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Source: Journal of Orthoptera Research, 19(1) : 133-137

Published By: Orthopterists' Society

URL: https://doi.org/10.1665/034.019.0108

Journal of Orthoptera Research July 28, 2010,19(1): 133-137

Credibility of an IPM approach for locust and grasshopper control: the Australian example*

Submitted January 12, accepted April 15, 2010

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*Paper delivered as part of a symposium: *Integrated pest management for locusts and grasshoppers: are alternatives to chemical pesticides credible?* Antalya, Turkey, 21-25 June 2009.

Abstract

In Australia, locusts are controlled using an Integrated Pest Management (IPM) system that aims to find and rapidly treat most gregarious locust populations. Many outbreaks have significant breeding in the arid interior of Australia during summer and treatments begin in the interior, to keep locust invasions of the agricultural zone to manageable levels. This preventive control program relies on IPM: moderately accurate forecasting and rapid response survey, followed by treatments of bands and swarms with a range of proven readily available products. IPM begins with a Decision Support System that uses data on weather and previous locust distributions to model locust development and possible migrations, so as to provide moderately accurate forecasts as to when and where locusts are likely to be present. When locusts are reported or forecast as likely to be in a region, surveys are conducted to locate any infestations and if bands or swarms are found, they are rapidly treated using a variety of techniques. Bands are commonly visible from an aircraft flying overhead and when bands are seen, the areas containing bands are normally treated using "barrier" treatments of fipronil, where synthetic insecticide is applied every few hundred meters. Swarms are located by helicopter and sprayed, using fast-acting organophosphorous compounds like fenitrothion. But an increasingly important part of IPM in Australia is having an environmentally friendly option. Locusts can then be treated even if they are found where synthetic insecticides cannot be used such as near waterways, where there are rare and endangered species, or on organically managed properties. It was the switch to produce organic beef for Japan by a number of properties in locust breeding areas in the interior that was an initial driver for the development of an alternative to synthetic pesticides for locust control in Australia. The result of an intensive research and development program was the mycopesticide Green Guard , which has as its active ingredient the FI-985 isolate of the fungus *Metarhizium anisoplae* var. *acridum*. Green Guard has played an important part in the IPM of locusts and grasshoppers in Australia, including large-scale control operations, with more than 100,000 ha treated since operational use began in 2000.

However, while Green Guard plays an important part in the IPM of locusts and grasshoppers, it still accounts for only about 10% of the area treated. Green Guard costs more than synthetic insecticides and locust and grasshopper mortality is delayed when temperatures are mild. An additional factor limiting its use is a lack of biological control products for most other pests, so that synthetic insecticides are still used in most cropping systems, resulting in residues being present in most products and in most environments. As restrictions on synthetic pesticides generally increase and biological alternatives become more available, it is expected that Green Guard use should expand to become an increasingly important component of locust and grasshopper IPM.

Key words

locusts, grasshoppers, microbial control, mycopesticides, *Metarhizium*

Introduction

In Australia, locusts and grasshoppers are major pests of agriculture that can cause substantial damage to pastures and crops. Wright (1986) reported that, during the 1984 plague of the Australian plague locust, *Chortoicetes terminifera* (Walker), damage would have been an estimated $103 million (1984 Australian dollars) without control. Control operations cost $3.4 million and limited damage to only $5 million, a saving of about $98 million, giving a cost-benefit ratio of 29:1. A more recent study conducted by the Australian Bureau of Agricultural Economics, found a cost-benefit ratio of 20:1 for the control operations conducted during the major outbreak in 2004-05 (Abdalla 2007). In addition to the clear economic benefits, the high visibility of nymphal bands and swarms generates the political will to control locusts. The most common pest, the Australian plague locust, forms dense band fronts of nymphs, with several thousand individuals/m^2, that can be seen from aircraft flying overhead (Hunter *et al.* 2008). This locust also forms dense swarms, but swarms can be even denser with two other locust pests in Australia: the spur throated locust, *Austracris* (formerly *Nomadacris*) *guttulosa* (Walker) and the migratory locust *Locusta migratoria* (L.) (Hunter 2004). In addition, there are substantial grasshopper outbreaks in the more temperate areas of Australia, with the wingless grasshopper *Phaulacridium vittatum* (Sjöstedt) dominating this grasshopper complex.

Worldwide, control of locusts and grasshoppers has relied on the use of synthetic pesticides; but following the widespread use of synthetic insecticides during the Desert locust plague of the late 1980s in Africa, the LUBILOSA (LUtte BIologique contre les LOcustes et les SAuteriaux) program was funded with the aim to find biological alternatives. Initial success with *Metarhizium anisopliae* var. *acridum* (Driver and Milner) (Deuteromycotina: Hyphomycetes) by the LUBILOSA program, led to the commencement in 1992, of similar research in Australia, initially in cooperation with scientists from LUBILOSA. LUBILOSA demonstrated that *M. a.* var. *acridum* killed locusts and grasshoppers in a wide variety of conditions, including in deserts (Langewald *et al.* 1997), leading to development of the commercial product Green Muscle® for use against locusts and grasshoppers in Africa.

Green Muscle has been tested in many field trials and has been registered for use in a number of countries, but as yet has had limited operational use against the Desert locust: only 1400 ha were treated during the 2003-2005 Desert locust outbreak, while over 13 million ha were treated with synthetic pesticides. The most notable recent success with Green Muscle has been against the Red locust in Tanzania, where over 10,000 ha of adults were treated during May/June 2009 (FAO 2009). On the other hand, the Australian commercial product, Green Guard®, has been used operationally since 2000, with more than 100,000 ha of locust and grasshopper infestations treated between 2000 and 2009. However, synthetic insecticides are still used in a vast majority of treatments in Australia, with Green Guard use still below 10% of the total treated area. The role that Green Guard plays in the Integrated Pest Management of locusts and grasshoppers in Australia will be examined here, along with the factors that still limit its use to a small part of total locust and grasshopper control.

The Integrated Pest Management of locusts in Australia

Locusts in Australia are managed through an IPM program and the most important locust pest is the Australian plague locust. Its outbreaks often originate in the relatively remote interior of Australia, where several generations of breeding during summer are followed by autumn invasions of the agricultural zone to the south and east (Wright 1987). After breeding during the winter/spring rainfall maximum in the southern agricultural zone, it is common for some of the locusts to return to the interior in time for the summer rains, resulting in a migratory circuit (Deveson *et al.* 2005). The realization that locusts can migrate long distances (several hundred kilometres in a night) led to the establishment of the Australian Plague Locust Commission, whose charter was to reduce the size of locust invasions of the agricultural zone by beginning treatments in the interior (Hunter 2004). Locust populations increase rapidly when conditions are favorable: each locust killed early in a breeding sequence is worth at least 50 killed two generations later. The early intervention treatment of several thousand hectares of low-density swarms, saves tens of thousands of hectares from being treated later, even when compensating for later swarms being of higher density.

Early intervention does not aim to find and treat all gregarious locusts, but to treat enough (30-60%) of the locust population in each generation to reduce the rate of increase and so delay the point in time when populations might reach plague proportions (Hunter 2004). Since the very favorable conditions that lead to rapid population increase often only last a year or so, delaying a plague can be sufficient to prevent it. However, even in situations where breeding continues long enough for populations to reach plague proportions, early intervention will reduce the size of the plague, giving the opportunity for the population to be controlled before widespread damage can occur.

This reduction of population increase relies on IPM: good forecasting and rapid response survey, followed by treatments of nymphal bands and adult swarms with a range of proven, readily available, products.

At least moderately accurate forecasts are important for the early detection of outbreaks. A Decision Support System takes data on weather and habitat condition and integrates it with information on locust migration, development and distribution, to prepare forecasts and aid decisions for control (Hunter & Deveson 2002, Deveson & Hunter 2002, Hunter 2004). Whenever forecasts suggest that locusts are likely to be in a region, whether because of appropriate rains, locust migration or recent hatching, surveys are conducted to locate any gregarious populations. While survey officers concentrate their efforts in areas forecast as currently being favorable or where local landholders have reported seeing locusts, some surveys are conducted elsewhere, because one never has all of the information required for completely accurate forecasts as to when and where locusts are likely to occur.

When a number of bands or swarms are found, they are treated using a variety of products using appropriate techniques. Bands are often visible from an aircraft flying overhead (Hunter *et al.* 2008), allowing for the rapid delimitation and spraying of the densest bands. Dense band infestations are normally treated by aircraft spraying a longer-lasting (~ a week at the low doses used) product like fipronil, which is applied in "barriers": strips of synthetic insecticide applied every few hundred meters. Swarms are best located by helicopter which can rapidly determine the boundaries of denser swarms, often within a background of lower-density locusts. The denser swarms are treated aerially as a blanket treatment at a 100-m track spacing, using a faster-acting organophosphorous compound like fenitrothion.

The use of aerial survey for the location of bands and helicopter search for the location of swarms means that only the denser parts of infestations are treated, substantially reducing the monetary and environmental costs of synthetic pesticide applications. But an increasingly important part of IPM in Australia is having a *Metarhizium* biopesticide so that treatment of locusts can occur when they are found in environmentally sensitive areas or on organically managed properties. Without this biological alternative, many locusts would be left untreated, limiting the effectiveness of preventive control programs.

For successful preventive control, it is important to treat populations rapidly, before they become flying migrant adults. Contributing to rapid control is the fact that only denser infestations are treated and that most band infestations are treated with fipronil applied in strips at every few hundred meters, allowing large areas to be treated quickly. However, even complete-coverage treatments are applied at track spacings of 100m, which is much wider than those commonly used elsewhere. The Australian Plague Locust Commission has undertaken a great deal of research into improved spray techniques, and has demonstrated that there is relatively complete spray coverage with 100-m track spacings, provided the aircraft apply mainly moderately sized 50 to 150-micron droplets, applied from a 10-m height, in light to moderate (3 to 6m/sec) winds. Such winds carry ULV spray for the 100m between spray runs and are able to overcome thermals when it is hot, allowing spraying to continue for most of the day (Nguyen & Watt 1980, 1981). The overall result is that for small-to-moderate preplague populations, the densest parts of infestations can often be sprayed in a week or less, leading to a rapid reduction in the locust population—an important component of preventive control.

Factors contributing to the use of Metarhizium as part of locust control in Australia

The preventive locust control program in Australia initially relied entirely on the use of synthetic pesticides (Hunter 2004). While constraints on the use of synthetic insecticides had been increasing for some time, particularly with the broad-acre spraying required to control large infestations of locusts, it was the switch, during the mid 1990's, to produce organic beef for Asian markets that spurred an intense search for a biological alternative. Many properties in the locust-breeding areas of inland western Queensland and northern

South Australia changed to organic beef production: synthetic insecticides could no longer be used in a significant locust-breeding area, which threatened the continuing success of preventive control.

To ensure the rapid development of *Metarhizium* to commercial reality, the Locust and Grasshopper Biocontrol Committee (LGBC) was formed. The LGBC consisted of research, government and landholder groups interested in furthering the biological control of locusts and grasshoppers and in consultation with end users, developed products suitable for use in environmentally sensitive areas and on organically managed properties (Hunter 2005). Green Guard® ULV was developed as an oil concentrate that is further diluted in oil for aerial ULV application, while Green Guard® SC is mixed with water for application from ground equipment that landholders commonly use.

But critical to the success of the LGBC was that an important end user, the Australian Plague Locust Commission, agreed to purchase about $200,000 worth of Green Guard® per year for 3 y. The agreed purchase contract led to the commercial partner spending significant amounts of money in improving production, leading to higher and higher yields of a consistently high-quality product. Higher yields meant lower costs of production and yields have improved in recent years, such that 120g of spores are produced per kilogram of rice substrate, much higher than reported by manufacturers of other isolates such as the LUBILOSA isolate in Africa (Cherry *et al.* 1999) and the isolates in Mexico (Cepeda-Puente *et al.* 2005).

Critical to its uptake in Australia was the ability of the FI-985 isolate of *M. a.* var. *acridum* to survive well and cause relatively rapid high mortality when it is very hot. On organically managed properties in the interior, treatments are often required during midsummer when maximum temperatures are commonly above 40°C. While the FI-985 strain used in Green Guard does develop at slightly higher temperatures than some other isolates of *Metarhizium* (Milner *et al.* 2003), even FI-985 does not develop at much above 36°C. In spite of a lack of development in the laboratory at high temperatures, mortality of locusts treated with Green Guard is most rapid when it is very hot, with >90-95% mortality being reached in 6-10 d. When it is very hot, with temperatures in the 23 to 33°C range; this is suitable for optimal *Metarhizium* development all night, as well as for much of the day: only in the middle of the day is it too hot for development. The high level of mortality is important for the dense bands common with the Australian plague locust, where band fronts are at densities of several thousand nymphs/m^2 (Hunter *et al.* 2008).

The 6-10 day mortality when using *Metarhizium* where it is hot is also acceptable with the preventive control programs against nymphs of the Australian plague locust: even fipronil applied in strips takes a number of days to kill nymphal bands. This high mortality in 6-10 d has been seen not only with Green Guard applied as a blanket treatment, where applications occur every 100m, but also at wider track spacings ("barrier treatments").

During February 2004, mid-to-late instar bands were initially treated at the normal 100-m track spacing, but insufficient supplies of Green Guard led to nearly 5000 ha of bands being treated at 150-m or 200-m track spacings. A helicopter search 11-12 d later found only scattered (<0.1/m^2) adults in the treated areas: 30 swarm targets were sprayed during this period, but none of the swarms were in areas where bands had been treated. Secondary pickup of spores from the vegetation has been shown to be important in allowing low doses of Green Guard to cause high locust mortality (Thomas *et al.* 1997, Scanlan *et al.* 2001). Rapid marching of bands is particularly consistent during hot summer days, resulting in locusts marching into and through sprayed strips, allowing pick-up of a lethal dose and hence this success of wider track ("barrier") treatments with *Metarhizium*.

Moderately rapid high mortality when it is hot has meant that a major use of Green Guard has been on organic properties in the interior during summer. A second important use has been in environmentally sensitive areas such as near waterways or where there are rare and endangered species: there are a substantial number of such areas not only in the interior but also in the agricultural zone.

But an increasingly important use is by individual landholders wanting to limit the amount of synthetic insecticide residues in their products. Landholders selling products must present a Vendor Declaration that lists synthetic insecticides used for pest control on their products: more and more landholders prefer the use of Green Guard because of a perceived lower price received for products on which use of synthetic insecticide has been declared.

Some exporters, while not certified "organic" because they need to use artificial fertilizers, are moving to eliminate the presence of synthetic pesticides in their products. For wines destined for export, the Australian Wine Research Institute, which sets the standards for pesticide use in vineyards, has severely restricted the use of synthetic pesticides for locust and grasshopper control. In its 2008-09 booklet Agrochemicals Registered for Use in Australian Viticulture, (www.awri.com.au/agrochemicals/agrochemical_booklet), only Green Guard is allowed for control of Australian plague locusts, and use is allowed up to 7 d before harvest. For the wingless grasshopper, Green Guard is also recommended and the one synthetic pesticide that is allowed for grasshoppers can be used no later than 56 d before harvest: in the 8 weeks before harvest, when grasshoppers can still be common, no synthetic insecticides can be used.

This wide variety of uses of Green Guard has meant that in Australia it has been applied to over 100,000 ha during the period 2000-2009, which is probably more than the combined use of biological products against locusts and grasshoppers elsewhere in the world.

Most treatments have been against locust bands, though during 2007 adult swarms of the migratory locust were successfully treated in East Timor, an island nation to the north of Australia. Following on from the success of Green Guard against adult locusts in East Timor, adults of the red locust, *Nomadacris septemfasciata* (Audinet-Serville) in Tanzania were treated with Green Muscle® during May-June 2009 (FAO 2009). The red locust has a long adult stage and is common in environmentally sensitive areas subject to flooding, an ideal situation for the use of biologicals: this demonstrated success should be an impetus for operational use against other locust and grasshopper species in Africa.

Factors currently limiting the use of Metarhizium for locust control

However, synthetic insecticides still account for about 90% of the area treated for locusts and grasshoppers in Australia. One factor limiting the use of Green Guard is that mortality is delayed when temperatures are mild. While Green Guard causes >90-95% mortality of locusts within 6-10 d when it is very hot (maximum temperatures 37-42°C), mortality is often slightly less (80%) and is slower (2 weeks or so) at the mild temperatures (maxima 20-30°C) of spring and autumn in the agricultural zone (Hunter *et al.* 2001). Locust mortality then takes about two nymphal instars, and to ensure mortality occurs before the flying adult stage, when locusts could rapidly fly to and damage crops, the main use during spring and autumn has been against mid-to-late instar bands in pastures. A critical part of treatment in spring and autumn has been modelling of *Metarhizium* development under various conditions that allows landholders to be told how long mortality is likely to take, as part of reassuring them that mortality *will* occur, even if it takes longer.

Higher price can be a major problem limiting biological control. For Green Guard, the price difference has been reduced by the higher yield of the FI-985 isolate during production. But a significant contributor to the higher cost is a direct consequence of the specificity of *M. a.* var. *acridum* to only locusts and grasshoppers: specificity means that volumes in production are much lower than with broad-spectrum synthetic insecticides, so that economies of scale are rarely realized. The same applies for registration costs. However, prices for new synthetic pesticides may well be closer to that of Green Guard, because research, development and registration costs for new synthetic insecticides are likely to be very high. For now the problem is that many older inexpensive synthetic insecticides are still on the market and as long as these are present, biologicals like *Metarhizium* will be at a substantial cost disadvantage.

But as pointed out by Hunter (2005), it is a fallacy, albeit a common one, to compare costs of control based solely on the cost of the product. The real cost/ha of a control program is actually the total budget for the program (which includes the cost of staff, administration, survey, search and aerial application) divided by the number of hectares treated.

Of course, cost alone cannot be the major factor that determines if treatments should occur during preventive control programs: successful preventive control requires that locusts be treated whenever and wherever they are found. With the Australian plague locust, bands cost much less to treat when synthetic insecticides like fipronil are applied at wide-track spacings of several hundred meters. But almost always many locusts survive to the adult swarm stage and the high cost of helicopter survey for swarms means that while swarms are expensive to treat, they still must be treated if preventive control is to succeed. Similarly, even though treatment with Green Guard is more expensive than treating either bands or swarms with synthetic insecticides, Green Guard still needs to be applied in areas where synthetic insecticides cannot be used, to ensure that the preventive control program is successful.

Farmers want locusts to be controlled and when locusts threaten their crops, they will apply large amounts of synthetic insecticides to prevent damage. Use of a moderate amount of Green Guard in environmentally sensitive areas early in an outbreak is much less expensive than leaving the locusts uncontrolled and then having to use a large amount of synthetic insecticide a generation or two later, when locust numbers have increased substantially and directly threaten crops.

Conclusion

The IPM of locusts in Australia relies on moderately accurate forecasts, rapid response survey and treatment using a variety of products and techniques: the result is that locusts can be treated whenever and wherever they are found. Biological control using Green Guard is an important part of IPM, but the higher cost and slower action of Green Guard during mild conditions has meant it is mainly used only where synthetic insecticides cannot be used such as on organic properties and in environmentally sensitive areas. The lack of biological alternatives for most pests means that many growers see little advantage in using a biological product for locust and grasshopper control when synthetic insecticides still have to be used for most other pests. However, the use of Green Guard in vineyards producing wines for export shows that reducing synthetic insecticide residues is beginning to be seen as a way of giving Australian exports a competitive advantage. The desire by many countries for lower and lower synthetic insecticide residues in imported foodstuffs, combined with the ability to enforce lower levels of residues via increasingly sensitive methods of detection, means that the pressure is strong for having biological alternatives. The use of Green Guard is likely to increase as pressure increases to reduce synthetic insecticide residues in agricultural products and in the environment.

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