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JARRAH DIEBACK— SOIL TEMPERATURE AND MOISTURE REGIMES OF SOME SOUTHERN FOREST TYPES

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SUMMARY

Soil temperature and soil moisture studies were carried out in the southern forests of the south-west of Western Australia to determine when conditions occur that favour the spread of jarrah dieback. It was found that favourable soil temperature and soil moisture conditions for zoospore infection and spread of dieback rarely occurred on well-drained sites in southern forest areas. Results suggest that it is only in moist gullies, swamp edges and similar situations, where soil moisture is maintained by ground water, that infection and spread by this means could occur.

The effect of ground cover and soil type on the length of the susceptible period was also examined, and results showed that soil cover influenced soil moisture and soil temperature. Removal of canopy, scrub or litter cover could increase moistness of the soil and cause soil temperatures to rise above the critical level earlier in spring, lengthening the period of susceptibility on moist sites.

Both felling operations and fuel reduction by burning may thus extend the period of susceptibility on susceptible sites, or cause previously unsusceptible sites to become susceptible.

JARRAH DIEBACK—SOIL TEMPERATURE AND MOISTURE REGIMES OF SOME SOUTHERN FOREST TYPES

(Original manuscript submitted for publication February 1971)

INTRODUCTION

Jarrah dieback is a root disease of jarrah (*Eucalyptus marginata* Sm.) caused by the fungus *Phytophthora cinnamomi* Rands. The pathogen has a great many hosts amongst the native vegetation, but has become significant as a forest disease in Western Australia largely because of the importance of jarrah, a major timber species. It has the ability to cause broadscale killing of jarrah on some sites (Podger, 1968).

Zoospores are considered to be the main agent of spread and infection. Soil temperature and soil moisture affect sporulation and zoospore motility, and are thus two important limiting factors in the spread of the disease.

Soil temperature and soil moisture studies have been carried out in the northern jarrah forest environment (Shea, 1975). Since the climate in the southern forests (Fig. 1) is considerably cooler and moister, a separate study was considered necessary.

Chee and Newhook (1965) have established the critical temperature limits for vegetative growth and sporulation of *P. cinnamomi*. Optimum mycelial growth occurs between 26°C and 28°C, and growth is slow below 12°C. Sporangium (i.e. zoospore) production is prolific between 22°C and 28°C, and negligible below 15°C. Kuhlman (1964) found that infection did not occur below 15°C, and was only one third as frequent at 15°C as at 20, 25 and 30°C.

Hine *et al.* (1964), in their investigations on root rot of pineapple, demonstrated the effect of fluctuating temperature on disease development. They found there was only 50 per cent root destruction when soil temperature alternated between 19°C and 36°C in 12 hour regimes for one month. One hundred per cent root destruction occurred when soil temperature was kept steady at 19°C.

Roth and Kuhlman (1966) summarized current knowledge on the effect of soil moisture on pathogenicity. They postulated two thresholds, namely "soil saturation", which provides the stimulus for sporulation, and "field capacity", which allows spore migration and infection.

From the foregoing evidence, it seems reasonable to assume that two conditions must be fulfilled for zoospore infection to occur. Soil temperatures must be above 15°C to allow sporulation, and soil moisture content has to be at field capacity or above to enable zoospores to migrate. The aim of this study was to determine when these conditions occur. The effects of ground cover and soil type on the length of susceptible period were also considered.

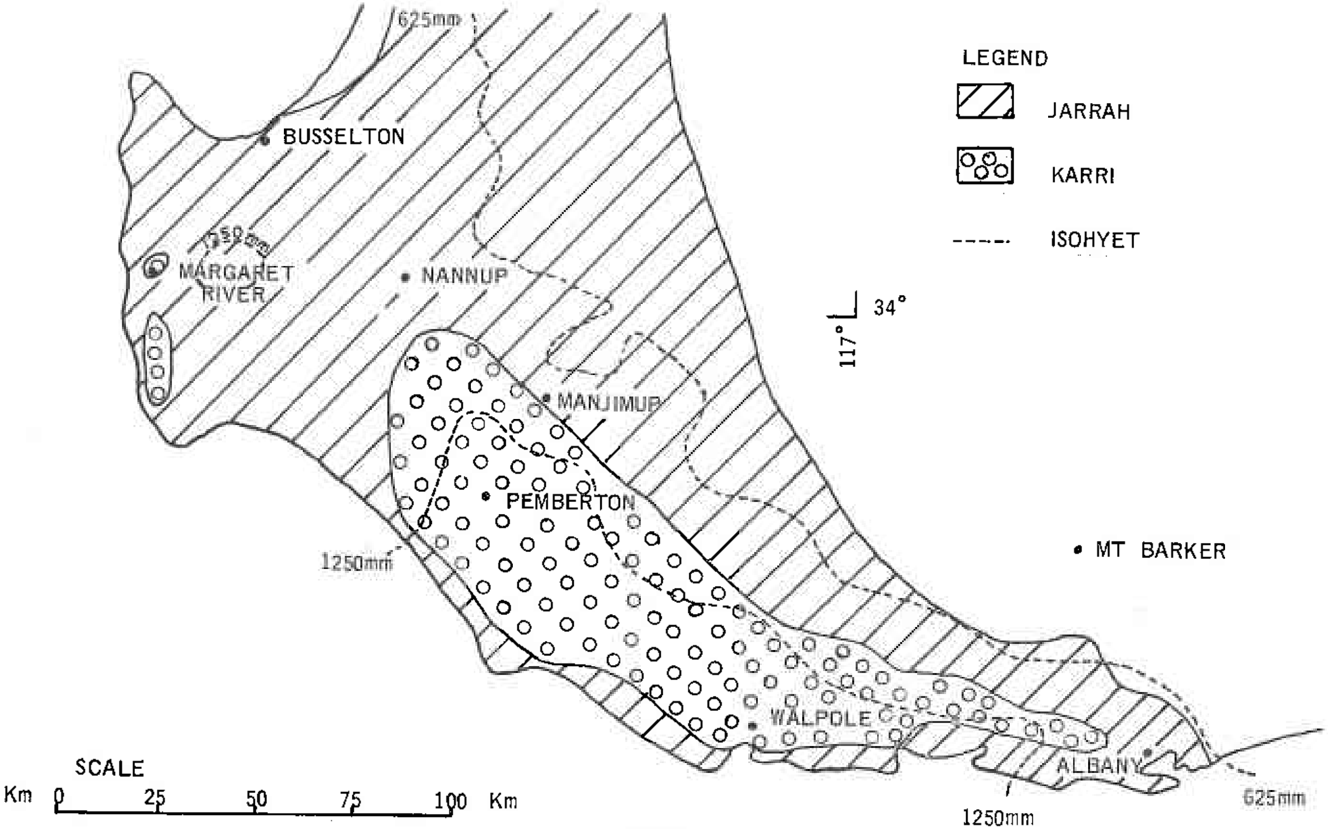


Figure 1
The major forest formations of the south of south-west Australia.

SOIL TEMPERATURE AND SOIL MOISTURE REGIMES ON A RANGE OF SITES

Method

Eight sites were selected for study within a 312 ha block of prime, southern jarrah forest, 31 km west of Manjimup. Only four sites, representing the widest range of conditions, will be considered here. These sites are arranged in pairs representing open and closed canopy on moist gully sites and dry hillside situations.

Site S1 was situated on the lower slopes of a valley in a pocket of karri (*Eucalyptus diversicolor* F. Muell.) forest. The understorey vegetation consisted primarily of hazel (*Trymalium spathulatum* (Labill.) Ostf.), 5 to 6 m in height. The soil was a deep, red loam, covered in a layer of litter 50 to 75 mm in depth. The site was fully shaded by both the overstorey tree cover and the understorey.

Site S2 was situated on the lower slopes of a valley in jarrah forest. Little understorey scrub was present, since the site was on the edge of an old mill landing. The soil was lateritic gravel, commonly associated with jarrah forest. The site was almost completely exposed.

Site G1 was situated in a gully head in jarrah forest. The understorey vegetation consisted mainly of blackboy (*Xanthorrhoea preissii* Endl.). The soil was a red, clay loam. This site was heavily shaded.

Site G2 was situated in a gully head which appeared to be identical to that of Site G1. However, the area and surrounds had been logged, so the forest was comparatively open.

Further data for these sites are shown in Table 1.

TABLE 1

Data on tree cover and soils for the four sites

Site	Tree Cover		Soil		
	m^2/ha	% Crown Cover	% Stones over 7 mm diam.	% M.C. at 75 mm at wilting point	% M.C. at 75 mm at field capacity
S1	27·6	100	15	20·2	41·2
S2	20·7	39	52	7·8	19·5
G1	36·8	77	3	14·9	41·2
G2	23·0	30	2	15·2	40 (approx.)

M.C. = Moisture Content.

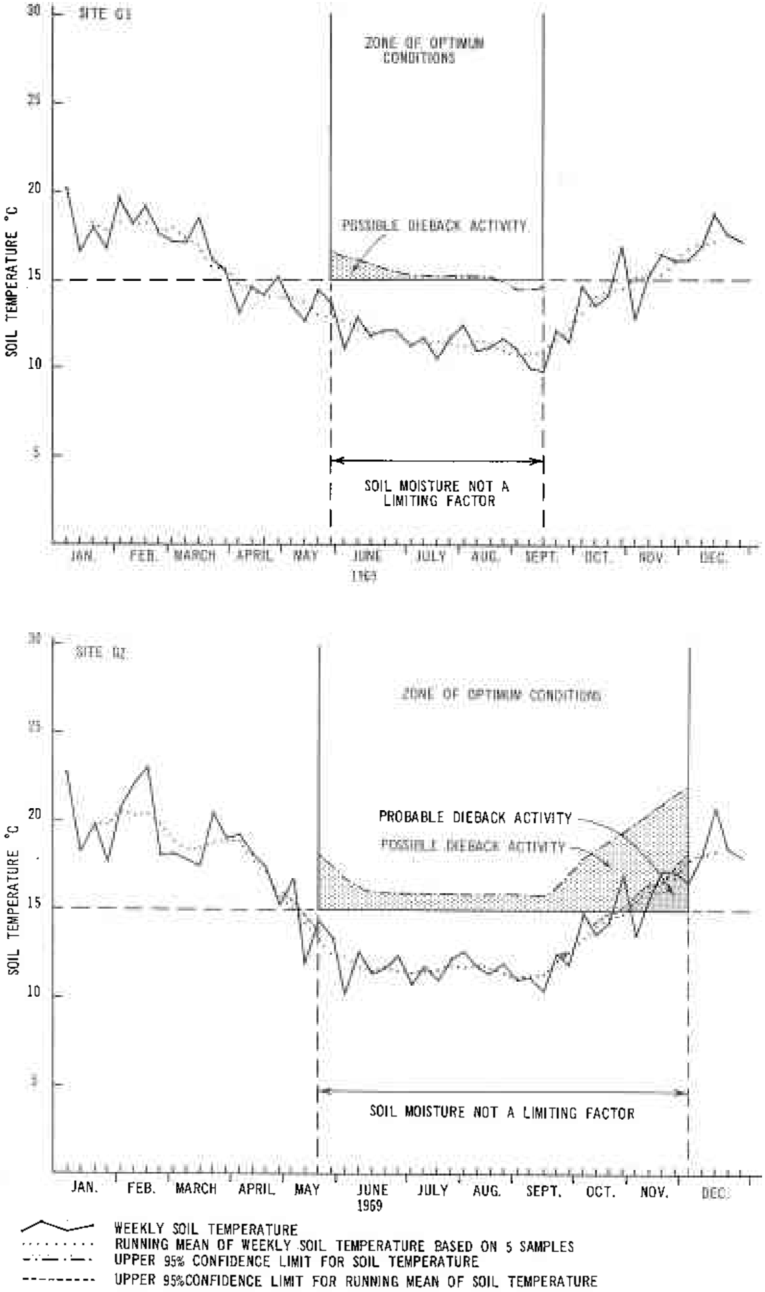


Figure 2

Weekly soil temperature and moisture at 75 mm depth at 10.0 a.m. on moist, gully sites.

Stevenson screens, containing soil thermographs to record temperature at 75 mm depth, were installed on Sites S1 and G1. A soil thermometer, located at random, was installed on each of the four sites. The soil thermometers were read at 10 a.m. and 3 p.m. once each week. In addition, and at the same times, further soil temperatures were recorded using three Teltru thermometers pushed into the soil at random points within a 20 x 30 m plot on each site. The charts in the thermographs were changed, and a soil sample, consisting of eight sub-samples taken at 75 mm depth, was collected for soil moisture analysis. Information not presented here indicates that, on the soils studied, soil moisture observations at 75 mm depth may be applicable to depths of up to 750 mm.

The main experiment was carried on for a period of just over one year, from 9 December 1968 to 2 February 1970. However, since 1969 was an exceptionally dry year (Manjimup, with a mean annual rainfall of 1 050 mm, recorded only 681 mm), it was decided to repeat the observations. Recording of soil temperatures and soil moisture sampling were therefore repeated over the period 7 September 1970 to 23 November 1970, the most critical time of the year.

Results

The soil temperature and soil moisture regimes over the period of one year on the four sites are illustrated in Figures 2 and 3. The data were obtained from the weekly soil thermometer and Teltru readings. Comparison of continuous recording of soil temperatures by thermograph with intermittent measurements by fixed soil thermometers and moving Teltru thermometers indicated that the three sets of observations were analogous. Weekly fluctuations were reduced by plotting the running mean of successive series of five readings. Both the actual readings and the running mean are shown on the graphs. Where critical, their 95 per cent confidence limits are also shown. A line indicating limiting soil moisture conditions (field capacity) represents the lower limit of the 95 per cent confidence limit on moisture. These temperature and moisture limits have been used to indicate periods of possible and probable dieback activity.

Field capacity was taken as the mean soil moisture percentage over the period 15 June to 31 August. During this period, soil moisture is predominantly at field capacity, fluctuating above and below for brief periods according to the incidence of rainfall. Site G2 was exceptional, as this site was under water or permanently saturated during the winter months. Since it was impossible to determine field capacity for this site, it was taken to be similar to that of the other gully site, Site G1, which had an almost identical soil type.

Conditions did not favour *P. cinnamomi* zoospore activity on any of the sites during the summer months, soil moisture conditions being unsuitable. By the time soil moisture had reached field capacity, following the autumn rains, soil temperature on all sites had dropped below 15°C. On only one site, G2, was soil moisture still at field capacity by the time the temperature had reached the 15°C limit in spring. On this site there was a period totalling some five weeks during which conditions remained suited to zoospore activity. If, however, we interpret the data to its extreme (the 95% confidence limit on

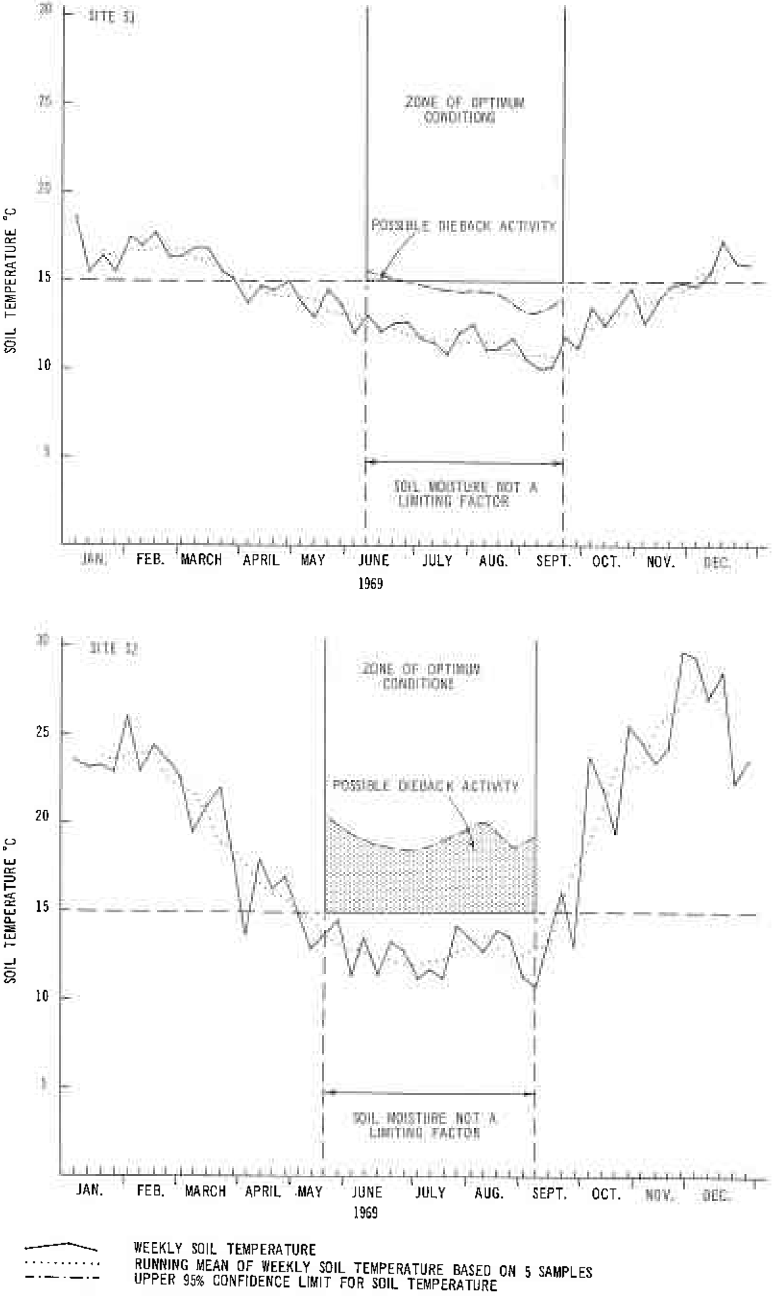


Figure 3

Weekly soil temperature and moisture at 75 mm depth at 10.0 a.m. on dry, hillside sites.

soil temperature), it is possible that short periods of suitable conditions may occur sporadically throughout the winter months on Sites G2 and S2. The other two sites, G1 and S1, even under this extreme interpretation, present little opportunity for zoospore activity.

No soil moisture data are available for Site G2 before felling took place. No valid comparison of the effects of felling on the soil moisture regime is therefore possible, although the two gully sites were similar in all respects except tree cover. The soil on Site G2 remained above field capacity for a period of 11 weeks longer than on Site G1. It seems that at least part of this difference was due to the reduction in tree cover on Site G2. Felling therefore appears to have been at least partly responsible for creating conditions suitable for zoospore activity on Site G2. Similarly, the reduction in both crown cover and ground cover caused by logging appears responsible for the creation of a marginal opportunity for zoospore activity on the landing, Site S2.

These results are not entirely in agreement with field observation, because dieback has been isolated from some apparently well-drained and undisturbed sites in the lower south-west. However, few of these sites have been seriously affected to date.

A glance at Figures 2 and 3 makes it clear that the temperature curves are markedly affected by ground cover. The temperatures under the dense canopy and litter on Site S1 remained fairly low and remarkably steady. Those on the open site, Site S2, rose very steeply in early spring and fluctuated markedly. This is less evident on the other open site, Site G2, where the ground had a fairly dense cover of herbaceous species.

Had Sites S1 and S2 been poorly drained, soil temperature would have greatly influenced the duration of their period of susceptibility. The soil temperatures on Site S2, the open site, rose above the 15°C limit in mid September, whereas those on site S1 with closed canopy did not reach this level till 12 weeks later, at the beginning of December.

In view of the apparent important effect of soil temperature on the duration of the susceptible period, a further set of trials was initiated to obtain more precise data on this aspect.

THE EFFECT OF GROUND COVER AND SOIL TYPE ON SOIL TEMPERATURE

Method

Two sites, both situated on relatively flat terrain but very different edaphically and ecologically, were selected.

(1) The Strickland Road Site, situated 31 km west of Manjimup, was a jarrah site on a lateritic gravel soil with an understorey of *Acacia lateriticola* B. R. Maslin and a 50 mm litter layer.

(2) The Pine Creek Site, situated 26 km west of Manjimup, was a karri site on a red, clayey loam with an understorey of netic (*Bossiaea laidlawiana* Tovey and Morris) and *Casuarina decussata* Benth. with a 75 mm litter layer.

On each site, three, 0.2 ha blocks were selected for study:

(i) An open area with no canopy, vegetation or litter, situated on an old landing.

(ii) A partially shaded area with canopy of 60-70 per cent, vegetation and litter removed.

(iii) A fully shaded area with canopy of 60-70 per cent, understorey retained.

During the period 7 September 1970 to 23 November 1970, soil temperatures at 75 mm depth were recorded weekly at 10 a.m., using three Teltru thermometers on each of five, one-metre-square plots per block.

Since it was difficult to obtain fully uniform conditions on separate blocks under field trial conditions, a small supplementary trial was set up at the Manjimup Research Station. By this means, it was possible to standardize shade, soil cover and soil type on a number of small plots, so that a more direct comparison of the relative effects of these factors on soil temperature was possible.

Three different soils, a red clayey karri loam, a lateritic gravel and a grey sand, were laid out 0.3 m apart in parallel beds 9 m in length, one metre in width and 0.3 m in depth. One third of each bed received heavy shade, one third light shade, and the remainder was unshaded. In turn, one third of each shade treatment received heavy litter treatment, one third light litter treatment, and the remainder no treatment.

Flywire screens were used to give light shade. The heavy shade treatment was provided by a thin layer of gravel on the screens, thus achieving full shade without impeding rainfall. The litter used was karri leaf litter, 75 to 100 mm in depth for the heavy treatment and 25 to 50 mm in depth for the light treatment. Thus one square metre of each soil received one of the nine possible combinations of shade and litter.

Soil temperatures were recorded at 75 mm depth at 10 a.m. and 3 p.m. using three Teltru thermometers per plot. Readings were taken on both fine and overcast days during spring, so as to determine the relative effects of the different factors under different weather conditions. Three thermographs kept continuous records of soil temperature on selected plots.

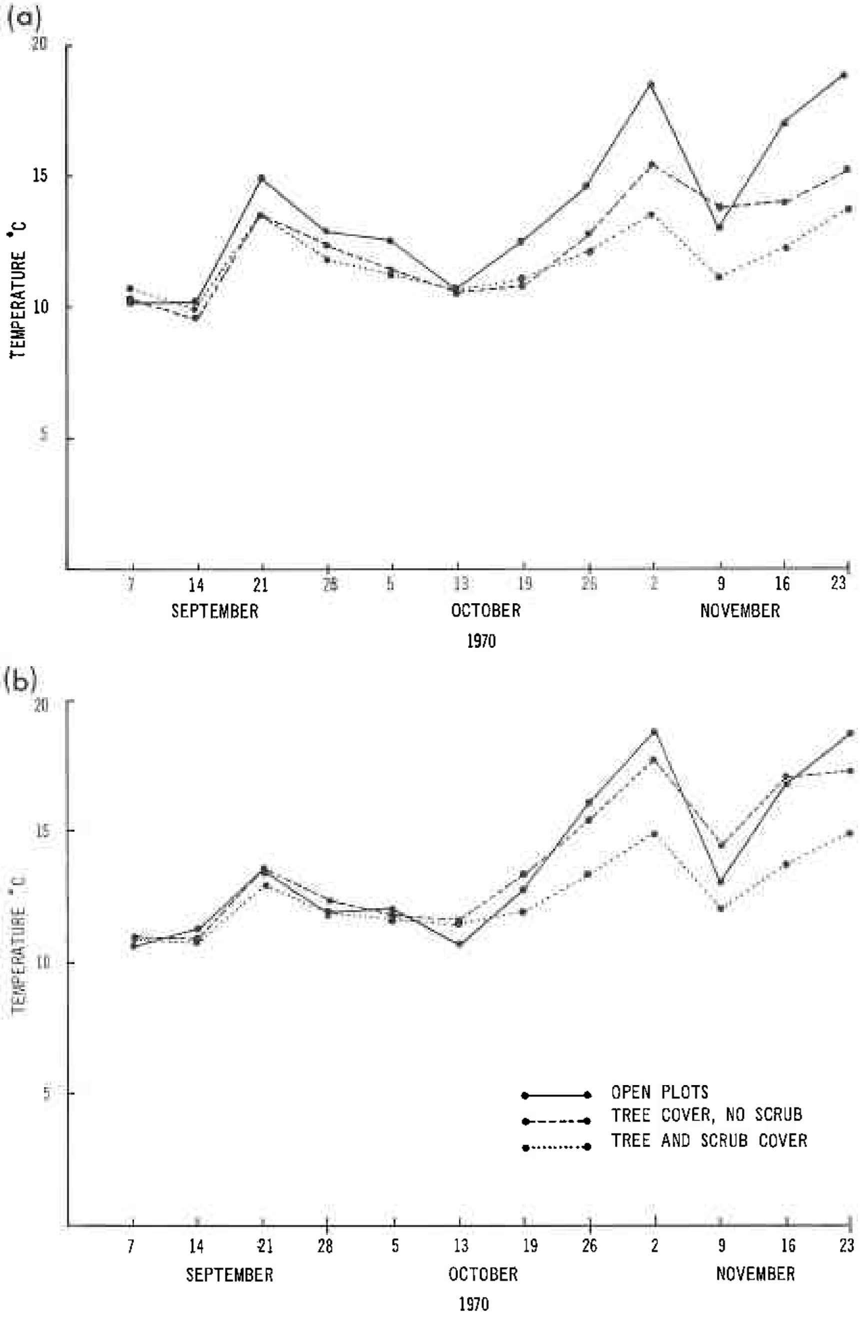


Figure 4

Mean soil temperature at 75 mm depth at 10.0 a.m. on (a) Pine Creek Plots (b) Strickland Road Plots.

Results

The mean soil temperatures at 10 a.m., recorded on each block on the Strickland Road and Pine Creek Sites, are shown in Figure 4.

During the cool weather in early spring, there were no significant differences attributable to either site or cover. However, as the weather became warmer, significant differences appeared, and the soil temperatures on two sites differed significantly at the 0.001 level. Soil temperatures under the three levels of cover also differed at the 0.001 level. On the open plots they were significantly higher than those on partially shaded plots, which in turn differed significantly from those on fully shaded plots. These differences were as much as 5°C in the Pine Creek Plots.

The results of the experiment at the Manjimup Research Station were similar, and are shown in Table 2.

TABLE 2

The effect of ground cover on soil temperatures

(This table shows the soil temperature (°C) at 75 mm depth, recorded on different soils with varying types of cover, on a fine, warm spring day).

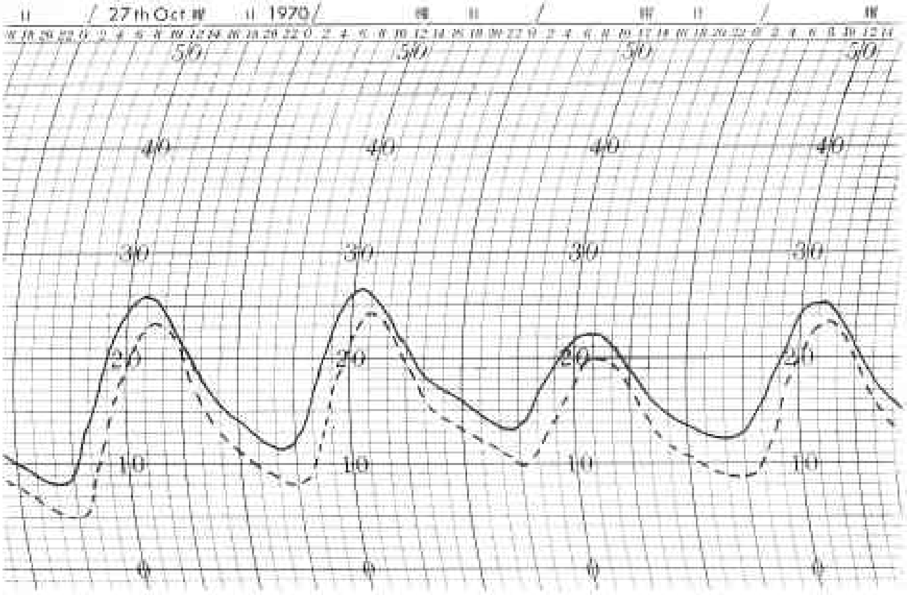
10 a.m. readings

Soil Cover		Soil Type		
Shade	Litter	Laterite	Loam	Sand
Nil	Nil	17·4	18·6	18·1
	Light	15·5	14·8	15·2
	Heavy	14·5	13·8	14·8
Light	Nil	14·3	12·5	13·2
	Light	13·5	13·1	13·1
	Heavy	11·9	13·0	13·2
Heavy	Nil	13·6	12·0	14·0
	Light	13·2	12·6	12·8
	Heavy	12·8	12·8	13·5

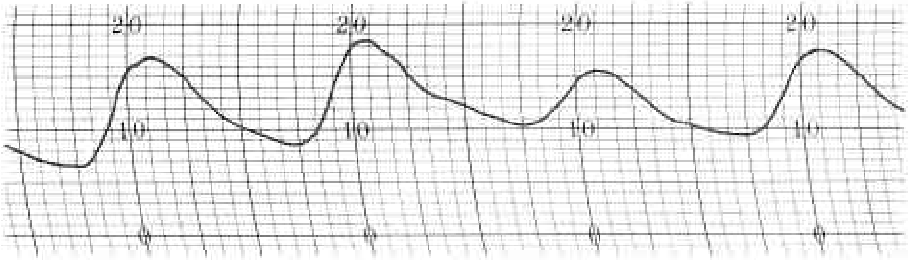
3 p.m. readings

Soil Cover		Soil Type		
Shade	Litter	Laterite	Loam	Sand
Nil	Nil	25·7	26·5	21·7
	Light	15·5	16·1	15·7
	Heavy	14·3	15·0	16·2
Light	Nil	15·5	15·3	15·1
	Light	13·4	13·6	13·1
	Heavy	13·4	12·9	13·0
Heavy	Nil	17·2	14·5	14·2
	Light	13·2	14·0	13·3
	Heavy	13·7	13·1	13·4

a) No shade, no litter



b) Light shade, no litter



c) Heavy shade, heavy litter

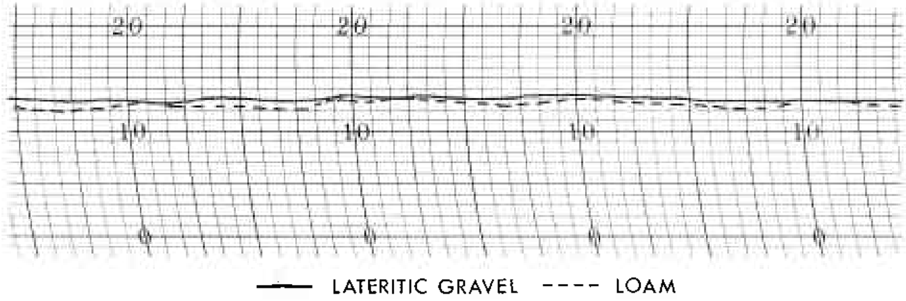


Figure 5

Sections of thermograph charts showing soil temperatures at 75 mm depth.

On warm, sunny days, the shade and litter treatments both affected soil temperatures significantly. Both morning and afternoon temperatures under heavy and light shade were significantly lower than those in the open plots (0.001 level). The litter also had a significant cooling effect. In the afternoon, both light and heavy litter treatments were very significantly cooler than bare plots, whereas in the morning only the heavy litter treatment was significantly cooler.

The results of an analysis of interactions between shade and litter treatments are shown in Table 3.

TABLE 3

The effect of shade/litter combinations on soil temperatures

(Results of Duncan multiple range test (0·05 level) on shade/litter interaction, Manjimup Research Station experiment, p.m. readings)

Treatment	NL NS	LL NS	NL LS	NL HS	HL NS	LL HS	HL HS	LL LS	HL LS
Mean Temp. °C	24·63	15·77	15·30	15·30	15·17	13·50	13·46	13·37	13·10

Treatments: N—Nil
L—Light S—Shade
H—Heavy L—Litter

Whereas the mean soil temperature in the open plots was 24.63°C, that under shade or litter treatments ranged from 15.17°C to 15.77°C. Combinations of litter and shade treatments further reduced the temperature to between 13.10°C and 13.50°C. The importance of both shade and litter is obvious from these figures.

Figure 5 illustrates the effects of shade and litter on the soil temperature regime. Cover not only reduced the mean daily temperature, but also dampened diurnal fluctuation to a very marked degree. Soil type did not have any significant effect on soil temperature in this experiment.

DISCUSSION

Soil moisture

Moisture can be regarded as the prime factor determining the susceptibility of a site to dieback. Only those sites that receive moisture from sources other than direct rainfall, for example gully heads, depressions and swamp edges, are likely to remain at field capacity long enough during spring to allow production and spread of zoospores. Well-drained sites on ridges and slopes do not remain moist sufficiently long in spring to allow infection or spread by zoospores. It seems that on those apparently well-drained sites that are at present infected, the fungus must depend on means other than zoospore disposal for infection and spread. It is possible that mycelial spread through root contact zones might prove to be of greater significance than was previously realized (there is evidence that mycelium may in fact be more infective than zoospores under certain conditions (Marx and Bryan, 1969)). It can operate earlier in spring under lower temperatures while the soil moisture is still high, and would be facilitated by root fusion, which has been observed in jarrah (P. Kimber, Forests Department of Western Australia, personal communication). This would make possible some spread from moist, infected sites onto the drier surrounds, regardless of soil moisture conditions. It does not seem likely, however, that *P. cinnamomi* will become a real threat on well-drained sites in the lower south-west areas.

The danger period on susceptible sites may vary from year to year according to the rainfall. During very wet seasons, the susceptible period would be prolonged, and lower-lying sites not normally susceptible might have short periods of conditions favourable for spread and infection of dieback. There are also indications that reduction of the tree cover may markedly influence the site. It seems possible that felling might cause a drastic increase in the duration of the susceptible period of a site. This would result from the reduced transpiration loss causing the topsoil on felled sites to remain at field capacity for prolonged periods during spring and early summer (for example, Site G2). Felling might not only increase the duration of the susceptible period on susceptible sites, but it might also influence a non-susceptible site to become a susceptible one. For instance, Site G1 in the gully head could become a susceptible site if the surrounding area were logged.

Soil temperature

The effects of soil temperature are better documented. The duration of the susceptible period on any susceptible or potentially susceptible site may be profoundly affected by temperature. The earlier the soil temperature rises above the 15°C level in spring, the longer the duration of the susceptible period. There are two ways in which this can be accomplished:

(1) By the site being initially warmer at the beginning of spring (Figure 6a).

(2) By a steep rise of soil temperatures in spring (Figure 6b).

The open landing, Site S2, provides an example of both these conditions. During winter, the soil temperature at 10 a.m. never dropped below 12°C on this site, whereas on the other sites it was frequently at 11°C or lower. This is attributed to the northerly aspect of the site and the lack of ground cover causing a much steeper temperature rise during spring than on the other plots. The effect can also be observed in Figure 4, where it is apparent that the soil in the open plots reaches 15°C at a much earlier date than in the covered plots, owing to a steeper temperature rise.

The most important of these factors is the second, the steepness of rise of soil temperature. The first factor, the initial temperature, is of less practical importance, since it may be largely affected by factors beyond human control, such as geography and slope orientation.

The significance of the steepness of rise in temperature lies in the fact that even small differences have profound effects on the duration of the period of susceptibility. A very small increase in the steepness of rise between the

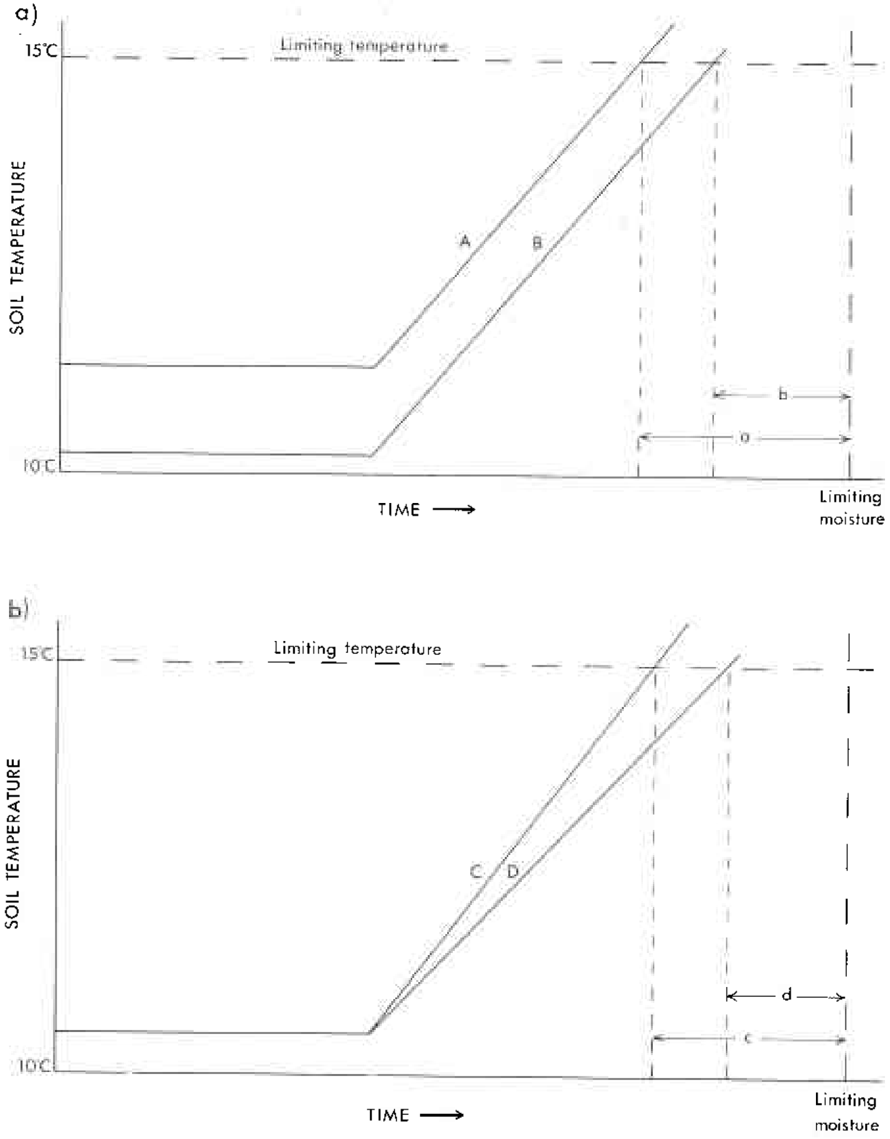


Figure 6
Diagrammatic illustration of the effect of both initial temperature and steepness of rise on the duration of the susceptible period.

(a) A higher initial temperature, A, results in a longer susceptible period, a, when the spring steepnesses of rise are equal.

(b) When initial temperatures are equal, a higher steepness of rise, C, results in a longer susceptible period, c.

open and covered plots results in the former reaching the 15°C limit more than four weeks before the latter. Any reduction in overhead canopy, scrub cover or litter depth has the same impact.

In this discussion we have been concerned mainly with 10 a.m. temperatures. A temperature of 15°C at 10 a.m. does not necessarily imply adequate temperature for the whole day; it represents only 80 to 90 hours per week above 15°C. The precise effect of temperature fluctuation on sporulation is not yet fully known. It seems likely that some sporulation will take place under these conditions. The diurnal fluctuation on the wet sites was less than on the drier sites. For instance, on Site G2 the diurnal fluctuation in mid October was 2 to 2.5°C, compared with 5 to 6°C on Site S2.

It appears that all low-lying areas may be in a delicate state of equilibrium, whose balance can be easily disturbed. Sites that normally would not be susceptible may become so after disturbance caused by logging or burning. It should be emphasized that this only applies to low-lying sites or other areas subject to moisture influx other than direct rainfall. The evidence is against large-scale infection of well-drained areas.

Practical implications

Although most of the southern forest appears to be, theoretically at least, safe from dieback, a portion is composed of susceptible or potentially susceptible sites. They can be split into two classes:

(1) Those sites where the soil moisture remains at or above field capacity during spring and most or all of summer. The susceptible period on these might vary from a few weeks to many months. These are susceptible sites, and can be identified by soil moisture sampling.

(2) Those sites on which soil moisture would remain at or above field capacity for a part of spring or summer if conditions were altered. These are potentially susceptible sites, and are difficult to identify.

It is apparent from the foregoing observations that operations interfering with crown or ground cover on susceptible or potentially susceptible sites in forest areas create conditions favouring infection and spread of the fungus. Some operations may also cause potentially susceptible sites to become susceptible. However, since the utilization of trees inevitably involves felling operations, and since there are compelling reasons for the current prescribed burning programme, some sort of compromise is the best that can be achieved.

Two suggestions that seem to offer the greatest promise are outlined below.

(1) Some system of clear felling that would leave the soil exposed for a minimum period of time before becoming covered in dense regrowth might be considered in certain areas.

(2) Felling in gullies and other moist situations could be restricted, especially in areas of high-quality jarrah, or where dieback is already present. It might be desirable to exclude from cutting a strip along either side of creeks and watercourses. Ideally, such strips should also be excluded from too-frequent burning. There are good ecological, and possibly also hydrological, reasons for having "stream reserves". The most desirable width of such reserves would have to be defined by discussion with interested parties, and could vary according to the nature of the gully. Landings on the edges of moist areas pose the greatest potential hazard.

ACKNOWLEDGEMENTS

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