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EFFECTS OF HIGH TEMPERATURE AND SOIL MOISTURE ON SURVIVAL OF FIRST-INSTAR LARVAE OF THE SCARAB *ANOPLOGNATHUS POROSUS* (DALMAN) (COLEOPTERA)

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INTRODUCTION

On the pastorally rich New England Tablelands (north-eastern New South Wales in Australia), there are over twenty-five pasture scarab species, many occurring together throughout the area (R. J. Roberts, personal communication). Sometimes these insects become so numerous that serious damage to pasture results. No control or management procedure yet proposed has prevented this damage.

In summer the scarab larvae, which aggregate near the surface of the soil, are subjected to short exposures to temperatures above 30° C. These temperatures have proved to be lethal to some larvae of *Sericesthis nigrolineata* Boisduval (Davidson, Wiseman & Wolfe 1972a, b). Using laboratory data on survival at high temperatures and various soil moistures, Davidson, Wiseman & Wolfe (1970) predicted the level of survival of larval populations in field experimental plots near Armidale.

A similar investigation with larvae of *Anoplognathus porosus* (Dalman) is described in this paper.

EXPERIMENTAL METHODS AND RESULTS

Anoplognathus porosus adults feed on the leaves of various species of *Eucalyptus*. Some were collected at the C.S.I.R.O. Pastoral Research Laboratory at Chiswick, 14 km south of Armidale, and were kept with these *Eucalyptus* leaves in a constant temperature room at $20 \pm 2°$ C on black riverine silt obtained from Yarrowyck, 32 km west of Armidale. The moisture content of the soil on a dry weight basis was maintained at 12–15% as determined by drying in an oven at 105° C for 48 h. The moisture characteristics of the silt are shown in Fig. 1. Eggs were laid in this soil which was then seeded with perennial rye grass (*Lolium perenne* L.) before the eggs hatched.

In the factorial and high temperature experiments, a batch of ten 1–2-week-old first-instar larvae was placed about half of the depth in unsterilized silt in 100-ml conical flasks lightly plugged with cotton wool. In the soil moisture experiments, a batch of five larvae was used. These latter experiments occupied longer duration. A smaller batch of larvae was used to avoid possible accumulation of carbon dioxide, which may affect survival. The soil was not sterilized as this would have destroyed the soil micro-organisms. The amount used at each moisture content was equivalent to 80 g dry weight. Temperatures of 37·5° C and above were controlled precisely to $\pm 0{\cdot}1°$ C by keeping the

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flasks almost completely submerged in a water bath. Otherwise experiments were performed in incubators.

After exposure to a treatment, the larvae were transferred to another flask containing soil at 15% moisture and kept at 20° C, these being the conditions permitting maximal survival.

The numbers of survivors and dead larvae were usually counted on the next day, but when larvae had been exposed in soil of 40% moisture content, they were still so comatosed at this time that it was not possible to decide if they were alive or dead. These larvae were, therefore, examined after seven days at 20° C. In the high temperature and soil moisture experiments, there were two replicates per treatment. There was no replication in the factorial experiment due to a shortage of larvae.

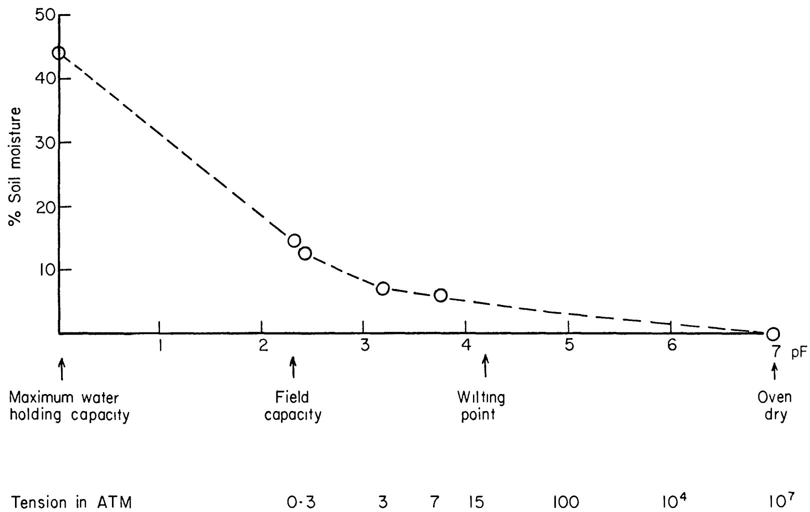

FIG. 1. Soil moisture characteristics of Yarrowyck silt (from Davidson *et al.* 1972b).

Temperature × moisture factorial experiment

Survival was determined at most combinations of temperature (20, 30, 32·5, 35, 37·5 and 40° C), soil moisture content (7, 15, 25 and 40%) with duration of exposure (3, 6, 12, 24 and 48 h). Short exposures to low temperatures and long exposures to high temperatures that would kill none or all the larvae exposed were omitted from the experiment.

The numbers of larvae alive after exposure decreased as the temperature was increased above 32·5° C, and at these high temperatures survival also decreased as the period of exposure increased. At 40° C the shortest exposure of 3 h killed all the larvae; at 30° C, mortality was unaffected by duration of exposure (Fig. 2).

Soil moistures of 7, 15 and 25% did not influence survival. For each soil moisture, the decrease in survival between 30 and 40° C was non-linear and can be represented by a similar curve (Fig. 3).

Mortality was much higher in soils of 40% moisture content (Fig. 4) for all exposure periods at all temperatures.

High temperature experiment

Factorial combinations of five temperatures (37·5, 38·5, 39, 39·5 and 40° C) and four durations of exposures (1·5 h, 3 h, 6 h single and 6 h double exposures with one-day interval in between) were employed.

Once again, the exposure needed to kill all the larvae decreased at higher temperatures. At 40° C survival was only 10% after 3 h whereas at 37·5° C, 80% survived.

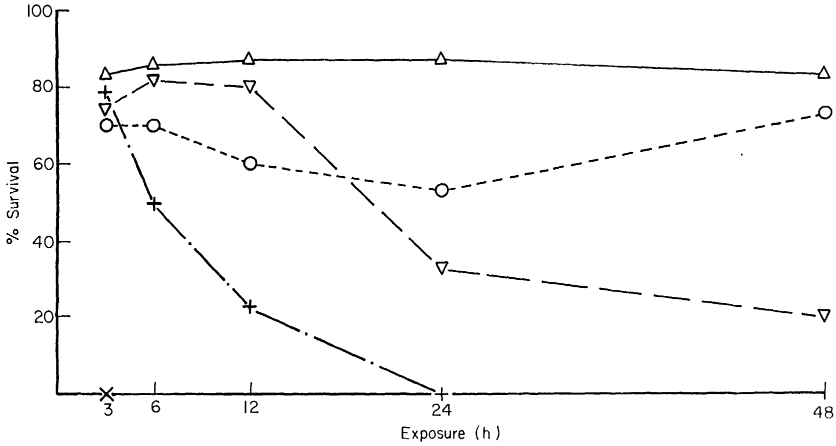

FIG. 2. Percentage survival of *Anoplognathus porosus* larvae after exposure to 30 (△), 32·5 (○), 35 (▽), 37·5 (+) and 40° C (×) for different periods.

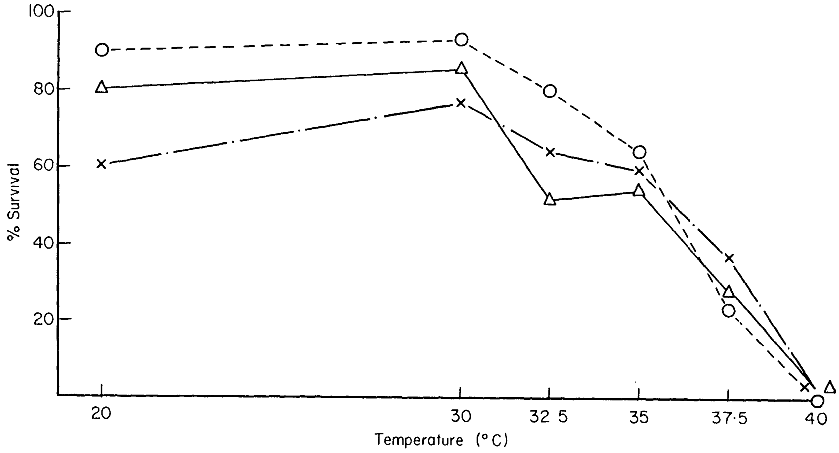

FIG. 3. Percentage survival of *Anoplognathus porosus* larvae at 30–40° C in soil moistures of 7% (○), 15% (△) and 25% (×), after one day recovery in 15% soil moisture at 20° C. Each curve derived from average survivals after 3, 6, 12, 24 or 48 h exposures. Survival at 20° C is the control.

Soil moisture experiments

Two experiments were performed in a constant temperature room at 20±2° C, usi soil moisture contents of 2·3, 3·5, 4·9, 7, 10·2, 15 and 20% and durations of exposure frc one day to three weeks. In the first experiment, the survivors were counted daily, as far as practicable and the soil in each flask was replaced every two days. In the second experiment survivors were counted and the soil was changed only at the end of each week.

Thus the possible effect on survival of frequent handling of the larvae would be minimized.

After three weeks there was survival only in the dry soils of 3·5% (pF 4·8) and 4·9% (pF 4·0) soil moistures (Fig. 6).

The highest survival was in 4·9% soil moisture, where it was 100% after one week,

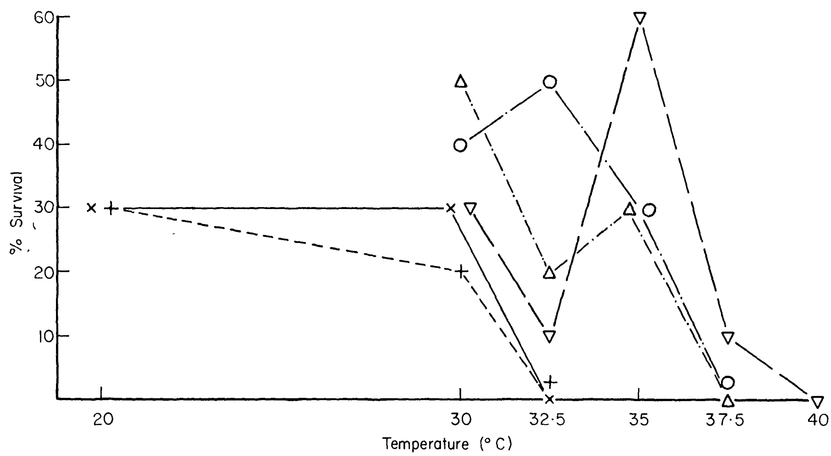

FIG. 4. Percentage survival of *Anoplognathus porosus* larvae after exposure for 3 (▽), 6 (○), 12 (△), 24 (×) or 48 h (+) to 30–40° C in soil at 40% moisture, and seven days' recovery in 15% soil moisture at 20° C.

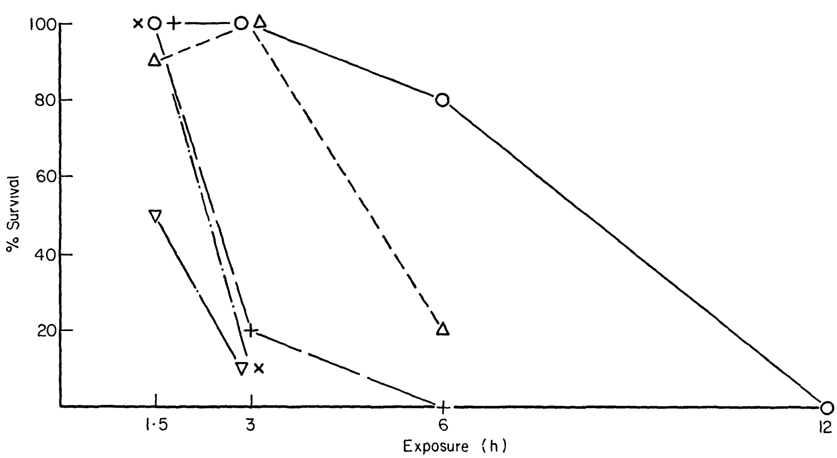

FIG. 5. Percentage survival of *Anoplognathus porosus* larvae after increasing durations of exposure to 37·5 (○), 38·5 (△), 39 (×), 39·5 (▽) and 40° C (+) in 15% soil moisture, after one day's recovery at 20° C.

95% after two weeks and 70% after three weeks. The next highest survival was in 3·5% soil moisture, where it was 40% after three weeks. In moistures from 7 to 25% the survival was extremely low after two weeks.

In the lowest soil moisture (2·3% ≡ pF 5·6) in the first experiment there was very heavy mortality (70%) even after one day, and after three days there was total mortality.

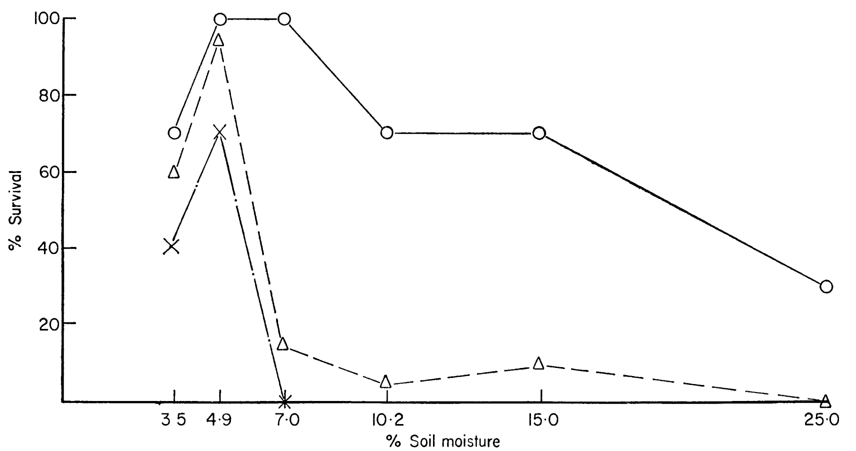

FIG. 6. Percentage survival of *Anoplognathus porosus* larvae in soil moistures of 3·5–25% for 1 (○), 2 (△) or 3 weeks (×) at 20° C. Each curve derived from average survivals in two separate experiments.

DISCUSSION

High temperature stress in *Anoplognathus porosus* appears to begin above 32·5° C (Fig. 2), although the mean survival over several durations of exposure (Fig. 2) suggests a gradually increasing mortality above 30° C. Single exposures to temperatures up to 35° C for as long as 12 h (which would exceed the duration of exposure to 35° C in the field in the New England Tablelands) do not cause appreciable mortality (Fig. 2). At 37·5° C good survival (80%) was still obtained after 6 h exposure (Fig. 5). This contrasts markedly with another scarab *Sericesthis nigrolineata* which shows a very low survival at 37·5° C after only a 3 h exposure (Davidson *et al.* 1972a). Thus, *Anoplognathus porosus* seems to be able to tolerate higher temperatures than *Sericesthis nigrolineata*. Yet both species occur in the same general area. At 40° C survival was very high (100%) after the shortest exposure (1·5 h) and very low (10%) after a 3 h exposure (Fig. 5). This temperature (40° C) may then be considered as slightly below the upper lethal temperature of first instar *Anoplognathus porosus*.

All larvae died after three days in the very dry soil (2·3% soil moisture, pF 5·6). The soil humidity is relatively low (75%). From their shrivelled appearance the writer concluded they died from desiccation. *A. porosus* larvae thus appear to require a high humidity environment as do most subterranean insects which are generally surrounded by a saturated atmosphere. Wightman (1973) maintained that in dry soil, even the forces that retain water in the eggs of the scarab *Costelytra zealandica* (White) were not strong enough to prevent desiccation. *Sericesthis nigrolineata* larvae are more tolerant of dry soil; there were some survivors after four days in 2·2% soil moisture (Davidson *et al.* 1972b).

The highest survival was obtained in 4·9% soil moisture equivalent to pF 4·2 (Fig. 6). The soil atmosphere is saturated and desiccation would not occur. A similar result was obtained with *S. nigrolineata* (Davidson *et al.* 1972b).

In wet soil (40% moisture content) mortality of *Anoplognathus porosus* was higher at low temperatures (Fig. 2). There was a layer of free water on top of the soil, and no escape from drowning was possible for the larvae. However, there has been no critical work reported concerning survival of scarab larvae in water.

On the New England Tablelands, between December and April, soil moisture conditions in the field are extremely variable (Begg 1959; Davidson *et al.* 1972b). At this time, eggs and first instar larvae are mostly found within the upper 5 cm of soils under pasture. Within this depth soil moisture and temperature fluctuate widely (Davidson *et al.* 1972b). Since *A. porosus* seems to be able to tolerate high temperatures, soil moisture content may probably be the more important factor affecting its survival. However, prolonged exposure to temperatures above 30° C, which occurs frequently in the field (Davidson *et al.* 1972a, b), may gradually weaken the larvae and cause increasing mortality, as indicated by the experimental results.

These laboratory experiments provide a basis for collating environmental data in field experiments on survival of scarab larvae, and help to identify periods of stress.

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SUMMARY

(1) A laboratory experiment testing survival of first instar larvae of *Anoplognathus porosus* at high temperatures and various soil moistures is described. High temperature stress appears to begin above 32·5° C. The mean survival over several durations of exposure suggests a gradually increasing mortality above 30° C. The upper lethal temperature is considered to be 40° C.

(2) In the soil moisture experiments, the very dry soil (2·3% soil moisture, pF 5·6) resulted in total larval mortality after three days. The relatively low soil humidity (75%) caused desiccation. The highest survival was obtained in 4·9% soil moisture (pF 4·2). The soil humidity is very high then (99%) and desiccation would not occur. In the very wet soil (40% moisture content, with a layer of water on top of the soil) mortality was high.

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