Proc. Eleventh Ann. Conf. Grassld. Soc. NSW, 1996, pp. 76-83

BEETLES, MITES AND CHICORY:

Integrated management of redlegged earth mite in pasture

David G. James

NSW Agriculture, Yanco Agricultural Institute, Yanco, NSW

Summary: Recent advances in our knowledge of redlegged earth mite (RLEM) biology and ecology have enabled development of basic guidelines for integrated pest management (IPM) of this mite. Considerably more research is required before a definitive integrated management strategy can be presented and adopted by growers. The current reluctance of pastoral and crop industries to fund research on integration of chemical, biological and cultural controls is a serious impediment to development of IPM for RLEM. Awareness of the seasonal threat posed by RLEM and well-timed early season action, are critical to successful management. Insecticides remain the most important weapon in RLEM management but their use must be selective, strategic and based on exploiting weaknesses and vulnerabilities in RLEM ecology. This will maximise efficacy whilst minimising use. Greater efforts should be made to minimise chemical disruption to the pasture ecosystem, thus fostering species richness of the microfauna and enhancing biological control of RLEM. Insecticides and rates which are effective against RLEM yet spare natural enemies of RLEM should be preferred. Cultural management options (*e.g.* grazing) have great potential in integrated management of RLEM. Similarly, RLEM-resistant sub-clover varieties, when develop-ed, will play a significant role in reducing the impact of RLEM on pasture production. However, all control options must be incorporated in an overall integrated scheme to derive maximum and sustained benefit. An integrated approach to RLEM management must begin now.

Redlegged earth mite (RLEM) (*Halotydeus destructor*) (Tucker) together with the closely related blue oat mite (BOM) (*Penthaleus major*) Duges, are generally accepted to be the most serious invertebrate pests of pastures in southern Australia causing estimated production losses in the sheep and meat industries of up to $300 million annually (Sloane *et al.* 1988; Ridsdill-Smith 1991a). Young *et al.* (1995) estimated a gain of $49/ha from controlling redlegged earth mite in pasture in Western Australia. In addition, earth mites are major pests of a number of winter crops including canola, lupins and field peas. Their economic impact on winter crop production in southern Australia has not been quantified but is undoubtedly substantial in most seasons.

RLEM has long been considered to be more abundant and widespread in southern Australia than BOM and therefore the most economically important species, however, recent studies indicate the importance of BOM may have been underestimated. Mixed populations of RLEM and BOM are frequent in southern New South Wales and in some locations/seasons BOM can predominate (James and O'Malley 1993 and unpublished observations). A trained eye is needed to distinguish RLEM and BOM in the field and correct identification is essential for good management. Virtually all of the research on earth mites during the last decade has been conducted on RLEM and it is only for this species that we now have a framework for integrat-ed management. Clearly, the economic importance of BOM requires clarification and it is likely a lot of basic research on the biology and ecology of this species will be required. One thing we do know is that RLEM and BOM differ significantly in their biology and ecology (*e.g.* James and O'Malley 1993) and integrated management guidelines for RLEM are not necessarily appropriate for BOM.

Pasture is at its most susceptible to RLEM damage at establishment. In most areas of southern Australia and in most seasons there is significant potential for RLEM to seriously reduce or prevent establishment of newly sown or regenerating pastures. The sheer numbers of RLEM emerging from oversummered eggs during most autumns often results in rapid and substantial damage to young shoots and developing seedlings. A well-timed chemical treatment in autumn is almost mandatory if economic losses are to be prevented. Once a pasture has successfully established, many growers tend to turn a 'blind eye' to RLEM. However, a number of recent studies have shown that RLEM can still cause dramatic losses in production. RLEM selectively attacks legumes, significantly reducing this component (Nicholas and Hardy 1976; Hopkins and Taverner 1991; Slater *et al.* 1996). However, RLEM and particularly BOM will feed on grasses if legumes are not available.

Integrated management of RLEM in pasture and grassland ecosystems incorporating population monitoring/prediction, biological control, chemical control, resistant sub-clovers and cultural strategies, should progressively become the preferred way of dealing with this pest. However, our knowledge, experience and the development of most of these options is currently incomplete and it will be some time before a 'state of the art' integrated management package for RLEM can be presented for grower adoption. The current reluctance of pastoral and crop industries to fund research on integration of biological, chemical and cultural controls is a serious impediment to development of IPM for RLEM. In the meantime, there is considerable value to be obtained in adoption of certain fundamental IPM-based strategies for RLEM control which have been developed in recent years.

I will briefly review the salient features of current knowledge of the biology/ecology, biological control, host plant resistance, chemical control and cultural control of RLEM, before providing guidelines, based on this information, for adopting integrated management strategies.

Review of current knowledge

Biology and Ecology of RLEM

Research conducted primarily by K.R. Norris and M.M.H. Wallace (CSIRO) (1940-1970), D.G. James and K. O'Malley (NSWAG) (1988-1996) and J. Ridsdill-Smith (CSIRO) (1990-1996), has resulted in a reasonably good understanding of many aspects of the biology and ecology of RLEM (*e.g.* Norris 1950; Wallace 1970a, 1970b; James and O'Malley 1991a, 1991b, 1993; Ridsdill-Smith 1991b; Annells and Ridsdill-Smith 1994). However, much more information is required, particularly in the area of natural population regulation, before we can fully exploit this knowledge in RLEM management.

RLEM is native to South Africa, where the earliest studies on biology were conducted (*e.g.* Tucker 1925). Most of the early South African and Australian studies focused on simple life history observations (Jack 1908; Newman 1925; Swan 1934), behaviour (Solomon 1937) and population studies (Norris 1938). Later studies covered egg incubation (Davidson and Swan 1943), egg dia-pause (Norris 1950; Wallace 1970a, 1970b) and geographical distribution (Wallace and Mahon 1971). No significant studies on biology and ecology of RLEM were published from 1971-1991.

James and O'Malley (1991a) showed that summer rainfall in southern New South Wales can have a deleterious effect on survival of oversummering eggs. This was supported by independent experiments in Western Australia (Annells and Ridsdill-Smith 1991). James and O'Malley (1991b) provided degree day requirements for development of both post-diapause and winter eggs of RLEM. Data collected in southern New South Wales during 1985-90 indicated that hot, dry summers, cool-mild, dry autumns and winters and wet, mild springs, promoted population development and survival of RLEM (James 1991a). Information on phenology of egg production and diapause in RLEM and BOM over two seasons in southern New South Wales was provided in James and O'Malley (1993). Currently, a number of workers in Victoria, South Australia and Western Australia are studying aspects of RLEM biology and ecology including reproductive biology, mating behaviour (Annells 1994), nutrition (Annells and Ridsdill-Smith 1994) and population dynamics and structure (Ridsdill-Smith *et al.* 1994; Weeks *et al.* 1994).

Biological control

The possibility of using biological control to manage RLEM was first raised in the mid 1960's when a species of predatory mite (*Anystis salicinus*) was introduced into Australia from France. This predator was observed feeding on springtails and mites in French pastures and was thought to have potential for controlling RLEM (Michael *et al.* 1991a). Today, of course, such a whimsical basis for introducing an exotic organism into Australia would not be countenanced! The fact that *A. salicinus* (now redescribed as *A. wallacei*) is a general predator, feeding on other arthropods as well as RLEM, would undoubtedly prevent importation of this species today. After release of *A. salicinus* at four sites in Western Australia in 1965, little follow up work was done until 1988 when P. Michael and co-workers recommenced the study. Michael *et al.* (1991a, 1991b) and Michael (1995) presented evidence indicating that *A. wallacei* can reduce RLEM populations. However, it appears unlikely that this predator, by itself, can provide economic control of

RLEM. Another problem is its apparent poor natural dispersal (45 m per year : Michael *et al.* 1991a).

Surprisingly, *A. salicinus* (=*wallacei*) was introduced into Australia without careful examination of the biological control potential of endemic predators against RLEM. Even more surprisingly, there has been no concerted effort in recent decades to study the endemic natural enemies of RLEM, despite an abundance of anecdotal evidence suggesting that RLEM populations in natural or unsprayed grasslands/pasture are frequently small. James (1995) recorded 19 species of predator and one pathogen as natural enemies of RLEM and BOM in southern New South Wales. Two further species were added to this list in 1995. Evidence was also presented to support the idea that this complex of natural enemies plays an important role in regulation of earth mite populations in unsprayed pasture. The most important predators appear to be from the mite families Anystidae, Bdellidae, Erythraeidae, Parasitidae and Cunaxidae. Although the possibility exists that there is a predator in South Africa or possibly South America (which may be the ancestral 'home' of RLEM) (Qin and Halliday 1995), which is 'specific' to RLEM, it is more likely that our best opportunity for biological control of RLEM rests with a complex of generalist natural enemies which may already exist in Australian grasslands. The complex already recognised in southern New South Wales may not be the most effective; only comparative studies on RLEM-natural enemy population dynamics in different regions of southern Australia will reveal this.

Host plant resistance

Extensive research aimed at developing resistant pasture plants has been underway for almost a decade in Western Australia, South Australia and Victoria with activities heightened since about 1990 (Berg 1994, Gillespie 1991, 1994; Lake 1991; Nichols, 1991; Ridsdill-Smith *et al.* 1995). A small number of RLEM-resistant (express-ed in the seedling stage) genotypes (~12) of subterranean clover and medic, have been identified but difficulties are being experienced in the field testing of these varieties (Gillespie 1994). One apparent drawback of some of these varieties is that they lose resistance to RLEM as the plants mature. Successful RLEM-resistant varieties may ultimately be less desirable agronomically than other varieties and the potential for RLEM to eventually overcome plant resistance can not be ignored. The work of Ridsdill-Smith and co-workers in looking at the biology of resistance (Ridsdill-Smith 1995) and plant resistance mechanisms is valuable in this respect (*e.g.* Jiang *et al.* 1994, 1996). In an alternative approach to isolating RLEM resistance in subclover, some of the genes and proteins involved in the plant's defence response to pest attack have been characterised, opening the way for their possible manipulation in transgenic clover (Weinman *et al.* 1995).

Chemical control

Insecticides remain our most potent weapon in the war against RLEM. However, it is their misuse and overuse which has greatly contributed to the problems experienced today in controlling RLEM. Most of the insecticides registered for control of RLEM are highly toxic to motile stages of the pest (James 1987). However, none are effective against the egg stage. It is probably this fact which has led to the majority of incidents where an insecticide has 'failed' against RLEM. Considerable improvements in efficacy and savings in insecticide costs can be achieved simply by targeting sprays at populations which have a minimal or nil egg load.

Insecticides have been the only management option for RLEM for the past 50 years or so and are likely to remain an important, strategic component of RLEM management for the forseeable future. Fifty years ago DDT as a spray, dust or topdressing mixed with superphosphate was highly effective against RLEM and was used in most states until the late 1960's or early 1970's (Dent 1960; Erlich 1962; Wright 1961). The efficacy of DDT as an RLEM treatment was largely due to its prolonged persistence on soil and vegetation. This provided excellent residual control and a single application annually often was sufficient for excellent results. Control of RLEM using DDT was simple, cheap and effective. The realisation that DDT and its chlorinated hydrocarbon cousins were a significant threat to the environment soon led to a search for alternative insecticides for RLEM. Carbamate and organophosphorus sprays like azinphos-ethyl, carbaryl, malathion and phosmet were subsequently recommended for RLEM control (*e.g.* Wright 1965; Button 1966) but none possessed the residual efficacy of DDT. It was this fact that led many growers during 1965-1985 to continue using DDT for RLEM. In fact, even as late as 1985 some growers were still using DDT illegally to control RLEM.

James (1991b) provided a list of 11 insecticides registered for use against RLEM, all of which are organophosphates except for the organochlorine compound, endosulfan. Today there are also at least three synthetic pyrethroids registered (or close to registration) for use against RLEM (alphacypermethrin, lambdacyhalothrin and bifenthrin). Despite the importance of chemical control in RLEM management, surprisingly little independent research has been done in this area during the past decade. Apart from the work of James (1987), Michael (1991) and James and O'Malley (1992, 1994), most other research on chemical control of RLEM has been conducted by chemical companies (*e.g.* Tucker *et al.* 1995). There is no doubt that most registered insecticides are effective if used correctly and the expectations derived from the DDT era are not placed upon them.

The area which suffered most from the withdrawal of DDT was protection of establishing seedlings. Prior to 1991, none of the alternative sprays recommended for establishing crops and pastures persisted longer than a week or two on bare earth. This often resulted in mite inundation of seedlings and seedling death. Systemic sprays (which 'lock' insecticide' within plant sap) were of limited use due to the need for mites to attack seedlings to gain their lethal dose. This was acceptable when mite numbers were low or moderate but unacceptable when thousands of mites attacked single seedlings. A breakthrough in control of RLEM in establishing crops and pastures occurred in 1991 when endosulfan, a contact insecticide, applied to bare earth was found to protect seedlings for up to 5 weeks, despite rainfall (James and O'Malley 1992). Endosulfan has been used widely as a bare earth treatment for RLEM since 1992 and has substantially reduced the incidence of early season crop/pasture losses from RLEM. A synthetic pyrethroid, bifenthrin (Talstar®), with the same efficacy as endosulfan on bare earth is now available, but only for use in canola at this stage.

For the last decade or so, the systemic organophosphates, omethoate and dimethoate, have been the most commonly used foliar treatments for RLEM in pastures and if used correctly provide good control for 1-3 months, depending on application timing. At least two synthetic pyrethroids (lambdacyhalothrin, alphacypermethrin) are close to being registered for RLEM control in pasture and are as effective, if not more effective, than the systemic organophosphates. The pyre-throids also have the advantage of being less toxic to people and animals and in the case of alpha-cypermethrin at least, have the potential to be used in an integrated management system for RLEM which incorporates biological control.

Impact of insecticides on natural enemies of RLEM

All of the insecticides registered for control of RLEM are broad-spectrum in their action killing non-target organisms to a greater or lesser extent. Similarly, insecticides used for other pasture pests are also generally non-selective in their activity. However, RLEM is highly susceptible to insecticides (James 1987), providing an opportunity, perhaps, to develop rates which kill RLEM but spare natural enemies. For example, James *et al.* (1995) showed alphacypermethrin at a rate of 2.5 g a.i. /ha would minimise mortality of a number of RLEM predators, whilst providing acceptable control of RLEM. These sort of studies are required for all of the insecticides used in pasture so that the impact on non-target and beneficial organisms can also be considered when decisions are made concerning chemical choice and rates.

Cultural control

Various possibilities for managing RLEM populations using cultural strategies are available but in general have been little studied. Wallace (1961) was the first to consider pasture burning during summer as a way of reducing numbers of oversummering eggs of RLEM. Although his experiments indicated a significant reduction in egg numbers in moderately or intensely burnt plots, it was concluded that for practical purposes, burning was unlikely to produce a widespread, uniform kill. Flooding of summer pastures may also increase mortality of oversummering eggs (James and O'Malley 1991a), but again is unlikely to be practical in many situations.

Management of animal grazing to suppress populations of RLEM is a cultural strategy with perhaps the most potential for minimising the impact of earth mites in pasture. Despite some evidence that sheep do not like eating RLEM-contaminated pasture (Pratley *et al.* 1991), results from Western Australia have shown winter grazing can significantly reduce RLEM populations in spring and the following autumn (Grimm *et al.* 1995).

Guidelines for integrated management

Our current knowledge of RLEM, summarised above, provides a good basis for developing more intelligent and integrated approaches to management. There are still many 'grey' areas which need considerably more research, but overall we do have the framework now for managing this pest in a more effective and sustainable manner.

RLEM emerge from oversummered eggs (often in vast numbers) every autumn, timed to perfection, in order to inflict the maximum amount of damage to vulnerable, newly-germinated seedlings. Of course this is no coincidence; hatching is stimulated by precisely the same environmental conditions which govern germination of their food resource:

winter-active plants.

Although damaging populations of RLEM occur virtually every year, the last two seasons (1994, 1995) in south-eastern Australia were characterised by generally small numbers of mites and localised pasture/crop damage. Indeed in many parts of the Riverina at least, spraying for RLEM was rarely warranted during winter-spring 1994 and autumn-winter 1995. The cause of this was the very dry winter/spring of 1994 which greatly restricted plant growth and RLEM population development The occurrence of good winter/spring rainfall in 1995 recussitated RLEM populations in most areas and by late spring very large numbers were again common in pastures and were even invading spring sown vegetable crops on the Southern Tablelands of New South Wales. The oversummered egg population in 1995/96 was the largest for a number of years and given a good autumn break very large RLEM populations are likely in most regions this winter. In fact, given a return to 'normal' seasonal conditions (*i.e* average rainfall during autumn-spring), we will probably enter a two-three year period of very high RLEM abundance, as was last seen in NSW, SA and Victoria during 1987-90. Populations during this period were sometimes described as 'plague-like' and extremely hard to control using insecticides. Episodes of extreme abun- dance followed by smaller populations (linked probably to drought cycles) have been a feature of RLEM population dynamics in NSW, at least, for 40-50 years.

Be prepared! The first rule of integrated management of RLEM is to be prepared! Awareness of the extent of the potential problem and its starting date each season is probably the key to success. If you get caught by surprise and miss the week in which mites first appear in autumn, you could spend the rest of the season trying to catch up! As indicated above the evidence from last season suggests large populations of RLEM will occur in 1996, given good seasonal conditions. Unfortunately, RLEM does not hatch at the same time each season so it is important to monitor temperature and rainfall conditions to determine the approximate date of first hatching. As a general rule of thumb, RLEM hatchings are triggered when rainfall of at least 15-25 mm is followed by 3-4 days of cool, cloudy weather with daytime temperatures below 20^{o}C. This can occur anytime from March-June. In March hatchings occur about 10 days after these conditions while in June it may be 3 weeks before the first mites are seen. The speed at which a large population of emerging first instar RLEM (which are almost 'invisible' to the naked eye) can destroy a germinating crop or pasture, is astonishing! There have been many instances in the Riverina of crops and establishing pasture destroyed by RLEM before they even break through the soil surface! The most effective spray for RLEM you will apply all season is the one targeted at this newly emerged population. This spray, if timed well, has the potential of virtually eliminating RLEM from the paddock. This is because mites at this stage are immature and not producing eggs which are resistant to all sprays. Once eggs are produced you can only kill the non-egg part of the population leaving the eggs to hatch and rapidly repopulate the paddock. The optimal spray period (*i.e.* between hatching and first production of eggs) may only be 8-10 days in March but as long as 2-3 weeks in late May and June.

Did you treat last spring?

Ideally, the first shot in the annual battle against RLEM should be fired in the previous spring. A well-timed spray or two in September, before mites commence storing oversummering eggs in their bodies, can substantially reduce the oversummering population and therefore the threat to establishing pasture/crop in the following season. Timing of this spray(s) is critical and again varies between years and locations. A simple way of determining timing has not yet been developed but as a rule of thumb, the optimal time is often sometime during late August-mid September.

Seed treatment

If you do not apply a spring RLEM treatment to the paddock you sow into in autumn, then you will certainly need to treat your seed with a systemic insecticide like omethoate. This will protect the seed in the soil from young earth mites as they hatch within the soil and find their way to the surface (nibbling all the way). A well-timed spring treatment may remove the need for seed treatment. Do not fall into the trap of believing seed treatments will always protect emerging seedlings from large numbers of RLEM. Although mites feeding on these seedlings will die, inevitably there will be more to take their place and the combined feeding effect sufficient to seriously injure or kill the seedlings.

Bare earth treatments

The only reliable way to protect emerging seedlings from large populations of RLEM is to apply an effective bare earth spray just prior to seedling emergence. The only insecticides demonstrated to provide reliable and prolonged bare earth control of RLEM, are endosulfan and bifenthrin. Endosulfan should only be used as a bare earth treatment for RLEM, never as an established pasture treatment. It should not be applied by air. It is hoped that bifenthrin will eventually be registered for use in pastures. The use of other less residual products as bare earth treatments is fraught with danger, particularly when mite numbers are high.

Winter treatments should be targeted

If the early season tactics outlined above were successful, the main threat to paddocks during winter will come from RLEM migrating in from surrounding areas. The ability of RLEM to traverse hundreds of metres during a season should not be underestimated. Mites can be dispersed by wind currents and by hitching rides on flying insects as well as by their own locomotion. However, 'barrier' treatments of insecticide applied to bare earth and weeds around paddocks can significantly delay paddock invasion. While RLEM populations often increase rapidly during autumn, the rate of population growth can decline markedly in winter. This is especially pronounced in wet winters when populations often diminish significantly during July-August. This 'weakness' in RLEM ecology can be exploited by applying a foliar spray at the time populations are undergoing this natural decline, or at least before numbers begin increasing again in late winter. More research is required to pinpoint more accurately spray timing and to ensure sprays do not interfere with the natural mortality processes. Sprays should be targeted at populations dominated by motile stages to reduce the potential for rapid resurgence from insecticide-tolerant eggs. Routine sampling of populations and a predictive model for post-egg development would provide a good basis for spray timing decision making.

Preserve natural enemies

A key component of most integrated management programs for insects and mites is biological control. RLEM is no exception and there is increasing evidence to suggest that preservation and utilisation of endemic biological control agents should be a major feature of control programs for this pest (James 1995). More than 20 natural enemies of RLEM have now been discovered in the Riverina and this list is expanding annually. Most of these natural enemies are different species of predatory mites, but predatory insects and even a fungal pathogen have been recorded attacking RLEM. It is likely that no single species of predator or pathogen exerts substantial control pressure on RLEM; rather it is the combined impact of this assemblage of different natural enemy species, which regulates RLEM populations and therefore offers the greatest prospects for biological control. Biological control of RLEM is a resource available in every paddock but one we know very little about. However it is clear that minimal chemical disturbance of the pasture ecosystem should result in a healthy and diverse microfauna that will go a long way to providing effective natural regulation of RLEM. Anecdotal evidence over a number of years has shown certain farmers to have a continuing RLEM problem (chemically disturbed ecosystem?), whilst nearby farmers claim to have no problem at all (minimal chemical inputs?). Research in this area, including exploration within Australia for additional RLEM predators, is desperately required so that we can better incorporate natural mortality factors in overall management plans for RLEM.

One area in which some modest advances have been made is the compatibility of insecticides used for RLEM with survival of natural enemies. Research at Yanco has shown that there is potential for using RLEM insecticides at rates which kill RLEM but preserve natural enemies (*e.g.* alphacypermethrin at 2.5 g a.i. /ha: James *et al.* 1995). Far more research is required on integration of insecticides with biological control of RLEM. However, it is clear that minimal and strategic use of insecticides at the correct minimum rates will minimise their impact on RLEM natural enemies and maximise the role of biological control in population regulation.

Conclusion

Despite the considerable research effort into areas like biotechnology and development of RLEM-resistant plant varieties, control of RLEM in the forseeable future will continue to be based on insecticides. The development of integrated management strategies focusing on 'weaknesses' in RLEM ecology and 'endemic biological control', offer the best practical solution to more effective control with less use of insecticide. Thus, it is disappointing that pastoral and crop industries to date, have not recognised the value of developing IPM for RLEM. Even if research on resistant plant varieties and biotechnology is successful, these outcomes will still need to be used in an IPM environment to gain maximum long term value. However, there is still a lot that farmers can do now to reduce insecticide use and improve control, although more research is desperately needed to refine and optimise the suggested approaches and strategies. The farmer today is clearly in a much better position to deal with RLEM than he has ever been.

References

Annells, A.J. (1994). The reproductive biology and mating behaviour of redlegged earth mite: An overview. In

Proceedings of *Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite*, pp. 29-31. Rutherglen, Victoria.

Annells, A.J. and Ridsdill-Smith, T.J. (1991). The effect of moisture on aestivating eggs of *Halotydeus destructor* (Tucker) (Acarina: Penthaleidae). In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 7-9. Perth, Western Australia.

Annells, A.J. and Ridsdill-Smith, T.J. (1994). Host plant species and carbohydrate supplements affecting rate of multiplication of redlegged earth mite. *Experimental and Applied Acarology* **18**: 521-530.

Berg, G. (1994). Reducing the impact of redlegged earth mite and blue oat mite through the identification of resistant white clover lines. In *Proceedings of Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. p. 12. Rutherglen, Victoria.

Button, J.A. (1966). Organophosphorus insecticides for control of redlegged earth mite and lucerne flea. *Journal of Agriculture of Western Australia* **7** (6) Bull. No. 3433.

Davidson, J. and Swan, D.C. (1943). The incubation period of the eggs of *Halotydeus destructor* (Tucker) (Acarina) at different temperatures. *Australian Journal of Experimental Biological and Medical Science* **21**: 107-110.

Dent, R.G. (1960). Redlegged earth mite and its control. *Journal of the Department of Agriculture, South Australia* **63**: 333.

Erlich, S. (1962). Redlegged earth mite occurrence, biology and control. *Journal of Agriculture, Victoria* **60**: 291-293.

Gillespie, D.J. (1991). Identification of resistance to redlegged earth mite (*Halotydeus destructor*) in pasture legumes. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 72-75. Perth, Western Australia.

Gillespie, D.J. (1994). Identification and development of annual legume varieties with resistance to redlegged earth mite. In *Proceedings of Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 1-4. Rutherglen, Victoria.

Grimm, M., Michael, P., Hyder, M. and Doyle, P. (1995). Effects of pasture pest damage and grazing management on efficiency of animal production. *Plant Protection Quarterly* **10**: 62-64.

Hopkins, D.C. and Taverner, P.D. (1991). Damage caused by mites and flea in pastures. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 46-49. Perth, Western Australia.

Jack, R.W. (1908). The earth flea. *Agricultural Journal, Cape of Good Hope* **31**: 615-620.

James, D.G. (1987). Toxicity of pesticides to the redlegged earth mite, *Halotydeus destructor*. *Plant Protection Quarterly* **2**: 156-157.

James, D.G. (1991a). Environmental factors affecting autumn egg hatch and population development of *Halotydeus destructor* (Tucker) (Acari: Penthaleidae). In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 32-34. Perth, Western Australia.

James, D.G. (1991b). Chemical control of earth mites and lucerne flea. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp.60-62. Perth, Western Australia.

James, D.G. (1995). Biological control of earth mites in pasture using endemic natural enemies. *Plant Protection Quarterly* **10**: 58-59.

James, D.G. and O'Malley, K.J. (1991a). Oversummering of eggs of *Halotydeus destructor* (Tucker) (Acarina: Penthaleidae): Diapause termination and mortality. *Australian Entomological Magazine* **18**: 35-41.

James, D.G. and O'Malley, K.J. (1991b). Effect of temperature on development and survival of eggs of *Halotydeus destructor* (Tucker)(Acari: Penthaleidae). *International Journal of Acarology* **17**: 209-212.

James, D.G. and O'Malley, K.J. (1992). Control of *Halotydeus destructor* (Tucker) (Acari: Penthaleidae) on bare earth. *Plant Protection Quarterly* **7**: 10-11.

James, D.G. and O'Malley, K.J. (1993). Phenology of egg production and diapause in *Halotydeus destructor* (Tucker) and *Penthaleus major* Duges (Acari: Penthaleidae) in southern New South Wales. *General and Applied Entomology* **24**: 33-38.

James, D.G. and O'Malley, K.J. (1994). The effect of simulated rainfall on efficacy of omethoate, dimethoate and alphacypermethrin as foliar treatments for redlegged earth mite, *Halotydeus destructor*. *Plant Protection Quarterly* **9**: 88-89.

James, D.G., O'Malley, K.J. and Rayner, M. (1995). Effect of alphacypermethrin and bifenthrin on the survival of five acarine predators of *Halotydeus destructor* (Acarina: Penthaleidae). *Experimental and Applied Acarology* **19**: 647-654.

Jiang, Y., Ridsdill-Smith, T.J. and Ghisalberti, E.L. (1994). Approaches to the study of resistance mechnisms in subclover cotyledons against redlegged earth mite. In *Proceedings of Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 13-15. Rutherglen, Victoria.

Jiang, Y., Ridsdill-Smith, T.J. and Ghisalberti, E.L. (1996). Assays for the effects of volatile compounds from artificially damaged cotyledons of subterranean clover on the redlegged earth mite, *Halotydeus destructor*. *Experimental and Applied Acarology* **20**: 61:72.

Lake, A.W.H. (1991). Redlegged earth mite resistance in annual *Medicago*. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 76-79. Perth, Western Australia.

Michael, P.J. (1991). Season-long effects of four chemicals on redlegged earth mite and lucerne flea. In Proceedings of *A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 63-65. Perth, Western Australia.

Michael, P.J. (1995). Biological control of redlegged earth mite and lucerne flea by the predators *Anystis wallacei* and *Neomolgus capillatus*. *Plant Protection Quarterly* **10**:55-57.

Michael, P.J., Dutch, M.E. and Pekin, C.J. (1991a). A review of the predators of redlegged earth mite, blue oat mite and lucerne flea. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 115-120. Perth, Western Australia.

Michael, P.J., Dutch, M.E. and Pekin, C.J. (1991b). Successful spreading of *Anystis salicinus* (L.) (Acari: Anystidae) and *Neomolgus capillatus* (Kramer) (Acari: Bdellidae) and their effects on redlegged earth mite and lucerne flea. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 121-126. Perth, Western Australia.

Newman, L.J. (1925). The redlegged earth mite. *Journal of Agriculture, Western Australia* **2**: 469-475.

Nicholas, D.A. and Hardy, D.L. (1976). Redlegged earth mite cuts pasture production. *Journal of Agriculture, Western Australia* **17**: 33-34.

Nichols, P.G.H. (1991). Development of subterranean clover varieties with resistance to redlegged earth mite. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite*. pp. 80-82. Perth, Western Australia.

Norris, K.R. (1938). A population study of the redlegged earth mite (*Halotydeus destructor*) in Western Australia with notes on associated mites and collembola. CSIRO Pamphlet No. 84.

Norris, K.R. (1950). The aestivating eggs of the redlegged earth mite, *Halotydeus destructor* (Tucker). *Bulletin CSIRO No 253.*

Pratley, J.E., Watt, J., Seidel, J., Slater, P.D. and Lewington, D. (1991). Palatability effects by redlegged earth mite. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite.* pp. 50-52. Perth, Western Australia.

Quin. T.K. and Halliday, R.B. (1995). Systematic studies of redlegged earth mite, *Halotydeus destructor* and related species (Acarina: Penthaleidae). *Plant Protection Quarterly* **10**: 50-52.

Ridsdill-Smith, T.J. (1991a). A contribution to assessing the economic impact of redlegged earth mite on agricultural production in Australia. In *Proceedings of A National Workshop on redlegged earth mite, lucerne flea and blue oat mite* pp. 53-56. Perth, Western Australia.

Ridsdill-Smith, T.J. (1991b). Biology and ecology of redlegged earth mite, blue oat mite and lucerne flea. In Proceedings of *A National Workshop on redlegged earth mite, lucerne flea and blue oat mite.* pp. 36-41. Perth, Western Australia.

Ridsdill-Smith, T.J. (1995). Responses and feeding damage of redlegged earth mite (Acarina: Penthaleidae) to seedlings of resistant and susceptible subterranean clover varieties. *Australian Journal of Agricultural Research* **46**: 1091-1099.

Ridsdill-Smith, T.J., Annells, A.J., Thomson, C.J. and Fox, D.R. (1994). Factors affecting redlegged earth mite populations in pastures. In *Proceedings of Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite.* pp. 37-39. Rutherglen, Victoria.

Ridsdill-Smith, T.J., Jiang, Y., Gaull, K.R. and Gillespie, D.J. (1995). Redlegged earth mite performance on resistant subterranean clover varieties. *Plant Protection Quarterly* **10**: 43-45.

Slater, P.D., Lewington, D. and Pratley, J.E. (1996). An investigation into the effects of redlegged earth mite (*Halotydeus destructor*) (Tucker) and lucerne flea (*Sminthurus viridis* (L.)) on the performance of subterranean clover in annual pasture in southern New South Wales. *Plant Protection Quarterly* **11**: 6-8.

Sloane, Cook and King (1988). The economic impact of pasture weeds, pests and diseases on the Australian Wool Industry. *Report for the Australian Wool Corporation.*

Solomon, M.E. (1937). Experiments on the effects of temperature and humidity on the survival of *Halotydeus destructor* (Tucker), Acarina fam. Penthaleidae. *Australian Journal of Experimental Biological and Medical Science* **15**: 1-16.

Swan, D.C. (1934). The redlegged earth mite *Halotydeus destructor* (Tucker) in South Australia with remarks upon *Penthaleus major* Duges. *Journal of Agriculture, South Australia* **38**: 353-367.

Tucker, R.W.E. (1925). The black sand mite: *Penthaleus destructor* n. sp. *Union South African Department of Agriculture; Entomology Memoir* No. **3**: 23-36.

Tucker, G.R., Collingwood, P., Hildebrand, O. and McCormack, W. (1995). The use of synthetic acaricides as tools for management of redlegged earth mite in crop and pasture systems in southern Australia. *Plant Protection Quarterly* **10**: 60-61.

Wallace, M.M.H. (1961). Pasture burning and its effect on the aestivating eggs of *Halotydeus destructor* (Tucker). *Australian Journal of Experimental Agriculture and Animal Husbandry* **1**: 109-111.

Wallace, M.M.H. (1970a). Diapause in the aestivating egg of *Halotydeus destructor* (Acari: Eupodidae). *Australian Journal of Zoology* **18**: 295-313.

Wallace, M.M.H. (1970b). The influence of temperature on post-diapause development and survival in the aestivating eggs of *Halotydeus destructor* (Acari: Eupodidae). *Australian Journal of Zoology* **18**: 315-329.

Wallace, M.M.H. and Mahon, J. A. (1971). The distribution of *Halotydeus destructor* and *Penthaleus major* (Acari: Eupodidae) in Australia in relation to climate and land use. *Australian Journal of Zoology* **19**: 65-76.

Weeks, A., Fripp, Y. and Hoffmann, A.A. (1994). Population structure of redlegged earth mite and blue oat mite populations in Victoria. In *Proceedings of Second National Workshop on redlegged earth mite, lucerne flea and blue oat mite.* pp. 33-35. Rutherglen, Victoria.

Weinmann, J.J., Djordjevic, M.A., Creaser, E.H., Lawson, C.G.R., Broderick, K., Mathesius, U., Gartner, E., Pittock, C., DeMajnik, J. and Rolf, B.G. (1995). Preparing subterranean clovers for future biotechnology: Molecular analysis of genes and proteins involved in stress and defence reactions and the construction of transgenic plants. *Plant Protection Quarterly* **10**: 47-49.

Wright, W.E. (1961). Redlegged earth mites (Acarina). *Agricultural Gazette of New South Wales* **72**: 213-215.

Wright, W.E. (1965). Carbamate and organophosphorus sprays as alternatives to DDT to control redlegged earth mites (*Halotydeus destructor* and *Penthaleus major*). *Australian Journal of Experimental Agriculture and Animal Husbandry* **5**: 68-74.

Young, J.M., Ridsdill-Smith, T.J., Gillespie, D.J. and Michael, P. (1995). The value of reducing redlegged earth mite damage in pastures and the impact on optimal farm strategies for the great southern region of Western Australia. *Plant Protection Quarterly* **10**: 67-68.