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STIMULATION OF GERMINATION OF *ACACIA PULCHELLA*: LABORATORY BASIS FOR FOREST MANAGEMENT OPTIONS

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SUMMARY

(1) The leguminous shrub *Acacia pulchella* is a valued understorey species of jarrah (*Eucalyptus marginata*) forests in south-western Australia. It regenerates from buried seeds mainly after fire, which breaks seed dormancy.

(2) Experiments examined the effects on germination of five heating durations on *A. pulchella* seeds buried at five depths in two soil types kept dry or at field capacity.

(3) Mean germination of untreated seeds was only 4%, but germination was > 60% after temperatures reached 55–60 °C, with some seeds germinating after exposure to temperatures > 200 °C.

(4) Duration of heating, depth of seed burials, and soil moisture content all affected germination response to soil heating, but sand and gravel soils gave the same response.

INTRODUCTION

Acacia pulchella R.Br. (in W. T. Aiton) is a common understorey species of the jarrah (*Eucalyptus marginata* Donn ex Sm.) forest of Western Australia (Bell & Heddle 1989). Wildfires or prescribed burns occurring when the soil is dry, induce germination of buried seed, resulting in the establishment of dense stands of this short-lived leguminous shrub which can only regenerate from seed (Shea, McCormick & Portlock 1979). Legume germination and establishment occurs at very reduced levels with fires of low intensity and with moist soil conditions (Bell & Koch 1980; Bell, McCaw & Burrows 1989). Promotion of leguminous understorey shrubs at the expense of species susceptible to the jarrah forest dieback pathogen, *Phytophthora cinnamomi* Rands, is one of the objectives of the prescribed burning programme (Burrows 1985). Native legumes are important in the post-fire ecosystem because they increase nitrogen accumulation in the soil (Shea & Kitt 1976; Hansen *et al.* 1987), provide preferred habitat for endangered fauna such as the brush-tailed bettong (*Bettongia penicillata* (Gray 1837)) and Tammar wallaby (*Macropus eugenii* (Demarest, 1917)) (Christensen 1980), and favour litter-dwelling invertebrates (Postle, Majer & Bell 1986). Thus, an understanding of the germination ecology of the legumes of the jarrah forest in relation to fire is important in managing it. This paper describes two laboratory experiments to determine the effects of differing soil types, moisture levels and burial depths on the germination response of *Acacia pulchella* to simulated fire conditions.

MATERIALS AND METHODS

Heat effects in wet and dry sand and gravel

Simulated fire conditions were provided in asbestos boxes by infra-red gas heaters. The asbestos boxes measured 90 × 20 × 20 cm and were divided into two equal sections and lined with aluminium foil. Holes in the sides at depths of 0 (surface), 1, 4, 6 and 8 cm, each with an insulated section of glass tubing, provided access for thermocouple sensors for soil temperature measurement. The infra-red heater, suspended 15 cm above the soil surface, simulated the heat conditions of prescribed burns. Gravel and sand samples were collected from the forest in Holyoak block near Dwellingup, Western Australia (32°42′S, 116°08′E) and air dried. The soils were added to the trial boxes and 100 seeds carefully sprinkled in lines at five depths, 0, 1, 4, 6 and 8 cm. For each trial, one of the asbestos box sections was watered to field capacity while the other section remained dry. Replicate trials examined heating durations of 5, 10, 20, 30 and 40 min.

Soil temperatures during the trials were measured at 4-min intervals for 90 min beyond the 30-min heating period. Initial soil moisture contents were determined gravimetrically. After heat treatment, all soils were maintained near field capacity with daily waterings. Germination was recorded weekly until no further seedlings appeared. Statistical calculations were determined using the Statistical Package for the Social Sciences (Nie *et al.* 1970).

Field simulation trial

Information on the distribution of *Acacia pulchella* seed in the soil profile under natural conditions indicated that most seeds in gravel occur in the top 3 cm (Shea, McCormick & Portlock 1979; Majer 1982). However, in sandy soils, there is some indication that ants tend to bury seeds more deeply (Majer 1982). Duration times of eucalypt forest fires vary considerably depending on fuel characteristics. Leaf litter fuels are usually consumed within 1–3 min, but eucalypt logs may take several hours to burn (McArthur & Cheney 1966). Thirty minutes for small-wood burnout time in the jarrah forest is within the range observed and, from previous controlled measurements, seems to be an appropriate duration to simulate conditions most likely to occur in the field. We therefore carried out a further series of trials in which eighteen replicates, each of 100 seeds buried at 4 cm in wet and dry gravel, were heated for 30 min using the same experimental design as before.

RESULTS

Heat effects in wet and dry sand and gravel

At the time of the trials, the water contents (% ± S.D.) of the wet and dry gravels were 17·0 ± 4·1 and 5·0 ± 2·3%, respectively and of the wet and dry sands, 21·0 ± 2·4 and 3·4 ± 3·4%, repectively. Both soils had more ($P < 0{\cdot}05$) water at field capacity than when air dried, but the moisture levels of the two soils did not differ when air dried or at field capacity. Analysis of variance also indicated that the temperatures reached in the gravel soils were not significantly different from those in the sand soils. These similarities showed that the physical properties of the two soil types were not as different as first thought. Consequently, the data on the two soil types were used as replicates.

Combining the soil types for a three-way analysis of variance revealed highly significant main effects of soil depth ($P < 0{\cdot}001$), heating duration ($P < 0{\cdot}001$) and moisture level ($P < 0{\cdot}01$). There were also significant interactive effects of both soil depth and heating

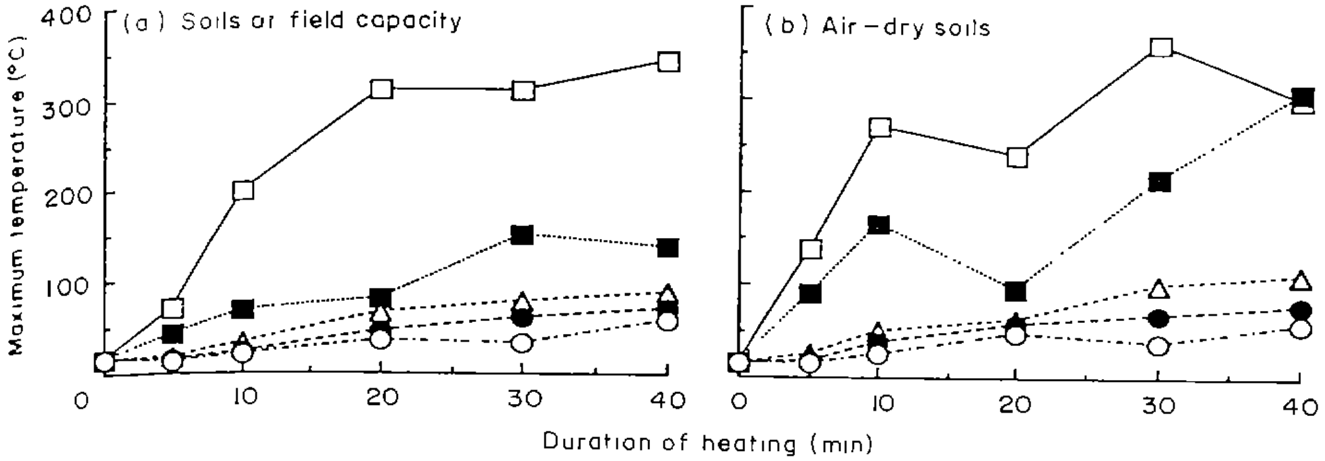

FIG. 1. Maximum temperature reached in (a) wet (field capacity) and (b) air-dry soils at different depths (surface □, 1 cm ■, 4 cm △, 6 cm ●, 8 cm ○) and with different periods of heating.

duration ($P<0{\cdot}001$) and depth and moisture level ($P<0{\cdot}01$), but not of heating duration and moisture condition. These significant interactions are of some concern, as they may indicate that the treatments were not entirely uniform.

In general, greater heating durations were required to reach comparable temperatures with increasing depth (Fig. 1). Moist soils tended to reach slightly lower temperatures than dry soils at comparable depths and heating periods. The most striking difference between the wet and dry soils was at 1 cm depth, with a less noticeable difference at 4 cm.

Germination of *Acacia pulchella* was generally poor with low heat intensities and durations, relatively high with some heat, but then decreased with the highest temperatures and longest heating periods (Fig. 2). Mean germination percentage for the unheated controls was 4·45 ± 4·39%. Germination was significantly affected by burial depth ($P<0{\cdot}001$) and heating duration ($P<0{\cdot}001$), but not by soil moisture levels. The only significant interaction was between burial depth and heating duration ($P<0{\cdot}001$).

No surface seeds germinated after heating for 40 min. However, the few seeds that germinated after 30 min of direct heating indicate that some *A. pulchella* seeds could, remarkably, survive temperatures up to 238 °C. The pattern of increasing then decreasing percentage germination for any particular heat duration or seed burial depth (Fig. 2) suggests that maximum germination percentages were reached when the combination of intensity and duration of heat was sufficient to break the dormancy induced by thick seed coats (Floyd 1976), but below levels which would damage the embryos. Critical levels for both processes were achieved earlier in dry soils.

Plotting percentage germination in all trials against the maximum temperature measured revealed that a critical temperature of approximately 60°C was required to induce a reasonable proportion of *A. pulchella* seeds to germinate (Fig. 3). Temperatures greater than 130°C appeared to approach the tolerance limits of the majority of seeds in *A. pulchella* seed cohorts.

Field simulation trial

After 30 min heating, the trial temperatures at the 4-cm depth averaged 67·1 ± 6·0 °C and 69·6 ± 5·3 °C for the wet and dry gravels, respectively. These were not statistically different by *t*-test, indicating that at the depths where most seeds occur in the field, soils reached comparable temperatures under air dry and field-capacity moisture conditions.

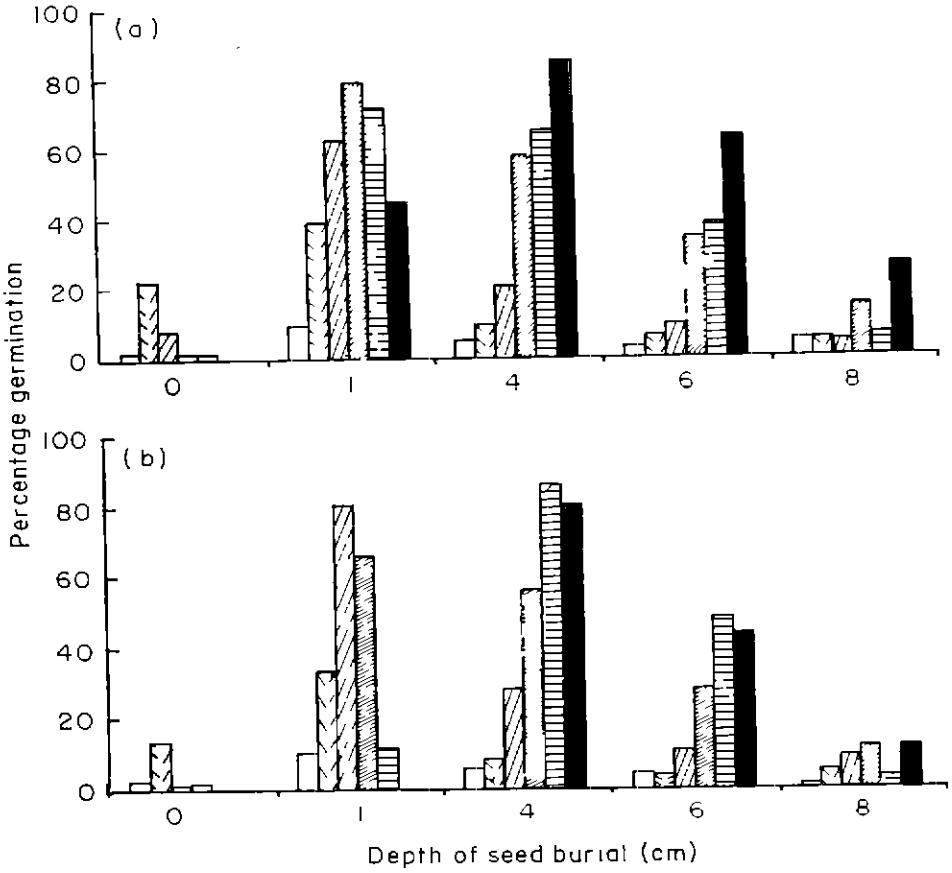

FIG. 2. Percentage germination of *Acacia pulchella* seeds buried at five depths in (a) soils at field capacity and (b) air-dry soils after heating for 0 (□), 5 (▧), 10 (▨), 20 (▩), 30 (▤) and 40 (■) min.

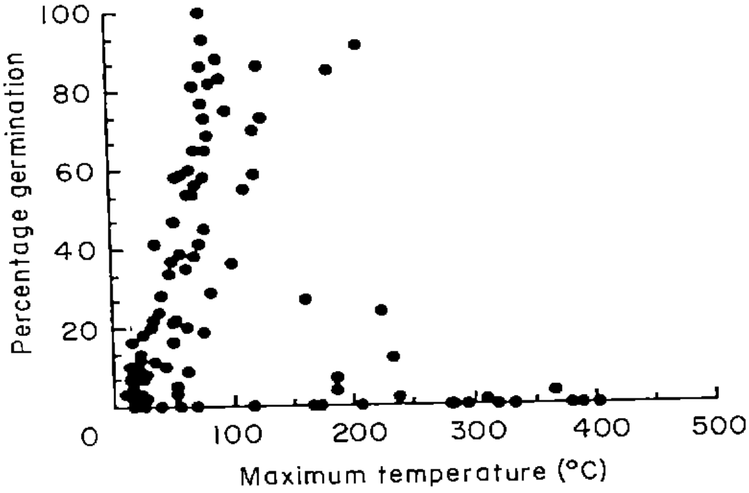

FIG. 3. Pattern of germination response to maximum temperature reached in all trials.

However, germination was higher in the dry soil (48·4 ± 9·5%) than the wet (32·3 ± 14·9%) ($P < 0·001$).

DISCUSSION

Dormancy induced by water-impermeable seed coats is common in the Leguminosae (Rolston 1978). In the jarrah forest this type of dormancy confers great longevity on leguminous seeds. The most important natural agent for breaking dormancy from hard seed coats is heat from fire or insolation (Stone & Juhren 1951; Rolston 1978; Sabiiti & Wein 1987). However, living cells of higher plants cannot normally withstand high temperatures outside a precise physiological range (Steponkus 1982). Thus, temperatures high enough and exposures long enough to remove the seed coat impermeability may lead to deterioration of seed vigour or even to embryo death. *Acacia pulchella* appears to require temperatures of 55–60 °C to induce significant germination, but temperatures above 135 °C generally prove detrimental. These temperatures were achieved more rapidly in dry soils. The temperatures we found necessary to induce germination in *A. pulchella* are similar to those for *Rhus javanica*, a pioneer tree species of temperate Japan, which is especially common in burnt forests (Washitani 1988). They were also similar to the 140 °C for up to 10 min tolerated by dry seeds of *A. cyclops* (Jones 1963).

Shea, McCormick & Portland (1979) reported that germination by *A. pulchella* after high intensity jarrah forest fire was generally from depths greater than 3 cm, although Majer (1982) found that most of the seeds occur in the upper 3 cm of soil. It is now apparent that the lack of germination in the surface 1–2 cm of soil was probably due to over-heating. Very high intensity autumn fires can reach 140 °C at 2 cm (Shea, McCormick & Portland 1979). With dry soil, low humidity, and high air temperatures and wind speeds, forest fires above 500 kW m^{-1} would probably result in major losses of seed in surface soil. Prescribed fires in autumn, however, can be of much lower intensity, and McCaw (1989) recently reported that *A. pulchella* germination was stimulated in an autumn fire of less than 350 kW m^{-1}. Our study has shown that intensities of about 100–250 kW m^{-1} would result in appropriately raised soil temperatures to maximize subsequent *A. pulchella* populations. Soil heating has close links with the quantity of fuel consumed (McCaw & Burrows 1989), but correlations are affected strongly by weather conditions. However, we cannot currently explain why greater germination resulted from heating dry soils than wet soils to comparable temperatures. Therefore, further information is required before prescribed fires can be tailored to induce maximum numbers of legumes in managed jarrah forests.

The additional nitrogen fixed by understorey stands of native legumes, promoted by appropriate burning and timber thinning treatments, could be enough to increase the growth of jarrah by 10–25% (Hansen, Stoneman & Bell 1988). *A. pulchella* is the understorey species which fixes nitrogen most actively and which could thus most benefit the productivity of the jarrah forest. Similar trials on other common jarrah forest legumes could enhance the basis for suitable fire management. Appropriate fire conditions would favour the important legume species over more *Phytophthora*-sensitive species, increase the richness, diversity and heterogeneity of the forest, and protect forest values.

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