The Germination and Early Growth of Three Selected Plant Species on Mine Tailings from the Argyle Diamond Project.

A Report for Argyle Diamond Mines Pty Limited

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Introduction

Two types of tailings materials will be produced from the wet processing of Diamondiferous Alluvium and Kimberlite ore by Argyle Diamond Mines Pty Ltd. These materials will be dumped separately in tailings empoundments within the project area. Kimberlite tailings will comprise approximately 43% of processing plant feed and alluvial tailings about 40%. Over the life of the project far larger quantities of Kimberlite tailings will be produced, although there are no estimates of total tonnages or areas of land surface to be filled (Dames and Moore 1982).

The aim of the experiments reported herein was to determine the potential of the two tailings to support plant growth necessary for stabilisation. Three species which grew locally were selected for the trials, two native shrubs **Acacia tumida** and **A. retivenia**, and the naturalised exotic Buffel Grass **Cenchrus ciliaris**. The use of superphosphate at an application rate of 100 kg ha-1 on the tailings materials was also to be evaluated.

In addition to the pot trials a number of germination tests were carried out on the seeds of **Acacia tumida**, **A. retivenia** and **Cenchrus ciliaris**. These involved investigations of seed dormancy and optimal germination temperatures and provided estimates of seed viability. These experiments will be reported first.

Germination in Acacia tumida, A. retivenia and Cenchrus ciliaris.

General Methods

All germination tests were done in dark, controlled temperature growth cabinets including units set at 15°C, 20°C, 25°C, and 30°C. Seeds were germinated in petri dishes lined at the base with about 5 mm of moistened vermiculite covered with a large diameter thin filter paper and then a smaller diameter heavy filter paper on top of the thin one. Fifty seeds were normally placed on the smaller central filter paper. The petri-dishes were watered when necessary with de-ionised water.

Various experiments were undertaken to test seed dormancy and optimal germination temperatures. The following germination parameters were determined for all experimental treatments.

a) Final percentage germination ie $\frac{\text{No. seeds germinated}}{\text{No. seeds sown}} \times 100$
b) Days to 1st germination (germination was scored at 2 mm radicle emergence)
c) Days to 50% germination
d) Days to final percentage germination
e) Germination rate (mean days per germinant). This was calculated as follows:-

$$GR = \frac{N1T1 + N2T2 + \ldots\ldots N1T1}{\text{Total numbers of seeds germinated}}$$

where N1 is the number of seeds germinated on the ith day and Ti is the day number.

Also graphs showing the time course of germination for species and treatments in all experiments were plotted. The time course is represented by the cumulative germination percentage plotted against time (days).

Acacia tumida

Seed Dormancy 1. Exposure time to boiling water

Sets of 50 seeds of Acacia tumida were exposed to boiling water for 0, 10, 30, 60, 90, 120, 160, and 180 seconds. These were then incubated in petri dishes at 25°C and germination recorded at daily intervals. The results are shown in Table 1.

Table 1: The effect of exposure to boiling water on seed dormancy in Acacia tumida

Germination Measurement	Boiling Time (seconds)							
	0	10	30	60	90	120	160	180
1. Final % germination	0	90	92	100	100	100	100	100
2. Days to first germination	0	3	5	3	3	4	3	4
3. Days to 50% germination	0	8	7.3	6.5	6.3	6.6	6.5	6.5
4. Days to final germination	0	17	17	16	9	12	14	9
5. Germination rate (days)	0	8.4	8.15	7.08	6.54	7.68	7.06	6.8

Seed Dormancy 2. Exposure to different wet temperatures.

Seeds in lots of 50 were placed in test tubes of water held at room temperature (20°C) and in water baths set at 40, 50, 60, 70, 80, 90 and 100°C for 30 seconds. These were then placed in petri-dishes and incubated in a 30 °C temperature cabinet. Germinations were recorded daily.

The results are shown in Table 2.

Table 2: The effect of 30 seconds exposure to different water temperatures on seed dormancy in Acacia tumida.

Germination Measurement	Temperature of seed treatment (°C)							
	room	40	50	60	70	80	90	100
Final % germination	0	6	4	100	22	83	87	14
Days to first germination	0	12	16	9	10	10	4	6
Days to 50% germination	0	11.5	16	14.5	16	20.5	15.5	14
Days to final % germination	0	17	18	34	31	38	36	22
Germination rate (days)	0	13	17	16.5	16.7	19.1	17.2	15

Incubation temperatures for seed germination

Eight hundred seeds of **Acacia tumida** were treated by placement in boiling water for 120 seconds. Two hundred seeds in sets of four replicates of 50 were then placed in petri-dishes and each set placed in growth cabinets set at 15°C, 20°C, 25°C and 30 °C. Germinations were scored daily. The results shown in Table 3 are the means of the four replicates for each incubation temperature.

Table 3: The germination of **Acacia tumida** incubated at four temperatures.

Germination Measurement	Incubation Temperature (°C)			
	15	20	25	30
Final % germination	95	94	96	91.5
Days to first germination	8	6.7	7.0	7.0
Days to 50% germination	19.2	17.0	14.0	13.0
Days to final germination	26.2	24.2	24.5	22.7
Germination rate	17.54	15.87	13.84	12.94

Figure 1 shows the time course of germination at each temperature using the replicates which gave the highest final percentage germination.

Acacia retivenia

Seed Dormancy - Exposure time to boiling water.

Seeds of **Acacia retivenia** were sorted into eight sets of 50 and then one set was exposed to each of seven periods in boiling water, 10, 30, 60, 90, 120, 150 and 180 seconds. The eighth set was left as an untreated control. All seeds were sown into petri-dishes labelled with the exposure time and incubated in a 30 °C growth cabinet. Germination was recorded daily. The results are presented in Table 4.

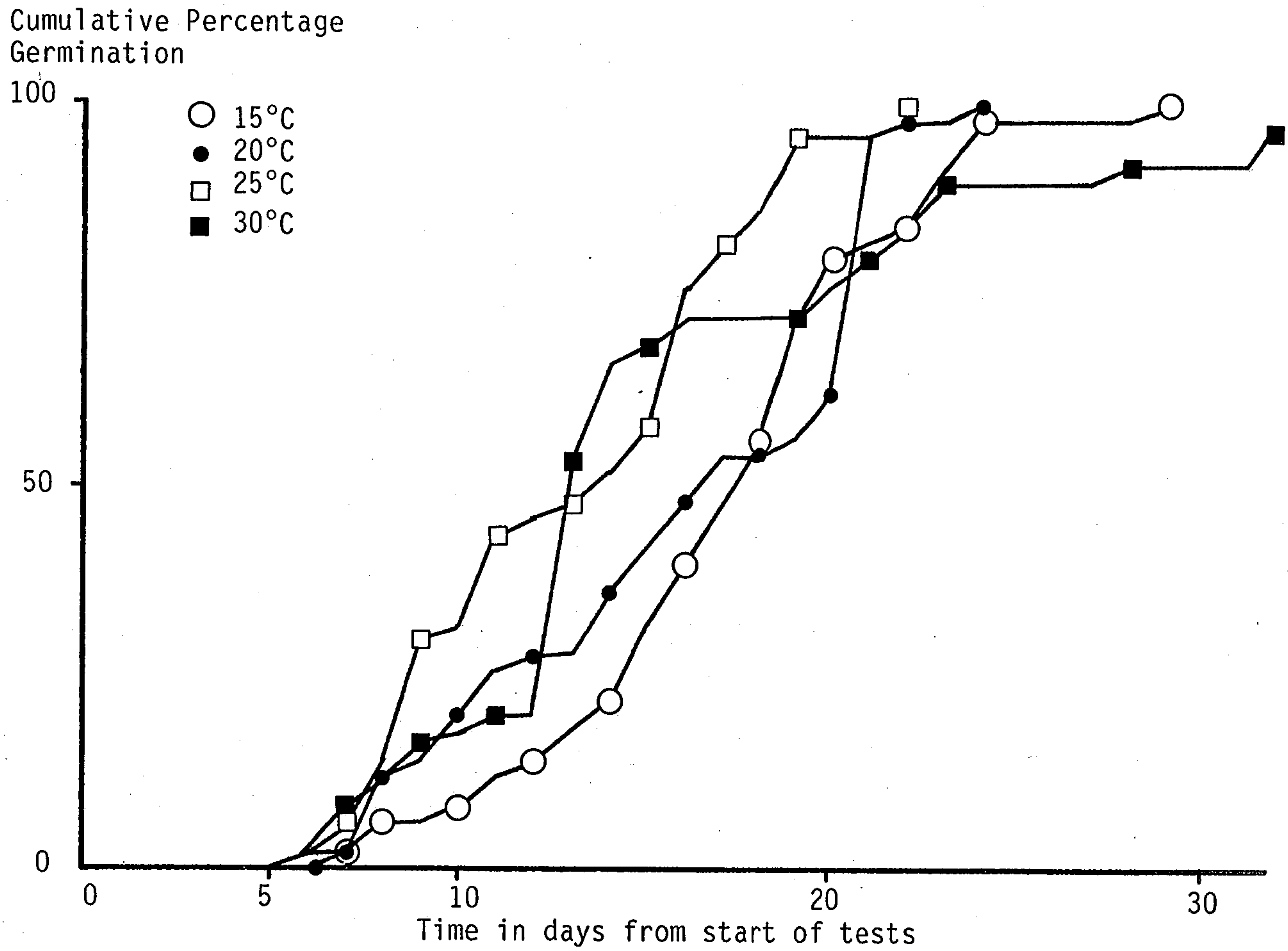

Figure 1. Time course of germination for Acacia tumida at 15, 20, 25 and 30°C, using that replicate at each temperature which gave the maximum percentage germination.

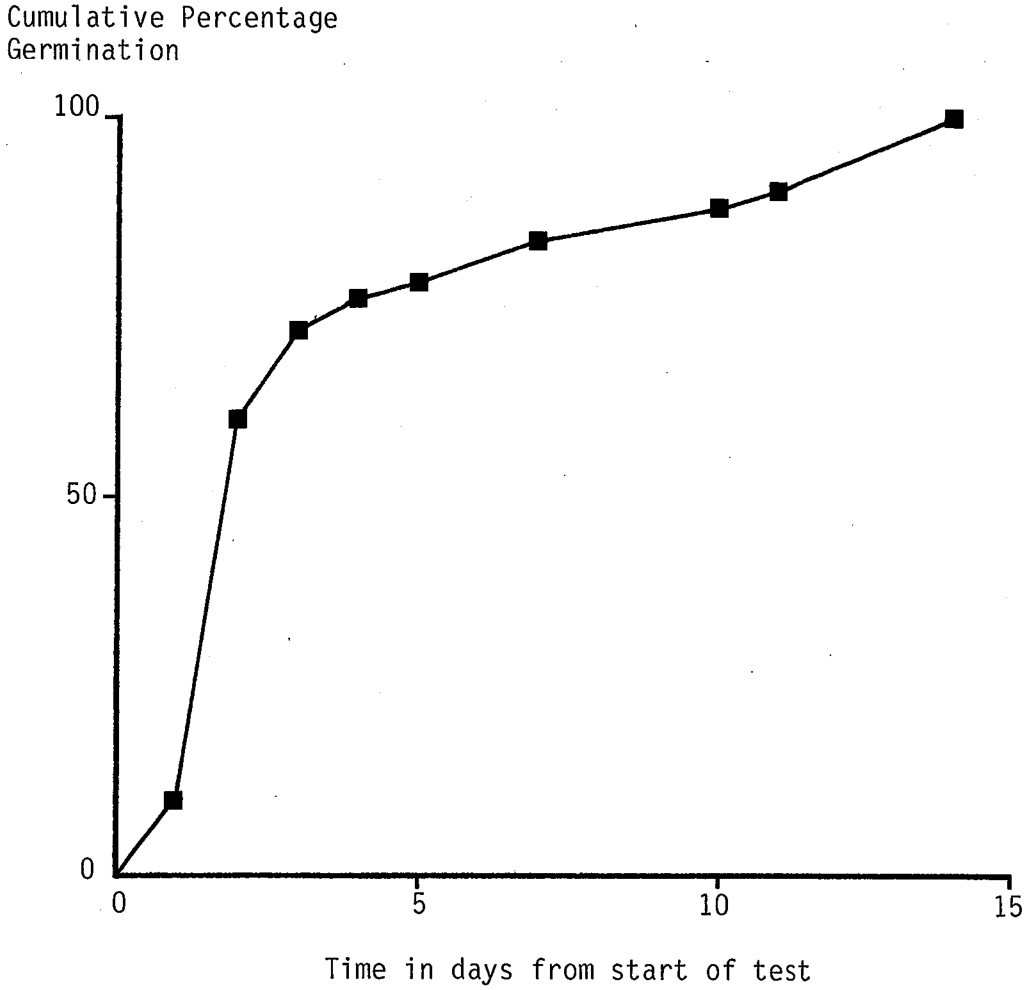

Figure 2. Time course of germination for *Acacia retivenia* at 30°C after exposing the seed to boiling water for 60 seconds.

Table 4: The effect of exposure to boiling water on seed dormancy in Acacia retivenia.

Germination Measurements	Control	Exposure times (seconds) 10	30	60	90	120	150	180
Final % germination	0	94	94	100	94	96	96	96
Days to first germination	0	1	1	1	1	1	1	1
Days to 50% germination	0	2	1	2	1	2	2	1
Days to final germination	0	3	4	14	8	4	7	3
Germination rate	0	1.68	1.49	4.0	1.49	1.56	1.92	1.44

Figure 2 shows the time course for germination in seeds exposed to boiling water for 60 seconds.

Cenchrus ciliaris

Fifty seeds of Cenchrus ciliaris were set up in petri-dishes and incubated at 15^{o}C, 20^{o}C, 25^{o}C and 30^{o}C. This experiment was replicated 3 times and the results shown in Table 5 are mean values.

Table 5: The germination of Cenchrus ciliaris incubated at four temperatures.

Germination Measurement	Incubation Temperatures (^{o}C) 15	20	25	30
Final % germination	48	78.6	85.3	86.8
Days to 1st germination	15	2	1	1
Days to 50% germination	19.5	20.0	21.0	21.0
Days to final % germination	31.3	31.3	33.3	36.3
Germination rate	18.78	15.70	16.38	17.45

Figure 3 shows the time course of germination at each temperature in the replicates showing the highest final percentage germinations.

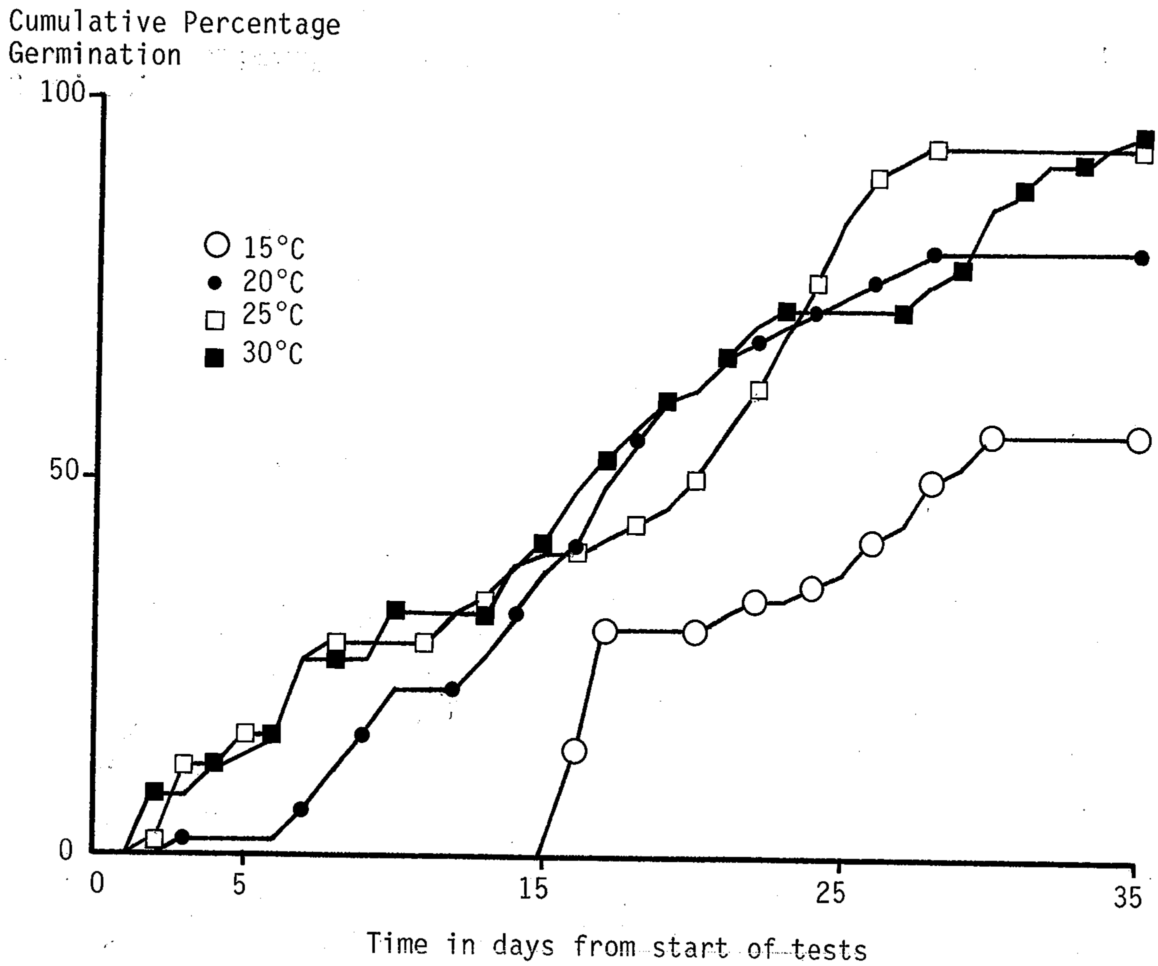

Figure 3. Time course of germination for Cenchrus ciliaris at 15, 20, 25 and 30°C, using that replicate at each temperature which gave the maximum percentage germination.

Discussion

All the species selected germinate well at the higher temperatures 25°C or 30°C although A. tumida also reached similar final percentage germinations at 15°C and 20°C, provided seed dormancy was broken.

There was no evidence of germination inhibition in Buffel Grass, Cenchrus ciliaris, but both the hard seeded legumes Acacia tumida and A. retivenia required treatment to break seed dormancy. In Acacia tumida 100 percent germination could be achieved by exposing the seed to boiling water from 60 to 180 seconds and over this range there were no significant differences in germination rate. Alternatively 100 percent germination was achieved by placing seed in water at 60 °C for 30 seconds. Germination rate increased with incubation temperature but optimum results in terms of rate and germination success would be achieved at 25°C.

The optimal treatment for Acacia retivenia was exposure to boiling water for 60 seconds. This gave 100 percent final percentage germination and the highest germination rate.

Germination and early growth on mine tailings from Alluvium and Kimberlite deposits.

Materials

Tailings materials were sent to W.A.I.T. as slurry in two 44 gallon drums. On arrival the fines had settled to the bottom of the drums which now contained about 80% water and the remainder tailings. Even when disturbed to decrease the bulk densities of these materials the amount available for experimentation was limited. This reduced the number of replicates below the number which had previously been planned for the experiments.

An analysis of the physical and chemical characteristics and of the macronutrients of the two tailings materials was carried out. The results are given in Table 6.

Table 6: Soil characteristics of Alluvial and Kimberlite tailings.

Tailings Property	Alluvium	Kimberlite
Soil texture	Sandy loam	Clay
Saturation percentage	29.8	47.5
pH	8.0	7.6
Conductivity ($M\Omega$ -1cm-1)	0.4	0.38
Organic matter (% loss on ignition)	1.8	4.1
Total N (%)	0.01	0.03
Extractable Elements		
Na(mg 100g)	5.0	6.0
K (mg 100g)	5.0	26.0
Ca(g 100g)	4.45	0.28

The tailings differ markedly in their physical properties with the Alluvium being a sandy loam, which compacts giving low penetrability, whereas the Kimberlite is a very heavy cracking clay. The Kimberlite has a high water holding capacity. Both materials are low in nitrogen but whilst the Kimberlite is relatively high in potassium the alluvium has a high calcium content. Though both materials are deficient in nutrients, the most serious impediments to plant growth were anticipated from the poor physical properties.

A control horticultural soil was prepared for the experiment which consisted of 70% leached medium to coarse sand and 30% cladium peat.

Because of the relatively high application rate of superphosphate it is was decided to use pots with a wide surface area, to prevent the concentration of fertiliser over a small area. The pots used were 165 mm in diameter and 155 mm in depth. Each pot contained about 50 mm depth of vermiculite at the base as an interface between watering trays and the soil. All pots were watered from beneath to prevent the seedlings being washed out and to prevent crusting in the Kimberlite. That is all soils were kept moist at the surface.

Methods

The experiment was set up in the roof-top glasshouse of the School of Biology, W.A.I.T. This glasshouse was covered with 50% shade cloth from January to April 1984. Enough tailings material was available to fill 24 pots with Kimberlite and Alluvium. The same number of pots were set up containing the horticultural control soil.

Pots were arranged in groups of 12 in metal watering trays, such that there were 2 trays of Kimberlite, Alluvium and Horticultural Control soils. One tray (12 pots) of each soil type was subjected to fertiliser treatment, each pot receiving the equivalent by surface area of 100 kg hectare of superphosphate. The remaining tray of pots of each soil type was not fertilised.

In each tray, fertilised and unfertilised, four replicate pots were sown with seed from each of the three selected plant species.

Seed of Acacia tumida and A. retivenia was placed in boiling water for 60 seconds to break dormancy. Five seeds were sown per pot, ie 20 per tray. Fifteen seeds of Cenchrus ciliaris were sown per pot (ie 60 per tray), these were scattered over the moist soil surface. Sowing of all species took place on the 11th January, 1984. This allowed germination during the warmest period in the year.

On 8th February, 1984, 28 days after the commencement of the experiment the number of germinants in each pot was scored, the height of each germinant was measured and the number of leaves was recorded (not including the cotyledons). At this point in those pots which had failed to produce Acacia seedlings, 2 seedlings 28 days in age were planted. Pots with no Buffel Grass were sown again with 15 seeds.

By June most of the Buffel Grass had 'headed' and the Acacia seedlings were beginning to die off due probably to the cold, humid conditions. All the plants from all the treatments were harvested on 4th July, 1984, 174 days after sowing. Plants from each pot were washed free of the soil to ensure all the root material was obtained. The plant matter (roots, stems and leaves) from each pot were placed in a labelled paper bag and dried in an oven at 60^{o}C for 7 days. The contents of the bags were then weighed to 0.001 g and expressed as total dry weight per pot.

Table 7: The number of germinated seedlings of Acacia retivenia, A. tumida and Cenchrus ciliaris on Standard Horticultural Soil with and without fertilisation as at 8th February, 1984 or day 28.

Plant Species	Pots 1	2	3	4	Total % emergence
<u>Unfertilised</u>					
Acacia retivenia	3	1	2	1	35
Acacia tumida	4	2	5	0	55
Cenchrus ciliaris	2	1	5	2	16.7
<u>Fertilised</u>					
Acacia retivenia	0	2	2	3	35
Acacia tumida	3	1	0	1	25
Cenchrus ciliaris	3	1	4	0	13.3

Table 8: The number of germinated seedlings of Acacia retivenia, A. tumida and Cenchrus ciliaris on Alluvium with and without fertilisation as at 8th February, 1984 or day 28.

Plant Species	Pots 1	2	3	4	Total % emergence
<u>Unfertilised</u>					
Acacia retivenia	0	1	1	0	10
Acacia tumida	1	0	0	1	10
Cenchrus ciliaris	0	0	2	0	3.3
<u>Fertilised</u>					
Acacia retivenia	1	0	1	0	10
Acacia tumida	0	0	0	0	0
Cenchrus ciliaris	3	3	1	4	25

Table 9: The number of germinated seedlings of Acacia retivenia, A. tumida and Cenchrus ciliaris on Kimberlite with and without fertilisation as at 8th February, 1984 or day 28.

Plant Species	Pots 1	2	3	4	Total % emergence
Unfertilised					
Acacia retivenia	0	2	1	2	25
Acacia tumida	4	2	4	1	55
Cenchrus ciliaris	9	7	13	15	73.3
Fertilised					
Acacia retivenia	0	1	2	0	15
Acacia tumida	2	3	4	1	50
Cenchrus ciliaris	12	12	9	12	75

Table 10: The total emergence of Acacia tumida A. retivenia and Cenchrus ciliaris seedlings on Alluvium, Kimberlite and Horticultural Control soils compared with 28 days percentage germination predicted from seed tests. Comparison is also made between unfertilised (U) and fertilised (F) treatments.

Plant Species	Expected % after 28 days	Total % seedling emergence Alluvium		Kimberlite		Control	
		U	F	U	F	U	F
Acacia tumida	100	10	10	25	15	35	35
Acacia retivenia	100	10	0	55	50	55	25
Cenchrus ciliaris	85	3.3	25	73.3	75	16.7	13.3

Table 11: Mean height of seedlings + s.d, mean number of leaves/phyllodes per seedling from four pots of Standard Horticultural Soil with and without the addition of fertiliser as at 8th February, 1984 or day 28.

Plant Species	Mean height of seedlings (mm)	Mean leaf/phyllode number
<u>Unfertilised</u>		
Acacia retivenia	36.85 ± 8.76	2.85
Acacia tumida	47.91 ± 9.38	2.54
Cenchrus ciliaris	129.20 ± 72.86	3.80
<u>Fertilised</u>		
Acacia retivenia	41.28 + 16.1	3.00
Acacia tumida	37.60 + 15.47	1.80
Cenchrus ciliaris	64.62 + 28.24	3.38

Table 12: Mean height of seedlings ± s.d., mean number of leaves/phyllodes per seedling from four pots of Alluvium, with and without the addition of fertiliser, as at 8th February, 1984 or day 28.

Plant Species	Mean height of seedlings (mm)	Mean leaf/ phyllode number
<u>Unfertilised</u>		
Acacia retivenia	31.5 ± 9.2	3.0
Acacia tumida	54.5 ± 0.7	2.0
Cenchrus ciliaris	30.05 ± 10.61	2.50
<u>Fertilised</u>		
Acacia retivenia	17.5 ± 10.61	2.50
Acacia tumida	0	0
Cenchrus ciliaris	37.0 ± 19.26	2.73

Table 13: Mean height of seedlings ± s.d., mean number of leaves/phyllodes per seedling from four pots of Kimberlite, with and without the addition of fertiliser, as at 8th February, 1984 or day 28.

Plant Species	Mean height of seedlings (mm)	Mean leaf/phyllode number
<u>Unfertilised</u>		
Acacia retivenia	15.20 ± 7.50	2.20
Acacia tumida	38.72 ± 15.41	2.18
Cenchrus ciliaris	74.34 ± 28.70	4.02
<u>Fertilised</u>		
Acacia retivenia	18.67 ± 4.16	2.67
Acacia tumida	36.70 ± 17.41	2.30
Cenchrus ciliaris	64.15 ± 39.05	3.34

Table 14: Total and mean dry weight production (g) of Acacia tumida, Acacia retivenia and Cenchrus ciliaris on fertilised and unfertilised alluvial tailings after 174 days.

Treatment	Replicates 1	2	3	4	Total D/W (g)	Mean D/W ± s.d (g)
<u>Unfertilized</u>						
Acacia tumida	0.11	0.04	0.11	0.10	0.36	0.09 ± 0.03
Acacia retivenia	0.14	0.07	0.05	0.14	0.40	0.10 ± 0.05
Cenchrus ciliaris	0	0.02	0.03	0.15	0.20	0.07 ± 0.07
<u>Fertilised</u>						
Acacia tumida	0.05	0.18	0.11	0.19	0.53	0.13 ± 0.06
Acacia retivenia	0.14	0.02	0.14	0.02	0.32	0.08 ± 0.07
Cenchrus ciliaris	0.19	0.10	0.11	0	0.41	0.13 ± 0.05

Table 15: Total and mean dry weight production (g) of *Acacia tumida*, *Acacia retivenia* and *Cenchrus ciliaris* on fertilised and unfertilised Kimberlite tailings after 174 days.

Treatment	Replicates 1	2	3	4	Total D/W (g)	Mean D/W ± s.d(g)
<u>Unfertilised</u>						
Acacia tumida	0.19	0.26	0.20	0.24	0.89	0.22 ± 0.03
Acacia retivenia	0.17	0.25	0.16	0.03	0.61	0.15 ± 0.09
Cenchrus ciliaris	0.49	2.68	2.69	3.31	9.17	2.29 ± 1.24
<u>Fertilised</u>						
Acacia tumida	0.05	0.19	0.36	0.19	0.79	0.02 ± 0.13
Acacia retivenia	0.14	0.11	0.06	0.07	0.38	0.09 ± 0.04
Cenchrus ciliaris	3.86	3.48	3.27	3.83	14.44	3.61 ± 0.28

Table 16: Total and mean dry weight production (g) of *Acacia tumida*, *Acacia retivenia* and *Cenchrus ciliaris* on fertilised and unfertilised Horticultural Control Soil after 174 days.

Treatment	Replicates 1	2	3	4	Total D/W (g)	Mean D/W ± s.d (g)
<u>Unfertilised</u>						
Acacia tumida	0.21	0.36	0.68	0.47	1.72	0.43 ± 0.19
Acacia retivenia	0.09	0.08	0.12	0.18	0.47	0.12 ± 0.04
Cenchrus ciliaris	0.23	4.22	3.74	7.07	15.26	3.82 ± 2.80
<u>Fertilised</u>						
Acacia tumida	0.06	0.01	0.01	0.01	0.09	0.02 ± 0.02
Acacia retivenia	0.03	0.04	0.05	0.07	0.24	0.05 ± 0.02
Cenchrus ciliaris	1.06	1.36	0.08	1.63	4.13	1.03 ± 0.68

Results

Seedling emergence

The number of seedlings which emerged in each pot after 28 days from fertilised and unfertilised Alluvium, Kimberlite and Horticultural Control soils is shown in tables 7,8,and 9. Table 10 compares the total percentage emergence of each plant species on each treatment with the expected percentage germination of each species based on the germination tests.

Percentage successful emergence (Total/expected x 100) ranges from 88.2 for **Cenchrus ciliaris** on fertilised Kimberlite to 0 for **Acacia retivenia** on fertilised alluvium. Seedling emergence was low for all treatments on Alluvium running at 10% in the **Acacias** except for **A. retivenia** in fertilised pots which failed to emerge at all. Emergence success of **Cenchrus ciliaris** on alluvium was markedly improved by fertiliser addition from about 4% to 29%.

Successful germination on Kimberlite ranged from 15% in **Acacia tumida** in fertilised pots to 88% in **Cenchrus ciliaris** in fertilised pots. Percentage emergence values were similar for unfertilised and fertilised treatments except in **Acacia tumida** which showed a marked reduction of success on fertilised Kimberlite. On the Horticultural Control soils percentage germination success varied from 13.3 for **Cenchrus ciliaris** in fertilised pots to 55 in **Acacia retivenia** in unfertilised pots. Fertiliser was probably toxic to **Acacia retivenia** on fertilised Horticultural Control Soil.

Growth

Tables 11, 12, and 13 give the mean height and mean number of leaves/phyllodes for seedlings of all three plant species after 28 days growth. On the Control Horticultural soil fertilisation had little effect on plant growth but reduced growth in Cenchrus ciliaris seedlings markedly.

On the Alluvium tailings however fertiliser reduced growth in the Acacias and marginally increased seedling height and development in Cenchrus ciliaris. The addition of fertiliser had little effect on plant growth on Kimberlite tailings.
Seedlings of Acacia retivenia developed most rapidly on the Horticultural Control soil and on the unfertilised alluvial tailings. Acacia tumida showed the best early seedling growth on unfertilised Alluvium but development was quite good on all soils/treatments except fertilised Alluvial tailings. The growth of Cenchrus ciliaris was good on the Horticultural Control soil and Kimberlite but poor on Alluvial tailings.

The total and mean dry weight production of the three plant species on Alluvial and Kimberlite tailings and on the Horticultural Control soils after 174 days are shown in Tables 14,15 and 16. Production was very low for all species on Alluvial tailings being marginally improved in Cenchrus ciliaris by the addition of fertiliser. On Kimberlite tailings there was good growth of Cenchrus ciliaris which was markedly improved by the addition of fertiliser. Acacia tumida production was poor by comparison with unfertilised control soil production. There were however no toxic effects from the fertiliser on Kimberlite tailings.

The highest dry weight production of bothCenchrus ciliaris and Acacia tumida was attained on unfertilised Horticultural Control Soil. Dry weight production was markedly reduced in all species when fertiliser was applied to this soil. This is the reverse of the trend for Cenchrus ciliaris on Kimberlite tailings.

Conclusions and Recommendations

Establishing Plant Cover on Alluvial Tailings

The alluvial tailings are a coarse sandy loam with low penetrability which resists root formation. They are also low in nutrients but the application of superphosphate at 100kg ha-1 is apparently toxic at least to the Acacia spp. No plant species tested grew satisfactorily on this material.

The Acacia species utilised do naturally occur on sandy loams but the low penetrability of these tailings is a major impediment to plant establishment. The possibility of discharging the fine alluvial tailings onto a bed of coarse tailings might improve the soil structure. If soil structure can be ameliorated then light applications of superphospate might also be beneficial.

Establishing Plant Cover on Kimberlite Tailings

This material will be subject in the long term to extreme seasonal changes, expanding when wet, contracting and cracking when dry. It is also low in nutrients.

Buffel grass Cenchrus ciliaris grows well on cracking clay soils. The addition of superphosphate at 100 kg ha-1 also beneficially affects plant production. The Acacias however are not suited to growing on this material. In the absence of legumes a nitrogen fertiliser such as urea might be used in the early stages of establishing plant cover. The seed of Buffel Grass might best be sown on wet tailings as soon as the surface is free of water.

Buffel grass is an introduced pasture grass and the use of native species on Kimberlite tailings could be explored further. Species from local cracking clay grassland such as **Dichanthium fecundum**, **Iseilema vaginiflorum**, **Heliotropium strigosum**, **Chrysopogon pallidus** and **Boerhavia** sp might be worth introducing (Dames and Moore 1982). Trees such as **Eucalyptus microtheca** and a Pilbara form of terete leaf mulga **Acacia aneura** are also able to survive under the severe seasonal conditions of cracking clay soils. The use of trees would help to dry the slimes after wet periods through transpiration.

REFERENCE

Dames and Moore (1982). Environment review and management programme ... Argyle Diamonds Project.

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