Distribution and potential for spread of *Adoryphorus couloni* (Burmeister) in Canterbury, New Zealand.

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ABSTRACT

A survey was conducted on Banks Peninsula and the Port Hills in Canterbury, to determine the present distribution and the potential for further spread of the subterranean pasture pest *Adoryphorus couloni*. It was found that *A. couloni* had spread from previous known infestations and that further spread was likely. In particular, it was found that several sites in Gebbies Valley and near McQueens Pass had been colonized by *A. couloni* and that invasion of the Canterbury Plains in the future is a distinct possibility. The rate of spread of *A. couloni* on Banks Peninsula and the Port Hills was estimated using a simple dispersal model. Natural dispersal was predicted to occur at a rate of 1.136 km/year and it is possible that human-assisted dispersal could have aided this species’ spread. A review of the relevant literature identified environmental conditions preferred by the species and potential methods of control.
INTRODUCTION

Australian black beetle, *Adoryphorus couloni*, is a native scarab of Australia that has become a serious pest of improved pastures in parts of Victoria, Tasmania, New South Wales, South Australia and is also causing concern on Banks Peninsula, New Zealand (Hardy and Tandy, 1971; Roberts and Stufkens, 1981). Most pasture damage is caused by the third instar larvae, which weaken the pasture by severing the plant roots just below the soil surface (Goodyer, 1977; Hardy, 1981; Hardy and Tandy, 1971). In heavy infestations, damage may result in pasture that can be rolled back in sheets and is easily uprooted by stock and wildlife (Hardy, 1981; Farrell, 1985).

*A. couloni* was first identified in New Zealand from specimens collected from Heathcote Valley in 1963 and is suspected to have been already well established at that time (Somerfield and Thomas, 1976b). Stufkens and Farrell (1980a) recorded *A. couloni* as occupying an area covering approximately 3000 ha, most of which lay in the eastern Port Hills with a smaller population occupying a 5 km strip from Purau to Camp Bay, in northern Banks Peninsula (Farrell, 1985). Subsequent unpublished studies (M. Stufkens, pers. comm.) have shown *A. couloni* has spread to occupy other areas on the Peninsula (see Fig. 2).

More recently, concern has mounted over the continued spread of the species and the prospect of it invading the Canterbury Plains. At present, the severity of the impact *A. couloni* will have on the Canterbury Plains is unknown.

The objective of this study was to determine the current distribution of *A. couloni* and to assess its capability for further spread.

MATERIALS AND METHOD

Literature research

A literature search for any scientific papers, articles and reference sheets regarding *Adoryphorus couloni* was carried out. The references were collated on to a computer database with a brief summary of their content.

Field survey

A field survey of Banks Peninsula took place over the summer of 1997-98. The area surveyed was approximately 9600 ha and ranged from Horotane Valley and Cass Bay in the northern Port Hills, to Teddington and Orton Bradley Park at the southern end of Lyttelton Harbour. The survey included Gebbies Valley and a brief search of Kaituna Valley and Kaituna Pass (see Fig. 1).
Figure 1. Survey area for *Adoryphorus couloni* on Banks Peninsula, Canterbury, New Zealand. Light grey shaded area indicates area surveyed.
The survey area was divided into a grid pattern based on the NZMS 260 series map, sheet M36. Each square in the grid covered 100 ha. Within each square, potential sites\(^1\) of *Adoryphorus* infestation were sampled using spade square soil samples (18 cm x 18 cm). Each sample was sorted in the field and any insects found were identified. The presence and approximate location of *A. couloni* was recorded. Sampling was carried out systematically, starting in areas already known to be infested and then moving out to include previously uninfested sites.

A proportion of specimens found were sealed in insect proof containers and delivered to AgResearch, Lincoln, for pathogen testing.

**Spread assessment model**

The asymptotic velocity or rate of spread \((x/t)\) was calculated using the formula:

\[
x/t = 2\sqrt{rD}
\]

where \(r\) is the intrinsic rate of population increase; \(x\) is distance; \(t\) is time; \(D\) is the diffusion coefficient where \(D= 2(\text{mean distance})^2/nt\) (Williamson 1996; Holmes 1993).

The expression \(rD\) (above) can be derived by using Skellam’s (1951) equation:

\[
\sqrt{\pi}R^2 = 2t(\pi rD)^{1/2}
\]

where \(R\) is the distance to the edge of the range and therefore:

\[
rD = \text{slope}^2/4\pi
\]

In this study, the slope was derived from the regression of the square root of the area colonised by *A. couloni* versus time. Information on the spread of *A. couloni* was obtained from distribution maps from this study and earlier surveys. Spread was calculated using only the area covered from 1976 onwards. This was because the time of initial colonisation could not be determined and therefore neither could the rate of spread be calculated.

The same method was used to calculate the rate of spread for *Heteronychus arator* F. (African black beetle) as a comparison.

\(^1\) Potential sites were those areas where previous experience would suggest a high probability of finding *Adoryphorus*. It is possible that light infestations in other areas would be missed because of the greater difficulty in locating light infestations.
RESULTS

Literature research

Very little information was available on *Adoryphorus couloni*. This is presumably due to it reaching pest status in Australia only in 1967. In total, 48 references regarding *A. couloni* were found (see Appendix 1). The majority of references focused on biological control, predominantly with the fungal pathogen *Metarhizium anisopliae*. Very few papers have dealt with chemical or other alternative control methods.

Approximately 20% of the literature focused on the life cycle and general biology of *A. couloni*. However, no references have been found that include information on the population dynamics of the species. A small proportion of the reviewed papers made reference to the identification of *A. couloni*.

(a) Environmental conditions preferred

*A. couloni* is predominantly associated with improved and semi-improved pastures (Rath et al., 1995). However, small numbers of larvae have also been found in native Australian pastures and some field crops (Goodyer, 1977; Hardy and Tandy, 1971; Rath, et al., 1995). Although many pasture species can become infested, evidence tends to suggest that *A. couloni* occurs most commonly in pastures consisting mainly of *Lolium perenne* L. and clover species such as *Trifolium repens* L. and *Trifolium subterraneum* (Hardy, 1981; Hardy and Tandy, 1971; McQuillan and Semmens, 1990; Stufkens and Farrell, 1980a). Pastures that are more than three years old also appear to be at a greater risk of infestation (Somerfield and Thomas, 1976b). Other favoured sites of *A. couloni* include thistles and rushes in hilly pastures and larvae of *A. couloni* preferentially select areas that contain concentrated sources of organic matter (Farrell, 1985; McQuillan and Webb, 1994; Stufkens, pers. comm.). Dense, dry pasture can also encourage *Adoryphorus* infestation as it insulates the soil and provides ideal conditions under which the larvae can develop and grow. Similarly, pastures that are kept short by frequent grazing or mowing, appear to restrict larval survival (Douglas, 1972).

*Adoryphorus couloni* is found on a wide variety of soil types (Hardy and Tandy, 1971). In Australia, the most heavily infested soils consist of sandy loam and loam soils which have a tight clay sub soil and at least 15 cm of topsoil (Douglas, 1972; Hardy and Tandy, 1971). Hardy and Tandy (1971) also noted that *A. couloni* is particularly common in free draining, self mulching clay soils. Some pasture damage has also been recorded on clay loam and very organic clay loam soils (Hardy and Tandy, 1971). In New Zealand, *A. couloni* tends to avoid clay and poorly drained soils and seems to prefer the well drained loess silt loam common to the Scarborough and Takahae hill soils of the Port Hills (Stufkens and Farrell, 1980a).
Adoryphorus couloni is also most commonly found in areas with an average annual rainfall between 700-800 mm and may occur in areas with rainfall as high as 1300 mm (Somerfield and Thomas, 1976a). However, if the weather in winter is too wet, the survival of Adoryphorus larvae is generally reduced. Likewise, the highest survival rates of A. couloni are thought to occur if the autumn and winter weather is dry (Douglas, 1972).

No direct references to the altitude favoured by A. couloni are present in the literature. However, one limited study by Stufkens and Farrell (1980a) found Adoryphorus was most common between 250 ft (76.2 m) and 500 ft (152.4 m) in altitude and was not found at all above 750 ft (228.6 m).

(b) Rate of spread

Information on the rate of spread of A. couloni is non-existent as no previous studies have been done. There are references, however, with information regarding flight distance, flight direction and population build-up after colonization. All of these are useful factors in determining the rate of spread. Although flights of several kilometres have been recorded for A. couloni, most observed flights appear to cover only short distances. These short flights generally only last up to 10-50 metres, although some can be as far as 100 metres (Somerfield and Thomas, 1976a; Somerfield and Thomas, 1976b; Stufkens and Farrell, 1980a). In windless conditions, the flight direction of A. couloni is usually non-specific. However, in windy conditions, Adoryphorus will tend to fly downwind, unlike many other scarab species which tend to fly against the wind (e.g., Hardy, 1981).

Stufkens and Farrell (1980a) suggested that the capacity for population increase of A. couloni after colonization of a new area is probably fairly low. This is because A. couloni lays relatively few eggs per female, high mortality occurs between the egg and the first instar stages and a two-year life cycle, which means the larvae have an increased exposure to mortality factors.

Somerfield and Thomas (1976b) estimated the spread of Adoryphorus to be only 1.6 km to 3.2 km a year given favourable conditions. However, this was not specifically measured.

(c) Recommendations for control

Because of the subterranean nature of A. couloni, most surface-applied insecticides have proved ineffective (Hardy and Tandy, 1971). Sub-surface applications of an insecticide mixed with superphosphate have also been ineffective. Despite these difficulties, some chemical control methods have been successful. Stufkens and Farrell (1980b) succeeded in controlling numbers of second instar larvae using broadcast granular lindane at 4 kg/ha, fensulfothion at 2 kg/ha, and isazophos at 4 kg/ha. Control of adults and third instar larvae using the same treatment was not successful. Berg and Williams (1983) achieved control of larval numbers using ethoprophos, fensulfothion and isofenphos.
However, due to the slow response of the chemicals, control measures did not succeed in reducing pasture damage. McQuillan (1993) added that the timing of pesticide application might improve results. Bishop and McKenzie (1986) [in McQuillan (1993)] suggested timing the application of pesticides to within approximately 12 hours before a light rain is expected. This is because of the tendency of some cockchafer species larvae to stop feeding during dry spells and therefore avoiding exposure to certain pesticides (McQuillan, 1993).

Biological control has been more effective. Biogreen® is a new biological control product that has been specifically developed for control of A. couloni in Australia. Biogreen is based on the fungal pathogen Metarhizium anisopliae and has shown consistently high mortality rates, particularly in the most damaging third instar larvae. Rath (1992a) recorded larval mortalities up to 94% when the agent was direct drilled into pasture during autumn. The optimal soil temperature for growth of M. anisopliae is a moderate 22°C, although it can still germinate and grow at temperatures as low as 5°C (Rath, 1992a). This ensures M. anisopliae is still active during the winter, giving year round control. M. anisopliae can also remain dormant in the soil for at least 3 years in the absence of a suitable host. In addition, Rath et al. (1995b) found that the number of conidia in the soil remained at or near application levels over a period of 12 to 30 months. This means that M. anisopliae has the potential to be an effective long-term control agent. Metarhizium anisopliae can also be used in integrated control because most chemicals, such as insecticides and herbicides, have no adverse affect on the fungus. Metarhizium anisopliae is also harmless to other beneficial invertebrates and animals.

Another biological control method, which shows considerable potential, is the use of entomopathogenic nematodes. One of the most promising species available is Steinernema glaseri, which gave an LT$_{50}$ of 37 days in some trials (Berg et al., 1993). Steinernema glaseri can also survive in the soil in the absence of a host for up to three years and the development of large scale application techniques makes nematodes an economically viable option (Berg et al., 1987). However, low soil moisture content and low temperatures ($<8-9^\circ$C) reduce nematode movement and thus their infectivity (Berg et al., 1993). Therefore, at many times of the year such as mid summer and winter, nematodes will be ineffective. The development of cold active strains is needed if nematodes are to be an effective biological control agent in most pasture systems.

Several cultural control methods and other alternatives to chemical and biological control are also available. These include the promotion of pasture vigour with fertilizer as compensation for pest damage and growing species with superior tolerance to environmental and biological stress such as lucerne, cocksfoot and phalaris (Hardy, 1970; McQuillan, 1993). Pastoralists can also re-sow pasture with fast growing annual species such as Italian ryegrass (Lolium multiflorum Lam.). Another alternative to control is to grow forage crops to supplement feed loss to pasture damage (Hardy, 1970). Rolling or cultivating pasture has also been suggested for areas infested by scarab larvae and grazing.
management has been shown to work against *A. couloni*, particularly in spring (Douglas, 1972.; McQuillan, 1993).

**Field survey**

Results of the field survey showed that *A. couloni* has spread from known infestations. The majority of movement has occurred at the southwest end of Lyttelton Harbour where approximately 1500 ha of previously uninfested land has been colonized. Newly colonized areas include several slopes at the northern end of Gebbies valley, which lie on the Canterbury Plains side of the Banks Peninsula (see Fig. 2). Invasion of these areas has apparently occurred via Gebbies Pass, to the southwest of Teddington. An area near McQueens Pass, directly south from Teddington, has also been found to have been colonized by *A. couloni* (see Fig. 2). In addition, a previously small infestation near Allandale appears to have spread and now occupies approximately 300 ha. A small population of *A. couloni* was also found below the summit of Mount Bradley near a forest remnant at approximately 360 metres above sea level.

Virtually no movement by *A. couloni* has been recorded from known sites in the northern Port Hills. This includes approximately 3000 ha of land in a 1.5-3.2 km strip to the west of the Summit Road from the Huntsbury Track to Gebbies Pass (see Fig. 2). The eastern face of the Port Hills from Dyers Pass Road to Bamfords Road in Governors Bay has also not been colonized. A brief survey of Kaituna Valley and Kaituna Pass also did not reveal the presence of *A. couloni*.

Sites where *A. couloni* was found varied from flat pasture at sea level to hill slopes approximately 360 metres above sea level. However, *A. couloni* was predominantly associated with shelterbelts and hill top ridges near rock outcrops, and many such areas were regularly associated with thistles. Pasture in which *Adoryphorus* was found was almost always on well drained soil and was well grazed. However, it should be noted that only sites most likely to be infested by *Adoryphorus* were sampled and that this species may infest other habitats.

*Adoryphorus couloni* was also frequently found with another pasture pest species, the Tasmanian grass grub (*Aphodius tasmaniae* Hope). Most *Adoryphorus* specimens collected were third instar larvae and dead adults. This reflects the time of year when the survey was conducted and no other life stages would be expected at this time. Some first instar larvae were found later in the season.
Figure 2. Previous and present distribution of *Adoryphorus couloni* on Banks Peninsula, Canterbury, New Zealand.
Severe pasture damage caused by *Adoryphorus couloni* at Orton Bradley Park, Banks Peninsula, Canterbury.

A close up view of typical pasture damage caused by *Adoryphorus couloni*. 
Potential for spread

Data derived from previous surveys of the distribution of *A. couloni* are summarised in Table 1.

<table>
<thead>
<tr>
<th>Time from first survey (yrs)</th>
<th>Area occupied (ha)</th>
<th>Total area occupied (ha)</th>
<th>Square root area occupied (√ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1500</td>
<td>1500</td>
<td>38.7</td>
</tr>
<tr>
<td>8</td>
<td>1367.5</td>
<td>2867.5</td>
<td>53.5</td>
</tr>
<tr>
<td>10</td>
<td>840</td>
<td>3707.5</td>
<td>60.9</td>
</tr>
<tr>
<td>21</td>
<td>1900</td>
<td>5607.5</td>
<td>74.9</td>
</tr>
</tbody>
</table>

Table 1. The area, cumulative area and square root of the area occupied by *Adoryphorus couloni* from 1976 to 1997.

Given the slope from the regression of the square root of the area occupied versus time from first survey (Table 1), the rate of spread of *A. couloni* was calculated to occur at 1.136 km/year. In comparison, the rate of spread of *H. arator* was calculated at 0.677 km/year.

*Adoryphorus* specimens delivered to AgResearch for pathogen testing were individually visually assessed and weighed. Samples were then frozen for later microscopic examination for the presence of pathogens. To date, only one insect pathogen has been found, a protozoan (*Vavria* sp.) in a third instar larva collected at Teddington on 16.12.97. The majority of samples remain to be processed.

**DISCUSSION**

The results show that *A. couloni* has spread from known infested areas and is continuing to disperse, mostly in a southerly direction. The rate of spread of *A. couloni* is estimated at 1.14 km/year. This result is similar to that arrived at by Somerfield and Thomas (1976b) who estimated a maximum spread of 1.6 to 3.2 km per year under favourable conditions. It is also faster than that of *H. arator* (estimated at 0.68 km/year), a species considered to be similar to *A. couloni*. As much of the adjacent land is suitable for *A. couloni* colonization, this means that invasion of new areas is likely to continue relatively quickly.

Given the present rate of spread, *A. couloni* could also potentially invade the Canterbury Plains in a matter of years. Invasion of the Canterbury Plains is most likely to be from Gebbies Valley where the majority of movement appears to be occurring. McQueens Pass may also act as an access route to the Canterbury Plains in the future. This predominantly southward movement observed in *A. couloni* may be partially explained by wind direction. The prevailing winds during the flight period are typically northerly and northwesterly (Somerfield and Thomas, 1976a). As *A. couloni* generally flies downwind, most movement is therefore likely to occur and continue to occur in a south and southeasterly direction (Hardy, 1981). As well as the
Canterbury Plains, other areas such as Kaituna Valley may also be colonized in the near future.

Spread in other sites in the Port Hills appears to have virtually ceased, particularly in the northern areas. Aside from a small negative correlation between soil type and Adoryphorus distribution from south of Dyers Pass Road towards Teddington, most areas on the Port Hills appear to be a suitable habitat for A. couloni. Therefore, factors other than environmental conditions must be at work. This may also be primarily due to the prevailing wind direction during the flight period. Prevailing northerly and northwesterly winds at this time will tend to direct beetles away from uncolonised areas in the north and western Port Hills. Thus, future movements of a large scale in these areas is considered less likely.

It is also possible that the spread of Adoryphorus may be assisted by human activities. For example, adults may alight on and be transported by vehicles or larvae may be transported in the soil around the roots of transplanted plants. Given that several large recreational areas are encompassed in the infested area, human-assisted dispersal cannot be dismissed.

However, the potential for spread of Adoryphorus may be underestimated due to difficulties involved in determining the actual area colonized from distribution maps. Distribution maps only give an approximate indication of land occupied by an animal species. Often, the exact proportion inhabited cannot be calculated. There is also the possibility that earlier surveys, and this one, have missed some areas inhabited by A. couloni, thus underestimating the area occupied and consequently the rate of spread.

Recommendations

In summary, future spread of A. couloni is very likely, particularly in a southerly direction. This poses a threat to the Canterbury Plains where the degree of impact by A. couloni is as yet unknown. A follow-up to this study is being proposed by Richard Townsend of AgResearch, Lincoln, to look at the potential impact of A. couloni should it reach the Canterbury Plains. This study should be backed by other studies investigating the spread of Adoryphorus in Gebbies Valley and McQueens Pass and the possibility of control of the species in these areas. An assessment of the perception of landowners about the impact of Adoryphorus on pastures would also be warranted. Evaluation of the effectiveness of the biological control agent ‘Biogreen’ in New Zealand should also be considered if control of A. couloni is deemed necessary.

Acknowledgements

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References


Stufkens, M.A. *Personal communication*.

Appendix 1

BIBLIOGRAPHY


No summary.


Summary:

Steinernematid nematodes. Potential but soil moisture and low temperature limits movement. Cockchafer movement into deeper soil may mean less likely to infected also. Early application of cold-hardy strains likely to be most effective in reducing pasture losses in the first year than later applications after damage has occurred.


Summary:

Six insecticides tested at Elleslie, Victoria in Australia. No treatment significantly reduced larval population until 56 days after application when 3 (Dovsanit, Oftanol, Mocap) had significantly lower larvae numbers. Since no control before 42 days pasture damage was not prevented.


Summary:

Steinernema (Neoaplectana) glaseri. 25% mortality of 3rd instar larvae 6 weeks after application at 5x10^6 nematodes m^{-2}. Heavy rain ruined rest of experiment, however, nematodes still found 15 months after application despite absence of host larvae.

Summary:

Modified drill successful introduced nematodes into established pasture. More efficient at introducing nematodes in terms of initial and long term survival.


No summary.


Summary:

S. glaseri (LD50=37), Heterorhaditis sp. V16 (LD50=21) & H. heliothidis (LD50=39). S. glaseri can survive for more than one year even in absence of host. Large scale application technique was successful. S. glaseri had significant mortality but no significant reduction in pasture damage. Apply as early as possible. Develop cold active strains so can continue to attack grubs throughout he winter as a fall in temperature is a major factor limiting performance.


Summary:

Advertisement for BioGreen, use, benefits, handling and effectiveness.


No summary.


No summary.

**Summary:**
Identification and taxonomy.


**Summary:**
Infectious to 3rd instar *A. couloni* larvae when injected (96%) but 0% infectivity when ingested. Virus cannot survive in the soil very long so it will not spread far or persist in the next generation. In its present form this virus is not a suitable biological control agent.


**Summary:**
Feeding habits, life cycle, observations on habitat preference and management methods.


**Summary:**
Identification, host plants, damage, distribution, life cycle.


**Summary:**
Damage to pastures, damage to crops, identification of larvae.


**Summary:**
Management suggestions - alternative crops, re-sowing, cash crops for few years, forage crops.

**Summary:**

Lifecycle, biology, behaviour, identification. Parasites, predators and diseases.


**Summary:**

Surface and subsurface insecticides ineffective. Incidence, identification, life cycle (Australia), damage to pastures and crops (3rd instar worst), mostly pastures 3 + years old. Pasture recovery and cultural management.


**Summary:**

Identification of head, thorax and abdomen.


**Summary:**

Sow species with superior tolerance to environmental hazards has worked for *A. couloni*. Grazing management. Promote pasture vigour for compensation. Cultivation and mechanical treatment, pesticide application time is important.


No summary.

Summary:

No long range pheromone detection- no sexual dimorphism in surface area and sensilla on antennal lamellae. Mandibles incapable of cutting, may crush and suck but probably does not feed, Comparable with Hardy (1981) who found no food in insect gut. So food bait and pheromone lures for adults not likely to be useful in control or monitoring.


Summary:

Larvae preferentially select concentrated sources of organic matter to eat. High quality organic matter in the root zone must become a limiting resource. Better management in soil organic matter content may be the key to ameliorating the impact of A. couloni.


Summary:

Sowing pest tolerant species has worked for areas of chronic A. couloni infestation.


Summary:

Effect of soil moisture, pH, Host age, temperature, soil type and micro-organisms on persistence, germination and sporulation of M. anisopliae. Also includes natural occurrence and hosts.

Summary:

Potential. Cold adapted (5°C = 80% germination I 17 days). Highly virulent on L3 instar at $10^4$ to $10^6$ spores per gram. Caused between 80% and 100% mortality in lab. 60% + expected in the field if introduced below soil surface level.


Summary:

*M. anisopliae* DAT F-001 in an effective control agent. Direct drilled method reduced pest population by 94% in Autumn but only 50% in Spring. Fungi survives in soil at least 3 years under Tasmanian conditions. Biology, Laboratory and field pathogenicity. Survival in soil. Long term control.


No summary.


No summary.


Summary:

Tailored experimental design and sampling plan for determining the efficacy of the control agent *M. anisopliae*.

Summary:

Economic control depends the production of a low cost *Metarhizium* product and also on the maintenance of fungi at a level which will limit cockchafer sizes for 5 to 10 years. Fungi survival in the soil and Cockchafer mortality and timing is also mentioned.


Summary:

*M. anisopliae* DAT F-001 reduced numbers of L3 larvae by 305 in early summer following a mid winter application. Non-feeding adults were reduced by 60-90% by winter the following year. Major reduction in second generation of larvae also. ryegrass percentage was 43% times greater than in untreated plots.


Summary:

Survival depends on the concentration and exposure time to *M. anisopliae*. LT50 ranged from 18.9 at $10^7$ spores per gram and 82.7 days at $10^1$ spores per gram. Infection had minimal impact on feeding by larvae which continued to feed virtually until death. All concentrations pathogenic to L3 larvae. Survival of treated and untreated larvae.


No summary.

Summary:

Clear distributional differences between strains related to soil type and average rainfall. Soil pH, conductivity, temperature and altitude had minor or no effect on distribution. Density was not correlated with any of the environmental variables investigated.


Summary:

Increasing the distribution and abundance of certain insect pathogens in the soil will lead to a longer term control of the major pasture pests in what is basically a stable ecosystem. A mixture of pathogens may be combined with pasture seed and sown into existing and new pastures. Long term control is possible regarding the survival of *M. anisopliae* in soils.


Summary:

Cost of control is significantly lower than even the short term production lost due to pest damage. However, industry-government co-operation is necessary to help establish production in Tasmania.


Summary:

Fungal biocontrol. Effect on 3rd instar larvae survival. Spore germination rates. effect on egg survival and production of adults. *M. flavoviridae* was the most virulent to adults, others were not pathogenic at all. All had a low virulence to 13 larvae.

**Summary:**

DAT F-001 reduced L3 larvae survival by 81.5% in late spring following incorporation of $6.3 \times 10^4$ spores per gm soil into pastures the previous autumn. Application in autumn unlikely to reduce L3 numbers quickly enough to avoid pasture damage in the first year. In the following year, overlapping larval populations were reduced by 80% and subsequent generation of L3 2 years after application were reduced by 47%. Level of DAT F-001 remained at or near application levels over the 12-30 months the experiment was run.


**Summary:**

After 5.5 months at a mean temperature of 7.5°C, 555 of L3 larvae in the high dose had died from infection. 825 had died by early summer in the high dose while 74% died in the low dose treatment. In another experiment established in mid winter, by late summer 60% of L3 and pre-pupae larvae had died. Over all field mortalities of 60-80% over two years = good progress.


**Summary:**

There were 30.3% fewer larvae in treated plots 21 weeks after application. 57.8% fewer pupae 27 weeks after application and 69% fewer adults by 44 weeks after application. In short Adult population could be reduced by 45-79% and larval populations reduced by 45-63% before the damaging L3 stage in sequential generations. No reduction in non-target invertebrates. Greater retention of sown perennial grasses, reduced weed invasion and increased pasture productivity by 23%. Spore numbers remained at twice original application.

Summary:

F-001 able to germinate at temperatures from 2-25°C in agar. Was also pathogenic at all temperatures and LT$_{50}$ values ranged from 36.1 days at 15°C to 188.9 days at 5°C. No difference in virulence at 10°C or a fluctuating 15/5°C temperature.


Summary:

Identification, lifecycle, distribution, damage and control.


Summary:

Identification, flight period, biology, habitat and damage.


Summary:

Occurrence. Food plants. Flight period and life cycle. Habitat (Soil, Climate etc in Australia). Rate of spread.


Summary:

Life history (New Zealand). Distribution and Habitat. Flight and Population density.


Summary:

Broadcast granular insecticides Lindane, Fensulfothion & Isazophos did not affect Adults and 3rd instar larvae. First and 2nd stage effectively controlled.


**Summary:**

Pathogenicity.