

THE INTEGRATION OF THE PARASITOID *MICROPLITIS DEMOLITOR* INTO IPM SYSTEMS IN COTTON IN AUSTRALIA

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Summary

Microplitis demolitor (Wilkinson) (Hymenoptera: Braconidae) is a critical component of IPM in Australian cotton. High rates of parasitism (up to 65%) occur naturally in the field at a crucial stage in the development of the crop. Parasitised larvae cause negligible damage to the crop. *M. demolitor* adults were demonstrated to tolerate certain insecticides (chlorfluazuron methoxy fenozide and primicarb), but were very susceptible to many others (endosulfan< dimethoate< cyhalothrin< profenofos< deltamethrin< bifenthrin< spinosad). *M. demolitor* is extremely tolerant of most insecticides during the pupal stage. Larval *M. demolitor* were not directly affected by insecticides but survival was reduced due to host mortality. Susceptibility of the host to stomach insecticides was reduced about 5 days after parasitisation, while insecticides with a contact action caused host mortality throughout the parasitoid's larval stage.

Introduction

Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae) and *H. punctigera* (Wallengren) (Lepidoptera: Noctuidae) are the key pests of cotton in Australia (Fitt, 1989). Insecticide use is the major method of control of these pests. Extensive over-use of insecticides creates many social, environmental and resistance problems which threatens the sustainability of cotton production in Australia. In order to remain sustainable, the industry must reduce its reliance on insecticides and implement an integrated pest management (IPM) program. Conservation of beneficial insects (predators and parasites) is considered crucial to successful IPM. The extent to which predatory insects control *Helicoverpa* spp. on cotton is unclear (Stanley and Gregg, 1994), and is heavily influenced by insecticide disruption (Gregg, 1995). Parasitoids have a prominent place in IPM in cotton. Numerous adult parasitoids and high rates of parasitism have been found in cotton fields despite intensive insecticide regimes (King *et al.*, 1985; Powell and King, 1984; Murray *et al.*, 1996; Murray and Mensah, 1996). *M. demolitor* is a parasitoid indigenous to Australia and is the most common larval parasitoid of *Helicoverpa* spp. in Australian cotton (Murray, 1994). This paper outlines investigations of the role of *M. demolitor* in an IPM system in Australian cotton.

M. demolitor biology

M. demolitor successfully parasitise both *H. armigera* and *H. punctigera*. *M. demolitor* females attack larvae early in their development, usually the second instar. Any control of *Helicoverpa* spp. at this stage is extremely important. High natural mortality of eggs and first

instar larvae has already taken place, and only minor damage has been done to the crop. Third and fourth instar larvae are suitable as hosts but these larvae vigorously defend themselves often resulting in injury or death of the *M. demolitor* female (Shepard *et al.*, 1983). After oviposition, eggs hatch and the larval parasitoid consumes the host internally. The parasitoid exits from the host and pupates in a cocoon nearby. The life cycle of *M. demolitor* takes about 12 days at 25°C, with 7 days from egg lay to pupation and 5 days for pupal development (Murray and Rynne, 1992). This means that *M. demolitor* populations can build up rapidly. Occasionally twin *M. demolitor* are produced depending on the size of the host (Shepard *et al.*, 1983). Rarely (1%) parasitised host larvae pupate successfully (Titmarsh, 1985). Whether the resultant moths are viable needs investigation. The stresses placed on the host by the developing parasitoid have been demonstrated to affect the behaviour of the parasitised host.

Food consumption by *H. armigera* larvae after parasitisation by *M. demolitor*

The effects of parasitism by *M. demolitor* on *Helicoverpa* spp. are often underestimated. In addition to direct larval mortality, parasitised larvae cause relatively minor damage to the crop. Feeding experiments have shown that parasitised *H. armigera* larvae effectively stop feeding after a few days. Throughout the parasitoid's larval development, parasitised host larvae consume only 11.5% of that consumed by unparasitised larvae (unpublished data). Over 50% of the total food consumption by larvae occurs from the fifth instar to the second day before pupation (King, 1981). *M. demolitor* parasitised larvae die before they reach late instars, which means that a more accurate estimation of the amount that parasitised larvae consume is in the order of only about 5% of that consumed by unparasitised larvae. Reduced feeding by parasitised hosts is not sufficient to prove reduced yield loss. Often damage occurs when fruit is shed due to grazing. It has been demonstrated that *Heliothis* spp. larvae parasitised by *M. crociipes* (Cresson) (Hymenoptera: Braconidae), a closely related species from the USA, rest more frequently and crawl and feed less frequently than unparasitised larvae (Hopper and King, 1984). As a result, parasitised larvae damage fewer fruit by superficial grazing. Reduced feeding and movement has been observed in larvae parasitised by *M. demolitor* (unpublished observations). This indicates that damage caused by parasitised larvae is negligible.

Field studies on population sampling methods of *M. demolitor*

Monitoring beneficial populations is the first step in their conservation. Predator numbers are relatively easy to assess. Unfortunately, parasitoids are often inconspicuous and their activity difficult to assess in a crop. Parasite eggs and larvae are not easily recognised in the field and adult stages are usually small and inherently highly mobile. A rapid assessment method that provides an accurate assessment of parasitoid numbers would be very useful (Murray and Mensah, 1996). If a method to index parasitoid activity could be determined, farmers may be persuaded to reduce their reliance on insecticides. The aim of this study was to collect data on simple, practical sampling methods for field populations of *M. demolitor*.

Sampling methods examined included: suction samples, coloured water traps, sticky traps baited with virgin females, sweep netting and parasitism rates of the host. The first two

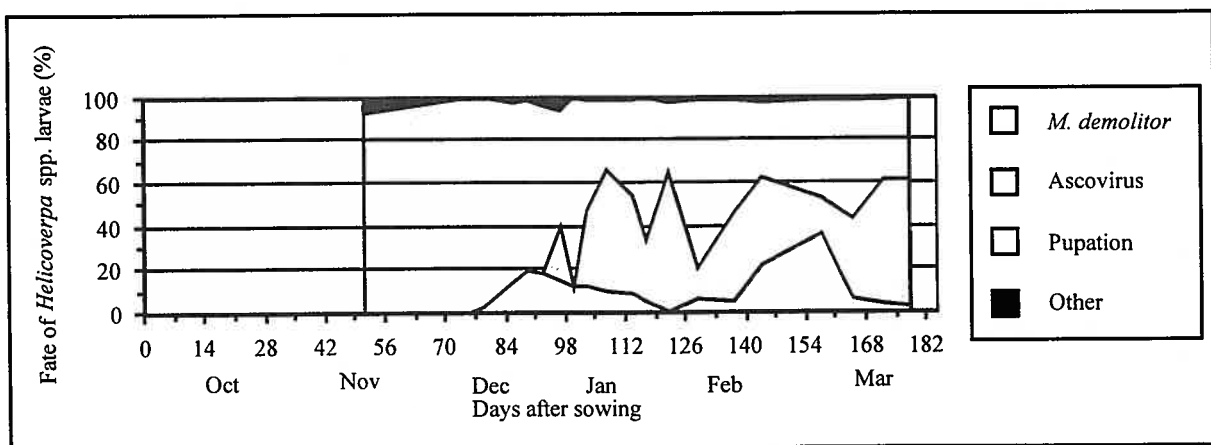
methods caught few *M. demolitor*. The virgin female traps used in this study may prove useful in intensive small-scale studies, but were impractical for regular large scale field monitoring. Of the methods trialed, only direct observations and percent parasitism are practical for use in the field (unpublished data). *M. demolitor* adults can be easily identified by their characteristic flight habit. Percent parasitism can be estimated by collecting larvae and rearing them through till parasitoid emergence or more easily and practically by splitting larvae and identifying the developing parasitoid larvae (small white larvae at the rear on the host). With a small amount of training both these methods are easy to carry out and can be done by consultants while doing normal crop checks. Although accurate calibration of these techniques to relate the number observed to the actual controlling impact on the pest requires further study, observations of high populations of parasitoids either as adults or parasitised hosts should be considered when making spray decisions.

Impact of *M. demolitor* on *Helicoverpa* spp.

Parasitism of between 30-50% of *Helicoverpa* spp. by *M. demolitor* has been recorded in cotton crops in Australia (Shepard *et al.*, 1983; Murray *et al.*, 1996). This is a significant level of control which can not be ignored. Seasonal patterns in percent parasitism have previously been recognised (Broadley, 1981). This study aimed to evaluate the impact of *M. demolitor* on *Helicoverpa* spp. in the field and determine any seasonal patterns in *M. demolitor* populations.

Estimates of percent parasitism of larvae (small, 7 mm to small medium, 13 mm) collected from 3 unsprayed raingrown cotton blocks at Warra, on the Darling Downs, during the 1996/97 season were pooled (Figure 1). Similar data from an unsprayed block at Warra during 1995/96 are presented in Figure 2. Larvae were reared on standard heliothis diet under controlled conditions, checked every few days and their fate recorded. Larvae which died of unknown causes, nuclear polyhedrosis virus (NPV) or parasitoids other than *M. demolitor* were grouped together in an "other" category.

Figure 1. Fate of *Helicoverpa* spp. larvae collected from 3 unsprayed cotton blocks, 1996/97.



Ascovirus is a pathogen found in many cotton fields. Infection results in reduced larval feeding and ultimate death. In order for a larvae to become infected, the virus must be introduced into the hemolymph, so infection can not occur by consuming virus particles. *M. demolitor* has been shown to transmit ascovirus to *Helicoverpa* spp. via oviposition by an infected female wasp (D. Murray pers. com.). As *M. demolitor* was the dominant parasitoid present in the cotton crop it is reasonable to assume that *M. demolitor* were responsible for most, if not all ascovirus infections. As a result, percent parasitism plus the level of ascovirus infection is a more accurate reflection of *M. demolitor* impact on *Helicoverpa* spp. populations rather than percent parasitism alone.

From Figure 1, it can be seen that *M. demolitor* appears in the crop at around the end of December and is responsible for high levels of control (up to 65%) of *Helicoverpa* spp. at certain times throughout the season. *M. demolitor* become important at a crucial period of the crops development.

Figure 2. Fate of *Helicoverpa* spp. larvae collected from an unsprayed cotton block, 1995/96.

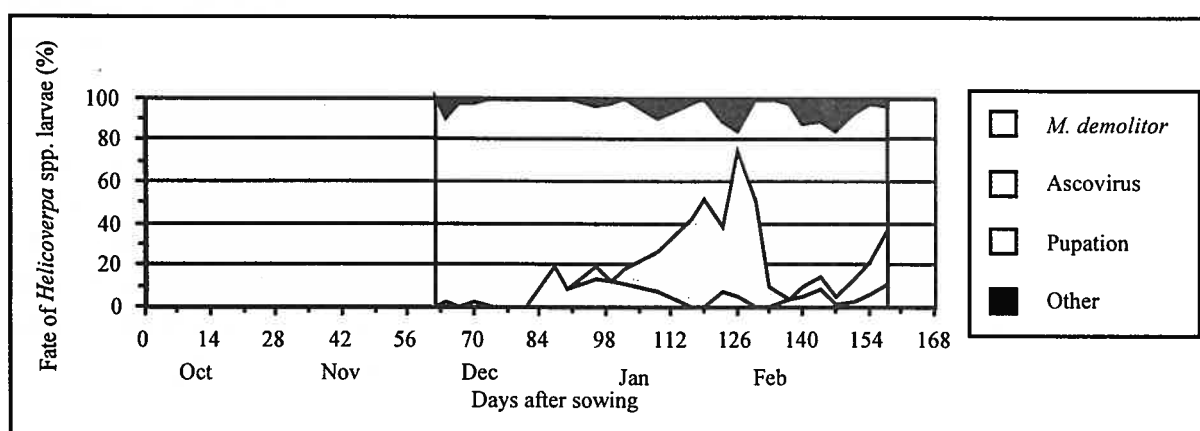


Figure 2 shows a similar pattern to figure 1, although the impact of *M. demolitor* was considerably less than the following year. Mortality of small and small medium sized *Helicoverpa* spp. larvae did, however, exceed 70% during the season.

Larval collections to determine the impact of *M. demolitor* on *Helicoverpa* spp. has the potential to bias results in favour of the wasps. Parasitisation by *M. demolitor* slows the rate of development of its host, thereby causing an accumulation of parasitised individuals in any given population. Powell and King (1984) showed that *Heliothis* spp. larvae parasitised by *M. crociopes* became uniformly distributed over the cotton plant after parasitisation. Their results show that larvae can be collected randomly from the plant and that larvae collected from the top of the plant canopy are not more likely to be parasitised. Ascovirus infection may also increase the probability of larvae being collected. Infected larvae tend to become less mobile at the top of the crop, and are therefore more prone to collection. A small scale study showed that 47.2% of larvae collected from squares were infected with ascovirus, compared to 64.7% of

larvae collected from leaves (unpublished data). These problems were identified early in the study and larvae were collected randomly from the entire plant, so as to minimise any bias.

M. demolitor contributes significantly to control of *Helicoverpa* spp. in unsprayed cotton. Mortality of between 20 and 60% was regularly observed in the field. Although this level of control is not satisfactory alone, as part of an IPM system is very significant and can not be ignored. Trial blocks were small scale (3-5 ha) unsprayed plots, and drift from nearby heavily sprayed commercial blocks may have impacted detrimentally on *M. demolitor* populations, or at the very least may have acted as "sinks". It is likely that any level of control would be increased if insecticide use could be reduced on a large scale.

Toxicity of insecticides used in the control of cotton pests to *M. demolitor* adults and pupae

Beneficial and pest insects often differ in their susceptibility to insecticides. Susceptibility to insecticides may also vary between different stages of an insect's life cycle. Beneficials may be conserved by using insecticides with minimal toxicity or by timing pesticide sprays to coincide with the most tolerant stage of the beneficial's development. The susceptibility of *M. croceipes* to certain insecticides has been studied extensively, and any work on this species is relevant to *M. demolitor*. *M. croceipes* is relatively susceptible to organophosphates (except phosphates) and organochlorines (except toxaphene and DDT), but is tolerant of some carbamates (oxime compounds) and highly tolerant of most pyrethroids (except bifenthrin) (Powell and Scott, 1985; Powell *et al.*, 1986; Elzen *et al.*, 1987; Elzen *et al.*, 1989; Powell and Scott, 1991). *M. demolitor* has been studied less thoroughly than its American relative. No work has been done to test the tolerance of *M. demolitor* adults or pupae to insecticides. Evidence such as abundant *M. demolitor* in heavily sprayed cotton fields (D. Murray *pers. com.*), indicates that this species may be tolerant to some classes of insecticides, especially pyrethroids. Work was carried out to investigate this.

Comparative toxicities of 11 insecticides to adult *M. demolitor* applied topically in the laboratory were determined (unpublished data). *M. demolitor* adults were non susceptible to the two insect growth regulator (IGR) compounds, chlorfluazuron and methoxy fenozide (these products became insoluble in acetone before any response). These compounds have a specialised mode of action, very specific range of activity and little contact activity. They are highly recommended for use in an IPM programme. The carbamate, primicarb was found to be relatively non-toxic to *M. demolitor*. Primicarb is registered for control of the cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae). Use of primicarb would not be expected to disrupt *M. demolitor*. The organochlorine, endosulfan was toxic to *M. demolitor* adults. The organophosphates, dimethoate and profenofos, were highly toxic to *M. demolitor*. The pyrethroids tested were all very toxic to *M. demolitor*. Cyhalothrin was the least toxic, followed by bifenthrin and deltamethrin was the most toxic. The high toxicity of the pyrethroids is somewhat unexpected, and reasons for this apparent anomaly are unclear. The naturallyte compound, spinosad, proved to be extremely toxic to *M. demolitor*. Spinosad was by far the most toxic compound tested. Spinosad is a new insecticide aimed at the control of Lepidopteran pests. No studies have examined the effects of topically applied spinosyns on

beneficials. Field trials have established that spinosad is non-disruptive to certain predator groups (Peterson *et al.*, 1996; Hendrix *et al.*, 1997; Murray and Lloyd, 1997) but may be disruptive to Hymenoptera (Murray, 1996). Hendrix *et al.* (1997) found that if wasps avoided direct initial contact with spinosad, residues once dry, were harmless.

Results show that *M. demolitor* were essentially non-susceptible to insecticides while in the pupal stage. *M. demolitor* pupae were tested with 1, 10 and 100 times the LD₅₀ previously determined for the adults. Most insecticides tested caused negligible mortality. The pyrethroids were innocuous at the LD₅₀, but were extremely toxic at 10 and 100 times the LD₅₀ (95-100% mortality) (unpublished data).

It is reasonable to predict that all tested insecticides except chlorfluazuron, methoxy fenozide and maybe primicarb would be very detrimental to populations of adult *M. demolitor* in the field. However, if insecticide applications can be timed to coincide with the pupal stage, their impact would be significantly reduced.

Development and survival of *M. demolitor* in *H. armigera* larvae exposed to insecticides

Often larvae targeted with insecticide sprays will be parasitised by *M. demolitor*. During this time, larval endoparasitoids may be affected by exposure of the host to toxins. Whether this is due to the direct effects of toxins on the developing parasitoid or due to effects on the host is unclear. Larval parasitoids may be protected from direct contact with insecticides, although it has been shown that toxic substances can be acquired by developing parasitoids (Self *et al.*, 1964). Often the effects on parasitoids are quite subtle and the main effect is due to host mortality, thereby depriving the parasitoid of the proper requisites to complete its life cycle. However, if host susceptibility to insecticides is increased or decreased due to the action of the endoparasite, then it is clear that endoparasitoids influence their own survival against toxicants.

Culin and Debose (1987) studied the effect of chlordimeform, methyl parathion and fenvalerate on larval *M. demolitor* in *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) hosts. They found that the number of parasitoids completing development was reduced, however, this was due to host mortality. They found that there was no increase in the development times of the parasitoids and parasitisation did not increase susceptibility of the host larvae to insecticides. Often host susceptibility to insecticides is reduced due to parasitisation, through reduced feeding and therefore, reduced uptake of toxins (Teakle *et al.*, 1985). Teakle *et al.* (1985) studied the effect of nuclear polyhedrosis virus (NPV) on *M. demolitor* developing within *H. armigera*. They found that if the parasitoid had two days development before infection with NPV, infection was suppressed. Insecticides have been demonstrated to increase the rates of parasitism in the field. Some insecticides when administered in a sublethal dose, retard development of the larval host so larvae remain suitable as hosts for longer (Wollam and Yendol, 1976; Ticehurst *et al.*, 1982). The impact on larval *M. demolitor* after exposure of the host *H. armigera* to insecticides was studied.

Parasitised larvae were treated with previously determined lethal doses each day after parasitisation until parasitoid emergence (0-7 days). Unparasitised larvae were also treated on each day to determine whether host susceptibility was influenced. Stomach poisons tested, included: chlorfluazuron, lufenuron, methoxy fenozide, *Bacillus thuringiensis*, thiodicarb, profenofos and spinosad. Poisons tested with contact activity included: chlorfluazuron, methoxy fenozide, profenofos and spinosad. Stomach toxins had less effect than topically applied insecticides due to reduced feeding of parasitised larvae. *M. demolitor* survival, expressed as the larval emergence, was significantly reduced up until approximately 5 days after parasitisation with stomach poisons. This reduction in *M. demolitor* survival was due to host mortality rather than mortality of the larval parasitoid with the host becoming less susceptible to stomach poisons after 5 days. Parasitoid survival was reduced even after 7 days when profenofos and spinosad were applied topically. This was due to the rapid death of the host, although the larval parasitoid may also have been affected.

This study clearly showed that the effects of exposing hosts to insecticides had negligible direct impact on the developing larval parasitoids, but parasitoid survival was dramatically reduced through host mortality. If insecticide application can be timed to coincide with late larval development of *M. demolitor* and contact insecticides are avoided then insecticides will have a reduced impact.

Implications to IPM

- With the advent of new cotton technologies, such as Environfeast® and Ingard cotton, pest control decisions will be based on pest and natural enemy numbers. It is important that parasitoids are not neglected in an IPM system. Lucerne has been trialed as a nursery crop, and *M. demolitor* is certainly active in lucerne (D. Murray *pers. com.*).
- As far back as 1980 recommendations were made to the Standing Committee on Agriculture that studies into rearing *M. demolitor* for possible use in inundative releases was warranted (Anon, 1981). Inundative releases as a biopesticide are probably not feasible, but maybe early season inoculative releases for early establishment and then preservation of these populations may be warranted

Conclusions

M. demolitor is a crucial piece in the IPM jigsaw:

- Larvae parasitised by *M. demolitor* cause very minor damage to the cotton crop. As a result, parasitised larvae should be tolerated and not counted in larvae checks.
- High rates of parasitism of *Helicoverpa* spp. larvae by *M. demolitor* have been found in the field.
- *M. demolitor* can be monitored in the field by direct observation or by estimating percent parasitism.
- *M. demolitor* become prominent at a crucial stage of crop development.

- *M. demolitor* is tolerant of some families of insecticides. Insecticides known to be relatively less toxic to *M. demolitor* should be used preferentially when *M. demolitor* are present.
- *M. demolitor* is relatively more tolerant of most insecticides during the pupal stage. As a result, insecticide applications should be targeted when *M. demolitor* are in their less susceptible stage.
- *M. demolitor* are relatively more tolerant of insecticides in larval stage if given a “head-start”.
- Interactions with ascovirus must be investigated further.

References

- Anon. (1981) Workshop report to SCA. *in* Workshop on biological control of *Heliothis* spp. 23-25 Sept, 1980. Toowoomba, Queensland, Australia. 123-124.
- Broadley, R.H. (1980). Parasitoids of *Heliothis* spp. larvae collected from sunflowers in south-east Queensland. *in* Workshop on biological control of *Heliothis* spp. 23-25 September, 1980. 66-69.
- Culin J.D. and Debose W.P. (1987). Insecticide interference with *Microplitis demolitor* (Hymenoptera: Braconidae) parasitization of *Heliothis zea* (Lepidoptera: Noctuidae). *Journal of Economic Entomology*. **80**: 1188-1191.
- Elzen G.W., O'Brien., P.J., Snowgrass, G.L., and Powell, J.E. (1987). Susceptibility of the parasitoid *Microplitis croceipes* (Hymenoptera: Braconidae) to field rates of selected cotton insecticides. *Entomophaga*. **31**: 545-50.
- Elzen, G.W., O'Brien, P.J. and Powell, J.E. (1989). Toxic and behavioural effects of selected insecticides on the *Heliothis* parasitoid *Microplitis croceipes*. *Entomophaga*. **34**: 87-94.
- Fitt, G.P. (1989). The ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology*. **34**: 17-52.
- Gregg, P. (1995). *Helicoverpa armigera* and *H. punctigera*- the key pests of cotton. Paper presented at the Australian Entomological Society 26th AGM and Scientific Conference, Tamworth, 23-28 September, 1995.
- Hamel, D.R. (1977). The effects of *Bacillus thuringiensis* on parasitoids of the western spruce budworm, *Choristoneura occidentalis* (Lepidoptera: Tortricidae), and the spruce coneworm, *Dioryctria reniculelloides* (Lepidoptera: Pyralidae), in Montana. *Canadian Entomologist*. **109**: 1409-1415.
- Hendrix, W.H., Huckaba, R., Nead, B., Peterson, L., Porteous, D and Thompson, G. (1997). Tracer insect control- 1996 EUP results. Beltwide Cotton Insect and Research and Control Conference. 1086-1087.
- Hopper, K.R. and King, E.G. (1984). Feeding and movement on cotton of *Heliothis* species (Lepidoptera: Noctuidae) parasitised by *Microplitis croceipes* (Hymenoptera: Braconidae). *Environmental Entomology*. **13**: 1654-1660.
- King, E.W. (1981). Rates of feeding by four lepidopterous defoliators of soybeans. *Journal of the Georgia Entomological Society*. **16**: 283-288.

- King, E.G., Powell, J.E. and Coleman, R.J. (1985). A high incidence of parasitism of *Heliothis* spp. (Lepidoptera: Noctuidae) larvae in cotton in Southeastern Arkansas, USA. *Entomophaga*. **30**: 419-426.
- Murray, D. (1996). The effect of spinosad (NAF-85) on arthropod pest and beneficial populations on cotton. Internal report prepared for the Department of Primary Industries, Queensland.
- Murray, D. (1994). Beneficials parasitising *Heliothis*: augmentation and efficacy. Proceedings of the seventh Australian Cotton Conference. Broadbeach, Gold Coast, Queensland. 51-55
- Murray, D., Ingram, B., Lloyd, R., Marshall, J., Thomson, S., Scholz, B., and Rynne, K. (1996). Four years of IPM in raingrown cotton. Proceedings of the eight Australian Cotton Conference. Broadbeach, Queensland. 153-158.
- Murray, D.A.H. and Lloyd, R.J. (1997). The effect of spinosad (Tracer) on arthropod pest and beneficial populations in Australian cotton. Proceedings Beltwide Cotton Conference. 1087-1091.
- Murray, D. and Mensah, R. (1996). Using predators and parasites to control cotton pests. Proceedings of the eight Australian Cotton Conference. Broadbeach, Queensland. 147-151
- Murray, D. and Rynne, K. (1992). Larval parasites- a biological option. Proceedings of the Australian Cotton Conference. Broadbeach, Queensland. 247-251.
- Peterson, L.G., Porteous, D.J., Huckaba, R.M., Nead, B.A., Gantz, R.L., Richardson, J.M. and Thompson, G.D. (1996). Beneficial insects their role in cotton pest management systems founded on Naturalyte insect control. Proceedings Beltwide Cotton Conference. 872-874.
- Powell, J.E., Edgar, G., King, J.R. and Jany, C.S. (1986). Toxicity of insecticides to adult *Microplitis croceipes* (Hymenoptera: Braconidae). *Journal of Economic Entomology*. **79**: 1343-1346
- Powell, J.E. and King, E.G. (1984). Behaviour of adult *Microplitis croceipes* (Hymenoptera: Braconidae) and parasitism of *Heliothis* spp. (Lepidoptera: Noctuidae) host larvae in Cotton. *Environmental Entomology*. **13**: 272-277.
- Powell, J.E. and Scott, W.P. (1985). Effect of insecticide residues on survival of *Microplitis croceipes* adults (Hymenoptera: Braconidae) in cotton. *Florida Entomologist* **68**: 692-693.
- Powell J.E. and Scott W.P. (1991). Survival of *Microplitis croceipes* (Hymenoptera: Braconidae) in contact with residues of insecticides on cotton. *Environmental Entomology*. **20**: 346-348.
- Self, L.S., Guthrie, F.E. and Hodgson, E. (1964). Metabolism of nicotine by tobacco-feeding insects. *Nature*. **204**: 300-301.
- Shepard, M., Powell, J.E. and Walker, A.J.Jr. (1983). Biology of *Microplitis demolitor* (Hymenoptera: Braconidae), a imported parasitoid of *Heliothis* spp. (Lepidoptera: Noctuidae) and the Soybean Lopper, *Pseudoplusia includens* (Lepidoptera: Noctuidae). *Environmental Entomology*. **12**: 641-645.

- Stanley, J. and Gregg, P. (1994). *Helicoverpa* predators: Do we know anything about them? Proceedings of the Australian Cotton Conference. Broadbeach, Queensland. 45-50.
- Teakle, R.E., Page, F.D., Sabine, B.N.E. and Giles, J.E. (1983). Evaluation of *Heliothis* nuclear polyhedrosis virus for control of *Heliothis armigera* on sorghum in Queensland, Australia. *General and Applied Entomology*. **15**: 11-18.
- Teakle, R.H., Jensen, J.M. and Mulder, J.C. (1985). Susceptibility of *Heliothis armigera* (Lepidoptera: Noctuidae) on sorghum to nuclear polyhedrosis virus. *Journal of Economic Entomology*. **78**: 1373-1378.
- Ticehurst, M.R., Fusco, R.A. and Blumenthal, E.M. (1982). Effects of reduced rates of Dipel 4L, Dylox 1.5 oil, and Dimilin W-25 on *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), parasitism and defoliation. *Environmental Entomology*. **11**: 1058-1062.
- Titmarsh, I.J. (1985). Population dynamics of *Heliothis* spp. on tobacco in far north Queensland. M.Sc. Thesis, James Cook University of North Queensland, Townsville.
- Wollam, J.D. and Yendol, W.G. (1976). Evaluation of *Bacillus thuringiensis* and a parasitoid for suppression of the gypsy moth. *Journal of Economic Entomology*. **61**: 113-118.
- Yanes, J., and Boethel, D.J. (1983) Effects of a resistant soybean genotype on the development of the soybean looper (Lepidoptera: Noctuidae) and an introduced parasitoid, *Microplitis demolitor* Wilkinson (Hymenoptera: Braconidae). *Environmental Entomology*. **12**: 1270-1274.

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