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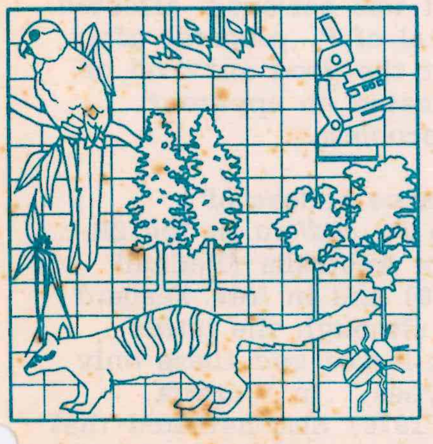

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Survival of *Pinus pinaster* Ait. seedlings on second rotation (2R) sites in Gnangara plantation north of Perth, Western Australia

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SUMMARY

Pinus pinaster Ait. seedling mortality on second rotation (2R) sites was a serious problem in Gnangara plantation north of Perth. Mortalities of up to 40 per cent were recorded. Three experiments were carried out to assess the effect of possible factors contributing to this poor survival, such as burning of logging slash, hydrophobic soils, poor nutrition, and furrow lining. Results indicated that burning the logging residue did not affect survival rates significantly. In Experiment 1 mortalities in burnt and unburnt (crushed) areas were 35 and 38 per cent respectively. With wetting agents and other soil amendments that are expected to improve the soil moisture status and reduce the hydrophobic character, there were no significant differences in survival, although mortality rates were reduced to 18 per cent (Experiment 3). Very low mortality rates (6 per cent) were recorded in Experiment 2 and furrow lining improved survival by 62.5 per cent.

INTRODUCTION

In Western Australia in 1984, exotic pine plantations managed by the Department of Conservation and Land Management (formerly Forests Department) covered an area of 57 000 ha. *Pinus radiata* D. Don, the major species, occupies about 30 000 ha, mainly on more fertile soils in the south-west of the State. *Pinus pinaster* Ait., second in importance to *P. radiata* in terms of total planted area, occupies over 27 000 ha on poor sandy soils of the coastal plain north of Perth and on the Harvey coast.

Some of the oldest stands of *P. pinaster* in W.A. are at Gnangara, north of Perth. The first *P. pinaster* plantations to be established at Gnangara were planted in the 1930's. Some of these have been clearfelled and replanted. About 600 ha of those stands still standing are now near or past the prescribed 30-year rotation.

Decline in productivity with successive rotations of *P. radiata* plantations was measured by Keeves (1966) in South Australia, who compared basal area growth of first rotation (1R) and second rotation (2R) radiata pine plantations on the same site: basal area growth on 2R sites where burning of the logging residue was practised, was consistently less (by about 30 per cent) than that obtained in the 1R. Consequently, studies were initiated in Western Australia in 1972 (Forests Department of Western Australia, unpublished data) to predict the magnitude of any 2R problems with *P. radiata* and *P. pinaster* before large areas of mature 1R stands became available for clearfelling. The aims were to compare the growth of successive rotations on the same site, and to determine whether altering the conditions (eg. thinning, burning or crushing the resulting residue, establishing a N fixing crop and heavy fertilization) of a mature stand during the final five years of the rotation would benefit the next crop. The experiment was seriously affected by poor survival of *P. pinaster* after replanting, but the good survival of *P. radiata* indicated no apparent establishment problem.

However, evidence of loss of productivity in *P. radiata* in the 2R was accruing in Australia (Bednall 1968; Muir 1970) and in New Zealand (Whyte 1973), although the latter measured small losses and these only on some soil types. In Victoria, Squire *et al.* (1979) demonstrated that first-year growth on unburnt 2R sites was substantially better than that on burnt/matched 1R sites. It was suggested that retention of the 1R litter and logging residue (i.e. mulching) improved early growth by increasing the availability of both water and nitrogen in the surface soil, and subsequent studies (Farrell *et al.* 1981) supported this hypothesis. In the same experiment, at age five years (Squire *et al.* 1985), comparisons of 1R and 2R growth on the same sites and on matched sites both showed that growth (height and volume) and survival were much better in the second rotation than in the first rotation.

The *P. pinaster* 2R establishment problem in Western Australia was evident during the 1974 summer. Mortalities of up to 40 per cent were recorded where site preparation involved burning 1R logging residue and disc ploughing between stump rows. In 1975 the surviving seedlings were removed and the area replanted. Again, high mortalities were registered in the following summer. Other small 2R areas replanted throughout the plantation also showed poor survival, and some had to be replanted several times to get the nominal stocking (2200 stems. ha^{-1}). A serious problem had therefore been identified.

Preliminary investigations indicated that neither weed competition nor allelopathy* (D. Bell**, personal communication) was likely to be involved in the survival problem. Also, frost damage is unlikely to have been an important factor in the poor 2R survival as suggested by Hall (1985): this problem occurred on unburnt (mulched) high altitude sites in N.S.W. According to meteorological records the frequency of frosts in the Gnangara area is less than one per year. Sampling for soil pathogens was carried out and showed no evidence of pathogens.

This paper reports the results of three experiments designed to assess the contribution of other factors (burning of logging residue, hydrophobic soils, poor nutrition and cultivation) to the poor survival of *P. pinaster* seedlings on 2R sites in Gnangara plantation.

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*. allelopathy is the interference of one plant with another through substances produced by the plant and released into the environment (Fisher 1980).

**. Dr. David Bell, Department of Botany, University of Western Australia, Nedlands, 6009, studied the effect of possible allelopathic substances from mature stands on young seedlings of both *P. pinaster* and *P. radiata*. The data showed no conclusive evidence of allelopathy.

MATERIALS AND METHODS

The experiments are located in the Gnangara plantation about 22 km north-east of Perth. The climate is typically Mediterranean (Gentilli 1972) and the annual rainfall for the Gnangara area is 810 mm (Butcher 1986). Frosts occur on average less than once per year (Bureau of Meteorology 1966). The soils are coastal sands belonging to the Bassendean dune system described in detail by McArthur and Bettenay (1960).

Experiment 1

The early Western Australian experiments used slash burning as the only site preparation treatment for 2R establishment. This experiment will, however, compare the long-term effects of burning and slash retention (unburnt), as well as assessing early survival and, therefore, complement the Victorian and South Australian 1R/2R comparisons. The study area comprised an unthinned section of a stand planted in 1952 at a spacing of 1.8 x 1.8 m. The area (4.8 ha) was severely affected by drought in 1977 in which the majority of trees perished. The dead trees were felled and left on the site, and in 1982 the remaining trees were clearfelled. Large amounts of slash covered the area. Burning or crushing slash were the major treatments, applied in a split-plot randomized block design as follows.

The major plots were 100 x 60 m each, with four replications. Two buffer rows surrounded every plot.

<u>Factor 1</u> - Site Preparation

(1) Crushing slash - The slash was crushed in March 1982 with a bulldozer fitted with a front rake to spread the debris. As the slash was dry and brittle, a crushing effect was easily

achieved by running the bulldozer over the plots.

(2) Burning slash - Slash was burnt in May 1982. A hot broadcast burn was effected, exposing bare soil in all the plots.

The minor plots were 60 x 25 m each, with two buffer rows surrounding every plot.

Factor 2 - Fertilizer (initial application in July 1982).

(1) P + N ('Agras') - 100 g. seedling^{-1} was broadcast on one side, 15 cm away from seedling, on the planting line.

(2) P (Superphosphate) - 60 g. seedling^{-1} was broadcast to a circle of 10 cm radius centred on the plant.

Factor 3 - Replication (Block) - four replications of the main treatments with the minor plots subdivided to give internal replications.

The entire experimental area was furrow lined at the end of June 1982, with a furrow line plough running between the old rows of stumps, to a depth of 10-15 cm. The aim of furrow lining is to create V-shaped trenches to concentrate moisture in the planting line. This is a standard procedure for planting 1R sites. When this type of site preparation technique was introduced, seedling survival improved greatly. Planting took place one week after furrow lining. The open-rooted seedlings were from orchard stock (S.N. 5096) and hand planting spears were used by a team of 12 workers planting at a daily rate of 1000 seedings.ha^{-1} with 3.6 x 2.5 m spacings. The depth of the planting hole was 20-30 cm and seedlings were firmed by heel pressure on one side. No rain fell at the site during planting time but two days after the completion of the operation 5.2 mm were recorded. The fertilizer was applied five days after planting. Periodic (monthly) visual assessments were carried out after planting and the first quantitative one was made in January 1983.

Experiment 2

On a crushed slash site, furrow lining removed the litter and slash (i.e. mulch) and exposed bare mineral soil in the furrow. This may have counteracted the mulching effect produced by crushing slash. The aim of this experiment was to determine whether furrow lining of crushed slash (with no burning) had a detrimental effect on the survival of 2R seedlings of *P. pinaster*. This 2R experiment encompassed 2.4 ha of a generally poor 44-year-old *P. pinaster* stand clearfelled in February 1983. Slash of diameter greater than 15 cm was removed from the site. The remaining slash was crushed twice with a Napier Land Conditioner in May 1983, to produce a uniform mulch.

The treatments applied in a split-plot randomized block design were:

Factor 1 - Site Preparation

(1) Furrow lining on crushed debris exposing bare mineral soil in May 1983.

(2) No furrow lining.

Factor 2 - Fertilizer - In July 1983, one week after planting

(1) P + N ('Agras') - 100 g. seedling^{-1} was placed in a slot approximately 15 cm away from the plant.

(2) P (Superphosphate) - 60 g. seedling^{-1} was placed in a spot application 10 cm to one side of the seedling.

There were thirteen blocks, each with two rows (one furrow lined and one not) and each row divided into two plots of 20 trees (one P + N and one P).

Planting was carried out in June 1983 at a spacing of 1.8 x 2 m using seed orchard stock (S.N. 8015). Only the most vigorous plants (average height 15-20 cm) with good fibrous root systems were used. One planter, working under strict supervision, carefully placed each seedling in a planting hole and then the soil was firmed by double spearing to ensure a tight soil-root contact on both sides of the original hole.

In September 1983 a wildfire destroyed two thirds of this experiment and as a consequence the experiment became statistically limited, so the entire experiment was repeated in the following year. This was done in the area immediately adjacent to the 1983 experiment. Several visual assessments were made and periodic quantitative survival assessments carried out. Heights were measured twice: first at planting time (June 1984) and again eight months later.

Experiment 3

Approximately 5 ha of a 40-year-old stand affected by a wildfire in October 1982 were clearfelled and the logging slash was heaped and burnt. The site was furrow lined in early June 1983. The aim of this experiment was to determine whether survival would be improved by treatments as listed, such as water absorbent gels, wetting agents, red mud, peat, to ameliorate soil moisture conditions, i.e. to test the hypothesis that the poor survival problem is caused by hydrophobic soils. Studies by Roberts and Carbon (1971) in Western Australia showed that hydrophobic zones in sandy soils occurred in unevenly distributed patches. Consequently single tree plots were used. A completely randomised experimental design was used comprising sixty replications of each treatment. Analysis of survival was done on non-contiguous plots of six trees.

The treatments were:

I - Soil mix - Seedlings were planted into a backfill soil treatment mix (20 x 20 x 20 cm), applied three weeks prior to planting.

(1) Local peat (5 soil:1 peat).
(2) Red mud (5 soil:1 red mud). Red mud is the fine fraction of the residue resulting from bauxite refining (Ward 1983).
(3) Red mud spread on the surface, 1 cm depth, lightly raked.
(4) Fly ash (5 soil: 1 fly ash). Fly ash is the residue from burning coal at a power station (Dames and Moore, unpublished report).
(5) Fly ash spread on the surface, 1 cm depth, lightly raked.
(6) Settling pond sediments (5 soil:1 sediment). These sediments are obtained from a water treatment plant and are commonly used in State Forest in firebreaks.
(7) Settling pond sediments spread on the surface, 1 cm depth, lightly raked.
(8) 3 g of 'Terrasorb 200'.
(9) 1 g of 'Terrasorb 600'.
(10) 3 g of 'Terrasorb 600'. 'Terrasorb 200' and 'Terrasorb 600' are products that absorb moisture.
(11) 8 g of 'Agrosoke'. This product also absorbs moisture.
(12) 1 g of 'Erosel' spread on the surface + 8 g of 'Agrosoke'. 'Erosel' is an anti soil erosion agent.
(13) 1 g of 'Erosel' spread on the surface.
(14) Control - backfill with no amendment.

(15) Control - light raking of surface.

II - Soil amendments mixed with water and spread at the bottom of the planting hole, applied at the time of planting.

(16) 3 g of 'Terrasorb 200'.
(17) 1 g of 'Terrasorb 600'.
(18) 3 g of 'Terrasorb 600'.
(19) 8 g of 'Agrosoke'.

III - Roots dipped into the following products, at the time of planting.

(20) Clay slurry (bentonite).
(22) 'Terrasorb 200' (2 $g.L^{-1}$).

IV - Transpirant retardant, sprayed on the foliage at time of planting.

(21) 'Acropol' diluted to 20 per cent in water.

V - Wetting agents applied by watering can to the soil surface of 1 m^2 at the rate of 5 $mL.m^{-2}$, diluted to 250 mL with water, three weeks prior to planting.

(23) 'Aquasoil'.
(24) 'Wettasoil'
(25) Combination of 'Wettasoil' and 'Terrasorb 200' root dip.

VI - (26) Control - no treatment.

Twenty-six seedlings formed a block and 10 blocks represented a replicate, with six replicates on the total experimental area. Each planting position was marked in the field with a plot peg placed in the centre of a 20 x 20 cm area where the seedling would be planted at the spacing of 1.8 x 2 m.

Planting took place at the end of July 1983, with stock (S.N. 8015) from the Mullaloo seed orchard. Rainfall occurred at the site during planting time. Each plant received 60 g of superphosphate in a spot application 10 cm from the stem, on the bottom of the furrow, at planting time. Several visual inspections and quantitative survival assessments were carried out. Height measurements were also taken initially on 5 September 1983 and finally on 1 February 1985.

RESULTS

Experiment 1
Widespread mortality of 37 per cent of seedlings occurred between November 1982 (4 months after planting) and February 1983 (Table 1). Analysis of variance showed no significant differences in mortalities between crushing and burning treatments. However, there were significant differences between the two fertilizer treatments.

Experiment 2.
Of the 230 seedlings that survived the 1983 fire, only 6 per cent were dead by the end of 1983-84 summer. Likewise, seedling survival was good (92-97 per cent) in the 1984 planting (Table 2). No significant differences between fertilizer treatments were observed in seedling mortality or height increments. However, there were significant differences between furrow lining and control, both in seedling mortality and height increments (furrow lining improved survival by 62.5 per cent but reduced height increment by 20 per cent).

TABLE 1

Effect on site preparation and fertilizer on seedling mortality during the first 6 months after planting *P. pinaster* in Experiment 1.

Treatment	Seedling Mortality (1)
Site Preparation	
crush	38^{a}
burn	35^{a}
Fertilizer	
P + N	43^{a}
P	31^{b}

Values not having a common letter are significantly different at $p \leqslant 0.001$.

(1) Percentage mortality in January 1983, transformed into arc sin square root values.

TABLE 2

Effect of site preparation and fertilizer on seedling mortality and height increment during the first 7 months after planting *P. pinaster* in Experiment 2.

TREATMENT	SEEDLING MORTALITY (1)	HEIGHT INCREMENT (cm)
Site preparation		
Furrow lined	3^{a}	8^{a}
Control	8^{b}	10^{b}
Fertilizer		
P + N	5^{a}	9^{a}
P	7^{a}	9^{a}

Values not having a common letter are significantly different at $p \leqslant 0.05$.

(1) Percentage mortality in February 85, transformed into arc sin square root values.

In contrast to the 1984 planting, in the 1983 planting (analysed not on plot average but on individual trees), furrow lining gave a slight (not significant) increase in height increment (1983-85), but again, differences between fertilizer treatments were not significant (Table 3).

Experiment 3
Frequent visual inspections and a quantitative survival assessment on 5 September 1983, indicated that all seedlings remained healthy until 1 November when three deaths and one unhealthy seedling (symptoms) were observed. In December some rainfall occurred and no further deaths were registered although a number of trees appeared unhealthy. However, on 16 January, deaths were occurring in all treatments and the total mean mortality rate was 11 per cent. On 1 February, the total mean mortality rate was 14 per cent. The mean mortality at the end of summer was 18 per cent. No significant differences in mortality rates (angular transformation) between different treatments were recorded. Height increments (1983-85) for the control treatments (14) and (15) were not significantly worse than those for other treatments, and control treatment (26) was only significantly different to treatments (21), (4) and (10) (Table 4).

TABLE 3

Effect of site preparation and fertilizer on height increment during the first 1.5 years after planting *P. pinaster* seedlings which survived the wildfire in 1983 in Experiment 2.

TREATMENT	HEIGHT INCREMENT (cm) [1]
Site Preparation	
Furrow lined	40[a]
Control	39[a]
Fertilizer	
P + N	40[a]
P	39[a]

Values with the same letter indicate difference not significant at $p \leqslant 0.05$.

(1) Height increment for the period 1983-85.

TABLE 4

Effect of moisture absorbent gels, wetting agents, red mud, and other soil amendments on heigh increments during the first 1.5 years after planting *P. pinaster* seedlings in Experiment 3.

TREATMENT	HEIGHT INCREMENT (cm) [1]
(21)	42.5 [a]
(4)	41.3 [ab]
(10)	40.5 [abc]
(23)	39.5 [abcd]
(11)	38.9 [abcd]
(14)	38.5 [abcd]
(19)	38.2 [abcd]
(1)	38.0 [abcd]
(6)	37.1 [abcd]
(18)	37.0 [abcd]
(15)	37.0 [abcd]
(12)	36.9 [abcd]
(17)	36.8 [abcd]
(5)	36.7 [abcd]
(9)	36.6 [bcd]
(25)	36.0 [bcd]
(3)	35.9 [bcd]
(13)	35.8 [bcd]
(22)	35.4 [bcd]
(16)	35.3 [bcd]
(8)	34.8 [cd]
(24)	33.9 [d]
(7)	33.7 [d]
(2)	33.5 [d]
(20)	33.4 [d]
(26)	33.4 [d]

Values with the same letter indicate no significant difference at $p < 0.05$.

(1) Differences between means were tested for significance by Duncan's multiple range test procedure.

DISCUSSION

In Experiment 1, the high mortality rates of 37 per cent were similar to those found in early Western Australian experiments where burning was the only treatment for 1R logging slash. Crushing slash was introduced as a treatment in Experiment 1, but did not significantly improve survival rates - mortalities on the two crush and burn slash treatments were 38 and 35 per cent respectively (Table 1). Significant differences in mortality rates (31 and 43 per cent between the two fertilizer treatments P and P + N) could be attributed, in part, to the toxic effect of N in 'Agras'. Woods (1976) reported that serious damage to the root systems of radiata pine seedlings could take place if direct root/N fertilizer contact occurred. In Experiment 1, placement of the N fertilizer (to one side of the seedling), not buried, may have caused some leaching of the fertilizer to the root systems. However, widespread deaths became apparent only in January 1983, and almost every seedling appeared healthy in the period immediately prior to its death. On excavation root growth was evident on both dead and live plants. Some dead seedlings had their roots curled up, although this was also observed in certain live plants. This root configuration suggests a poor planting technique.

In Experiment 2, very low mortality rates (6 per cent) were recorded in 1983 (original experiment) and in 1984. The fertilizer treatments had no significant effect on mortality rates and furrow lining improved survival by 62.5 per cent (Table 2). This improvement, although slight, is possibly related to a 'weed control' effect of furrow lining in addition to moisture concentration (Hopkins*, personal communication).

In Experiment 3, the application of a large number of treatments to improve the moisture status of the soil did not influence growth markedly (Table 4). Mean mortality at the end of summer was 18 per cent. It appears that the hydrophobic effects were not the cause of mortalities in Experiment 3. Also, at the time of application of treatments (soil mix with amendments) no hydrophobic areas were detected. Excavation of some dead and live plants showed some root development, but most of the dead seedlings had their root systems twisted upwards, indicating poor planting method.

Two experiments (Experiment 1 planted in 1982 and Experiment 2 planted in 1984) gave quite contrasting mortality rates (38 and 3 per cent respectively) for the same treatment, i.e. hand planting into furrow lined crushed slash. This mortality difference appears to be related, in part, to differences in rainfall patterns between years. In 1984 the distribution of rain during the winter months was even and late spring rains occurred, but in 1982 rainfall during winter was uneven and very little rain occurred in the spring/summer months. However, it also appears that the judicious selection of plants and the careful planting method may have strongly influenced the survival rates in Experiment 2. In Experiments 1 and 3, less attention paid to stock and poor planting techniques may have caused the seedlings to succumb when soil moisture became limiting at the surface, and the root systems were not able to explore the deeper soil horizons. Sands (1984) showed that air gaps at the root-soil interface (in transplanted *P. radiata* seedlings) caused water stress even in wet soil.

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*. Dr Eric Hopkins, Department of Conservation and Land Management, Como, 6152. W.A.

The seedlings only recovered from this water stress when new roots regenerated from the transplanted root system.

In Experiment 2, crushing slash (with no furrow lining) improved height growth by 25 per cent in the first year. Hall (1985), recorded consistently lower soil temperatures under mulch than in burnt or raked plots. In the furrow lines (bare soil), the higher soil temperatures in the summer period may have been detrimental to growth. However, in the second year, there was no difference between the two treatments (Table 3). This is possibly related to the levelling of the furrow with subsequent spreading of the mulch.

In Experiment 3 the mean height increments for most treatments and the controls were not significantly different. Other studies with water absorbent substances (Forests Department of Western Australia, unpublished data) also failed to show improvement in survival and growth with treatments.

CONCLUSION

There is no conclusive evidence from these experiments of the causes of the poor survival of *P. pinaster* seedlings in the second rotation on poor sandy soils in Western Australia. Burning slash did not affect mortalities significantly, nor did the fertilizer treatments. Wetting agents and other soil amendments to improve the moisture status of the soil and reduce the water repellent surface also did not affect survival significantly. Furrow lining improved survival in a generally low mortality area.

However, it appears from these experiments that attention should be paid to the possibly crucial importance of the planting method to improve establishment and survival during the first summer. Further work is planned to test this possibility as well as the selection of planting stock with fibrous root systems and general healthy appearance. Care must be taken during handling and transport of seedlings from the nursery to the planting site, to minimize moisture stress. Due to the presence of old rows of stumps on 2R sites, machine planting is difficult. Hand planting into unburnt logging slash is physically demanding and the risk of poor planting is high. Hand planting has to be carefully conducted so that no air gaps are present around the root systems of the transplanted seedlings.

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