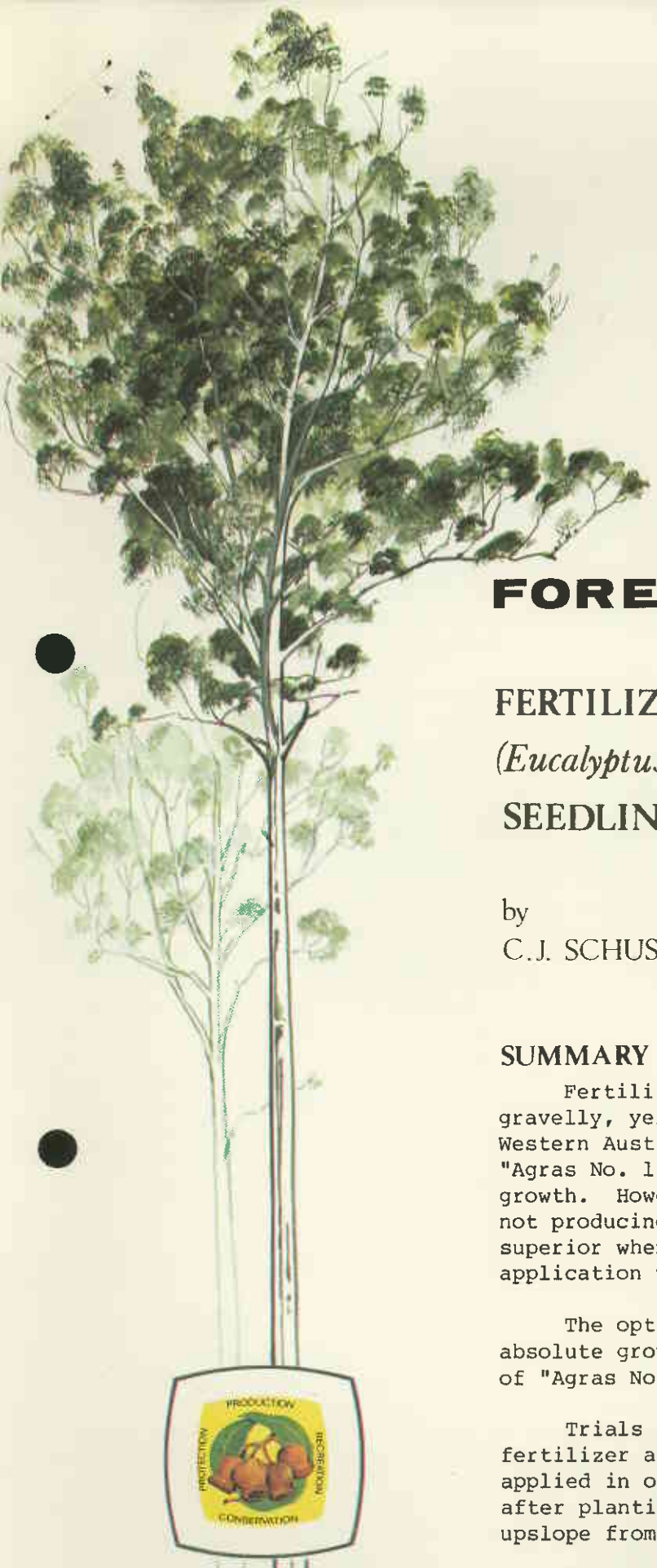

FORESTS DEPARTMENT
OF WESTERN AUSTRALIA

FERTILIZING PLANTED KARRI (*Eucalyptus Diversicolor* F. MUELL.) SEEDLINGS

by
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SUMMARY

Fertilizing planted karri seedlings on gravelly, yellow podsolic soils in the south-west of Western Australia indicated that "Vigran 9:9:9" and "Agras No. 1" produced the greatest seedling height growth. However, a superphosphate-urea mixture, while not producing the best absolute height growth, proved superior when the cost-efficiency aspects of fertilizer application were considered.

The optimal fertilizer regime for maximizing both absolute growth and cost-efficiency appeared to be 63 g of "Agras No. 1" (5 g elemental P per plant).

Trials investigating the timing and placement of fertilizer additions indicated that fertilizer should be applied in one or two applications, at most four weeks after planting, and buried in a shallow hole 10 cm upslope from the seedling.

The refertilizing of one-year-old karri planted on low quality sites was not considered economic at the application rate used (10 g elemental P per tree).

INTRODUCTION

Karri (*Eucalyptus diversicolor* F. Muell.) is an important commercial forest species in the south-west of Western Australia. Following logging, karri forest coupes are prepared for regeneration with an intense slash disposal burn to dispose of logging debris and assist in ashbed formation (White and Underwood, 1974). Several regeneration alternatives are then available; one is the hand planting of nursery-raised open-rooted seedlings with associated fertilizer applications.

The response of karri to fertilizer application after planting has been studied both in pot trials (Loneragan and Loneragan, 1964) and in field trials (Christensen, 1974). The field trials were located on red earth soil types classified Gn 2.15 (McArthur and Clifton, 1975). In the pot trials, phosphorus (P) and nitrogen (N) were the most important nutrients increasing karri growth. The field trials, however, indicated that phosphorus was more important for stimulating early growth. Barrow (1977) and Schuster (1979) also found that applications of phosphorus increased growth of karri seedlings.

The advantages of fertilizing other eucalypt species with nitrogen and phosphorus have been shown by McGrath (1979) in Western Australia, by May *et al* (1975) in Victoria, and by McIntyre and Pryor (1974) in New South Wales.

This paper describes concurrent trials initiated to determine the optimal regime for fertilizing karri seedlings. The trials examined the type, rate, timing and placement of fertilizer in new karri plantings on gravelly, yellow podsolic soils where most logging is now concentrated. Previous research had suggested that fertilizer applied four weeks after planting and buried 10 cm upslope from the seedling gave best results. A further trial on fertilizing one-year-old karri trees is also discussed.

METHODS AND RESULTS

The trials, using new karri plantings, were established in Nairn Block, 15 km east-south-east of Pemberton, while the refertilizing trial of one-year-old karri was in Poole Block, 20 km south-east of Pemberton.

Both trials were situated on gravelly, yellow podsolic soils, classified Dy 3.62 (McArthur and Clifton, 1975), which previously supported a mixed stand of marri (*Eucalyptus calophylla* R. Br.) and karri. These soils are nutritionally poorer than red earth soil types. The average annual rainfall of the region exceeds 1000 mm.

Type and application rate of fertilizer

The fertilizers tested in the trial are shown in Table 1. For each fertilizer, the registered analysis and cost per tonne (October 1979) are included. The rates of application were calculated at three levels of elemental P application (5, 10 or 15 g per plant), to allow for easier comparison between fertilizers. However, this meant that in some cases the amounts of N and potassium (K) applied were not uniform for all treatments.

Each of the five fertilizers was applied at the three different rates, including a control (no fertilizer) treatment. The fertilizers were applied four weeks after planting, and were buried 10 cm uphill from the seedling.

The trial design was a complete randomized block, with three replications of each of the 16 treatments. Each treatment plot measured 10 x 10 m (0.01 ha) and contained 50 seedlings in five rows, at a spacing of 2 m between rows and 1 m within rows.

This trial was assessed in August 1979, 14 months after planting. Seedling height, stem diameter (measured with calipers 20 c above soil surface) and plant survival were measured within a central sub-plot of 24 seedlings (three rows of eight plants). Thirty-three per cent of these trees were removed for biomass determination.

Results

The results of this trial are presented in Table 2a (height growth), Table 2b (diameter growth) and Table 2d (plant survival). Data were analysed using Duncan's Multiple Range Test (Duncan, 1955).

"Vigran 9:9:9" and "Agras No. 1" generally produced the greatest height growth increment, except for "Agras No. 1" at 10 g P per plant. In most cases all application rates of the slow-release fertilizer "Magamp" produced significantly

TABLE 1

Chemical analysis, costs and application rates (g per tree) of fertilizers used in trials

Fertilizer Type	Superphosphate-urea (1)	Superphosphate-"Agran 34" (1)	"Magamp"	"Agras No. 1"	"Vigran 9:9:9"
Registered Analysis (2)	7.9% N 7.9% P	7.5% N 7.5% P	7.0% N 17.8% P 5.0% K	18.0% N 7.9% P 16.9% S	9.0% N 4.0% P 7.5% K
Cost per tonne ($) (3)	95.00	100.00	1300.00	179.66	149.95
Application rate: equivalent of 5 g P per plant (g)	63.3	66.7	28	63.3	125
Cost per plant (¢) (4)	0.60	0.66	3.64	1.13	1.87
Application rate: equivalent of 10 g P per plant (g)	126.6	133.4	56	126.6	250
Cost per plant (¢) (4)	1.20	1.32	7.28	2.26	3.74
Application rate: equivalent of 15 g P per plant (g)	189.9	200.1	84	189.9	375
Cost per plant (¢) (4)	1.80	1.98	10.82	3.39	5.61

(1) Superphosphate-urea and Superphosphate - "Agran 34" are mixed by the Forests Department of Western Australia to a 1P:1N (elemental) ratio, after Christensen (1974). The price includes $10 per tonne for mixing the fertilizer.

(2) Registered analyses are from the Department of Agriculture, Western Australia (1979).

(3) Cost per tonne is based on prices ex C.S.B.P. and Farmers Ltd., Picton, Western Australia at 1 October 79. "Magamp" price is an approximation.

(4) Materials only.

TABLE 2(a)

Effect of fertilizer type and rate of application on height growth of karri seedlings 14 months after planting

Treatment*	N	C1	B1	C3	A3	B2	A1	D2	A2	C2	D1	E2	B3	D3	E3	E1
Mean height increment (cm)	49.5	82.4	88.4	91.2	99.0	102.0	102.5	105.4	108.7	109.4	113.7	117.2	117.6	126.6	126.6	129.2

TABLE 2(b)

Effect of fertilizer type and rate of application on diameter growth of karri seedlings 14 months after planting

Treatment*	N	C1	B1	C3	D2	D1	B3	A2	A3	A1	C2	E2	E3	B2	E1	D3
Mean stem diameter increment 20cm above ground (cm)	0.61	0.79	0.89	0.94	1.11	1.13	1.13	1.14	1.14	1.15	1.15	1.21	1.23	1.25	1.30	1.36

TABLE 2(c)

Effect of fertilizer type and rate of application on above-ground biomass production of karri seedlings 14 months after planting

Treatment*	N	B1	C3	C1	B3	A3	A2	B2	E1	D2	E3	C2	E2	A1	D1	D3
Biomass above ground - oven dried (gm)	110.1	235.0	269.4	280.8	282.6	355.4	357.1	386.9	397.1	399.1	401.3	402.0	418.3	421.9	529.1	570.4

TABLE 2(d)

Effect of fertilizer type and rate of application on survival percentage of karri seedlings 14 months after planting

Treatment*	E3	D2	E2	D3	A3	D1	A2	B3	C1	C3	N	A1	B2	B1	E1	C2
Survival %	72.2	75.9	75.9	79.6	87.0	88.9	88.9	88.9	88.9	90.7	92.3	92.6	92.6	92.6	96.3	98.1
g N/tree	27	22	18	33	15	11	10	21	3	10	0	5	14	7	9	7

Data underlined are not significantly different at p = .05 (Duncan's Multiple Range Test)

* N = Control (nil application)
A = Super.-urea
B = Super.-"Agran 34"
C = "Magamp"
D = "Agras No. 1"
E = "Vigran 9:9:9"

1 = 5 g elemental P per plant
2 = 10 g elemental P per plant
3 = 15 g elemental P per plant

less ($p = 0.05$) growth than corresponding treatments of the other fertilizers. However, "Magamp" produced significantly greater ($p = 0.05$) height growth than did the untreated control.

Generally, increasing the application rate of a fertilizer above 5 g P per plant did not significantly increase height growth. One exception was the superphosphate plus "Agran 34" treatment, where every increase in application rate produced a significant increase ($p = 0.05$) in height growth.

To some extent, diameter growth (Table 2b) showed the same trends evident for height growth. Generally, the "Vigran 9:9:9" and "Agras No. 1" treatments (particularly "Agras No. 1" applied at 15 g P per plant) showed the largest diameter growth. The "Magamp" treatment and the control (no treatment) resulted in less diameter growth than most other treatments.

The results of the biomass sampling are presented in Table 2c. The variations in biomass were not as great as the variations in either height or diameter growth. Generally, the "Vigran 9:9:9" and "Agras No. 1" treatments (particularly "Agras No. 1" applied at 5 g P per plant and 15 g P per plant) produced greater biomass. However, few significant differences existed between these fertilizers and either superphosphate plus urea, or superphosphate plus "Agran". Two of the three "Magamp" treatments, as well as the untreated control, showed relatively small biomass recordings when compared with other fertilizers.

Using a standard 80 per cent as an operationally acceptable plant survival percentage, four treatments were unacceptable (Table 2d): "Vigran 9:9:9" and "Agras No. 1" applied at 10 and 15 g P per plant. All other treatments gave acceptable survival rates, although, as the application rate of a particular fertilizer increased, the plant survival generally decreased.

Although the growth increments produced should be considered when deciding upon a particular fertilizer regime, the operational cost is also important. "Vigran 9:9:9" and "Agras No. 1" (both at 5 g P per plant) were among the best treatments for growth promotion. However, Table 1 indicates they are also the most expensive. Furthermore, "Vigran 9:9:9" is required in larger quantities to correspond with the elemental P contents of the other fertilizers.

To simplify the cost-efficiency aspects of each treatment, some simple measures of growth per unit cost of materials were devised. These were cm/cent (height), cm/cent (diameter) and g/cent (biomass). Each measure was obtained by dividing the growth increment for each factor (height, diameter and biomass) by the cost per plant for materials (Table 1).

The cost-efficiency values in Tables 3a, 3b and 3c indicate that it is only economic to use the lowest rate of application for each fertilizer. For every fertilizer, the comparative benefits decline as the application rate is increased.

For all three variables, superphosphate plus urea, superphosphate plus "Agran 34" and "Agras No. 1" (all at 5 g P per plant) produce the greatest benefits per unit cost. Superphosphate plus urea at 5 g P per plant is consistently superior to the other fertilizers although its effect on the plants' growth (Tables 2a, 2b and 2c) is inferior to "Agras No. 1".

"Magamp" at all application rates is relatively cost inefficient when compared with all other fertilizers. "Vigran 9:9:9", while producing the best absolute growth overall, is also comparatively expensive at the application rates tested. This results in the low figures for "Vigran 9:9:9" shown in Tables 3a, 3b and 3c, with only the 5 g P per plant application rate being comparable to the best three treatments.

Place of application of fertilizer

This trial was designed to determine the most effective placement of fertilizer relative to seedling position. The options tested were surface applications in:

(1) a circle of 30 cm radius around the plant;
(2) a spot 10 cm uphill and
(3) a spot 10 cm downhill

from the plant.

TABLE 3a

Cost efficiency of height growth of karri seedlings for each fertilizer and application rate tested

Type of Fertilizer	Cost efficiency of height growth at the various application rates tested (expressed as cm/cent)		
	5g P per plant	10g P per plant	15g P per plant
Super.-urea	1.90	1.00	0.56
Super.-"Agran 34"	1.19	0.81	0.69
"Magamp"	0.18	0.17	0.08
"Agras No. 1"	1.17	0.51	0.47
"Vigran 9:9:9"	0.87	0.37	0.27

TABLE 3b

Cost efficiency of diameter growth of karri seedlings for each fertilizer and application rate tested

Type of Fertilizer	Cost efficiency of diameter growth at the various application rates tested (expressed as cm/cent)		
	5g P per plant	10g P per plant	15g P per plant
Super.-urea	2.03	0.95	0.64
Super.-"Agran 34"	1.35	0.94	0.58
"Magamp"	0.21	0.15	0.08
"Agras No. 1"	1.02	0.50	0.41
"Vigran 9:9:9"	0.69	0.32	0.22

TABLE 3c

Cost efficiency of above-ground biomass production of karri seedlings for each fertilizer and application rate tested

Type of Fertilizer	Cost efficiency of increased shoot weight at the various application rates tested (expressed as g/cent)		
	5g P per plant	10g P per plant	15g P per plant
Super.-urea	713.5	301.7	200.1
Super.-"Agran 34"	355.0	292.3	142.4
"Magamp"	76.9	55.0	24.5
"Agras No. 1"	477.8	180.2	171.7
"Vigran 9:9:9"	213.2	120.2	71.8

Buried applications were placed:
(1) 10 cm uphill;
(2) 20 cm uphill;
(3) 10 cm downhill and
(4) 20 cm downhill
from the plant.

The amount and type of fertilizer selected was 126 g of "Agras No. 1" (10 g P per plant). "Agras No. 1" was used for its high N content, but this may cause burning and mortality if placed too close to the plant. All plants in the trial were planted in June 1978, and the fertilizer applied four weeks later. This four week lapse had provided the best results in a previous trial. The buried applications were placed in a hole 10 to 15 cm deep, and lightly covered with soil.

The trial design was a complete randomized block, with three replications of each of the seven treatments. Each plot measured 15 x 15 m (0.02 ha) and contained 75 seedlings in five rows, with a spacing of 2 m between rows and 1 m within rows. Height at planting was also measured.

The trial was assessed in August 1979, 14 months after planting. Seedling height and plant survival were assessed in a central sub-plot of 33 seedlings (three rows of eleven plants) within each plot.

Results

The results of the assessment for seedling height and plant survival (Table 4) were analysed using Duncan's Multiple Range Test (Duncan, 1955).

Although no significant differences in height growth increment appeared between treatments, burying the fertilizer 10 cm uphill or 20 cm downhill from the plant produced slight increases in height and plant survival. Only the surface application 10 cm uphill from the plant produced significantly lower ($p = 0.1$) survival percentages.

Time of application of fertilizer

This trial was initiated to determine the most appropriate time for fertilizer application relative to planting time. The times of application tested were:

(1) at planting (P);
(2) two weeks after planting (P + two weeks);
(3) four weeks after planting (P + four weeks);
(4) eight weeks after planting (P + eight weeks);
(5) at planting and four weeks after planting (P and P + four weeks);
(6) at planting, and eight weeks after planting (P and P + eight weeks);

TABLE 4

Effect of placement of "Agras No. 1" fertilizer on height growth and survival of karri seedlings 13 months after planting

	Surface applications			Buried applications			
Distance from plant (cm)	30	10	10	10	20	10	20
Position*	C	U	D	U	U	D	D
Height growth increment (cm)	154.8	107.4	146.2	168.7	119.2	137.2	162.2
Survival percentage	85.2[a]	63.0[b]	84.0[a]	85.2[a]	88.9[a]	87.7[a]	91.4[a]

Data notated with the same letter are not significantly different at $p = 0.1$ (Duncan's Multiple Range Test).
No significant differences in height growth were noted.

*U = uphill
D = downhill
C = circle around plant

(7) at planting, four weeks after planting, and eight weeks after planting (P, P + four and P + eight weeks).

The amount and type of fertilizer used was 126 g of "Agras No. 1" (10 g P per plant) buried 10 cm uphill from the plant. This place of application proved most effective in a previous trial. When a split application was used, the total amount of fertilizer applied (126 g) was constant: it was applied either in two applications of 63 g or three applications of 42 g.

The trial design was a complete randomized block, incorporating three replications of each of the seven treatments. Each plot measured 15 x 15 m (0.02 ha) and contained 75 seedlings in five lines at a spacing of 2 m between rows and 1 m within rows. The seedlings were planted and their height measured in June 1978.

An assessment of these trials was made in August 1979, 14 months after planting. Seedling height was measured and plant survival assessed in an internal sub-plot of 33 seedlings (three rows of eleven plants) in the centre of each treatment plot.

Results

The results of this trial (Table 5) were analysed using Duncan's Multiple Range Test (Duncan, 1955).

The most effective application times appeared to be P + four weeks, or P and P + four weeks.

Progressively larger height increments resulted from increasing time between planting and fertilizing from zero, to two, to four weeks. However, when the time between planting and fertilizing was increased to eight weeks, no improvement in growth was seen compared with growth after fertilization at planting. This was also the case for the P, P + four weeks and P + eight weeks treatment, which produced no increase over the P and P + four weeks treatment.

Refertilizing of one-year-old karri

This trial was initiated to determine the potential for improving growth of one-year-old karri (fertilized at planting with 60 g of superohosphate-urea mixture) with a further fertilizer application. The fertilizers chosen were "Agras No. 1" at 126 g per tree, "Vigran 9:9:9" at 250 g per tree, and the slow-release fertilizer "Magamp" at 56 g per tree. These application rates are equivalent to 10 g of elemental P. The fertilizer was buried in a spot 10 to 15 cm uphill from each tree in July 1978. A control with no fertilizer was included in the trial.

The trial design was a complete randomized block with four replications of each of the four treatments. Each treatment plot measured 20 x 20 m (0.04 ha)

TABLE 5

Effect of timing of "Agras No. 1" fertilizer application on growth and survival of karri 14 months after planting

Variable	Time of application (weeks)						
	P*	P + 2	P + 4	P + 8	P P + 4	P P + 8	P P + 4 P + 8
Height growth (cm)	c 109.1	bc 126.8	ab 148.3	c 105.6	a 166.7	bc 117.4	a 166.4
Survival percentage	86.1[a]	77.8[a]	84.0[a]	91.4[a]	95.1[a]	85.2[a]	85.2[a]

* P = time of planting
Data notated with the same letter are not significantly different at p = 0.01 (Duncan's Multiple Range Test)
Where two or more application times were tested, the same total amount of fertilizer was used as in the single application.

and contained approximately 50 seedlings at a spacing of 4 m between rows and 2 m within rows. In some plots trees had died in the first year of growth, before the second application of fertilizer, leading to slight variations in numbers of trees per plot.

This trial was assessed in April 1979, using a central sub-plot of 18 trees (three rows of six plants) in each treatment plot. The variables assessed were height growth and survival at the time of fertilizing in 1978.

Results

The results of this trial are shown in Table 6. The height data represents the height increments for each treatment between refertilizing and assessment at age two years.

All data were analysed using Duncan's Multiple Range Test (Duncan, 1955).

Of the fertilizers studied, only "Vigran 9:9:9" significantly increased ($p = 0.1$) growth increment over the control. All treatments showed greater than 95 per cent survival in this trial.

DISCUSSION

The objective of the trials was to define the optimum fertilizing regime for establishing karri seedlings. The aim of establishment techniques should be to achieve maximum growth and high survival levels (Woods, 1976).

All treatments tested in the trial of five fertilizers at three different rates, to examine type and rate of fertilizer applied, produced significantly greater increases ($p = 0.05$) in all parameters (height, diameter and biomass) than the untreated control. This has been confirmed for other eucalypt species by McGrath (1979), May *et al* (1975) and McIntyre and Pryor (1974). Christensen (1974) achieved a similar result with karri.

Generally, both "Vigran 9:9:9" and "Agras No. 1" produced greater growth than the other three fertilizers or the control. In most cases there was little gain from increasing the application rate of any fertilizer above the lowest rate (5 g P per plant) applied. This observation is supported by Christensen (1974). However, McGrath (1979) found that the height growth of five eucalypt species increased with increasing application rates, though not in a linear relationship.

Survival levels were acceptable (minimum 80 per cent) in all treatments except "Vigran 9:9:9" and "Agras No. 1", both at 10 and 15 g P per plant. Generally, survival levels decreased as application rates of N and P increased. This corresponds with the results of Christensen (1974) and McGrath (1979). In this trial, which assessed rate and type of application, the fertilizers with the highest N levels, "Agras No. 1", 18 per cent and "Vigran 9:9:9", 9 per cent, produced the highest mortalities. Consequently, great care should be taken when applying N to karri seedlings in an operational situation.

TABLE 6

Effect of refertilization on height growth of one-year-old planted karri (assessed at two years)

Fertilizer	Control	"Magamp"	"Agras No. 1"	"Vigran 9:9:9"
Rate of application (g/tree)*	0	56	124	250
Height growth increment (cm)	108.2^{b}	104.0^{b}	106.3^{b}	124.3^{a}

* all application rates are equivalent to 10 g elemental P per tree.
Data notated with the same letter are not significantly different at $p = 0.1$ (Duncan's Multiple Range Test).

The limited cost-efficiency study indicates that either superphosphate plus urea at 63 g per seedling, or superphosphate plus "Agran 34" at 67 g per seedling are the optimum treatments. However, both combinations, especially superphosphate plus "Agran 34", produced significantly poorer growth than "Agras No. 1" at 63 g per plant. This study has not considered the labour costs of application, but as they are approximately $25 per ha (1980) for an application of 70 g per plant, the viability of treatment rates higher than this would decline considerably.

The timing and placement of fertilizer application are important because a moderately rapid uptake of nutrients is necessary for optimal growth. At the same time, it is essential to avoid root burn and the promotion of competing species (Woods, 1976). In this trial (using 126 g of "Agras No. 1") significant growth increases were gained by making a split application at P (time of planting) and P + four weeks. However, a single application at P + four weeks also produced acceptable growth rates, and would be more feasible operationally, than a split application. Applications at time of planting produced relatively poor growth, as did all applications at P + eight weeks.

The success of the P + four weeks application, at the beginning of spring, could be caused by increased root activity resulting from warmer soil temperatures, and by the emergence of the seedling from post-planting shock. This should make the plant more efficient in nutrient uptake. The failure of the application at planting may be due to volatilization of N, and leaching of N and P away from the plant, before active uptake of nutrients had begun.

The poor growth responses to the P + eight weeks application may have resulted from the plants' lack of nutrients at the beginning of the growing season, when they were recovering from post-planting shock. The P + eight weeks application was made after the growing season commenced. Woods (1976) observed a similar result with *Pinus radiata* (D. Don) seedlings.

The optimum place to apply fertilizer appeared to be in a shallow hole 10 cm upslope from the tree. However, differences between treatments were slight. Only the surface application 10 cm upslope from the seedling produced poor growth and unacceptable survival levels. This could be attributed to the fertilizer washing directly onto the seedlings, causing mortalities of seedlings by releasing large quantities of N ("Agras No. 1" contains 18 per cent N) near the base of the seedling.

No economic advantage can be seen in refertilizing one-year-old karri with any of the options tested. However, this should not preclude further research as the technique is used elsewhere in Australia (Woods, 1976).

CONCLUSION

It is evident that any application o fertilizer can improve the early growth o karri, while in most cases not significantly impairing plant survival.

For future karri plantings, an application of 63 g of "Agras No. 1" per seedling should ensure acceptable growth and survival. The fertilizer should be applied in one or two applications, at most four weeks after planting, in a shallow hole 10 cm upslope from the seedling. The hole should be covered to prevent wash and the excessive mortality of the karri seedlings which would result.

None of the options tested for refertilizing one-year-old karri plants produced any great increase in plant growth.

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