INVITED REVIEW

STRATEGIC USE *OF,* AND ALTERNATIVES TO, CHEMICALS FOR THE CONTROL OF ARTHROPOD PESTS OF LIVESTOCK

*P. J. JAMES**

SUMMARY

To address increasing consumer concern over the potential for pesticide residues in farm produce, as well as other problems associated with pesticide usage, it is important that the livestock industries utilize integrated programmes which maximise the efficiency of use of pesticides. Effective integrated programmes are available for the control of many livestock pests but often the non-chemical components are under utilized. Biological, genetic, and immunological means of control, breeding for improved resistance. and improved strategies for the administration of chemicals for the control of Australian livestock pests are discussed, Education of consumers of the rigorous safety standards required for registration of veterinary chemicals and of the low potential for residues from modern ectoparasiticides should be a priority.

INTRODUCTION

Most attention on residues from ectoparasiticides has to date focused on two main groups, the organochlorines and arsenic. Industry bodies have been quick to act. The sale of these compounds for controlling any species of livestock parasites has been banned and monitoring systems to check for residues in meat, wool, milk and eggs are now in place. This paper is not concerned with these chemicals. However, currently there seems to be a perception in the community that use of all synthetic pesticides is bad and the presence of residues of any sort is unacceptable.

Regardless of whether the fears expressed are real or imagined, pesticide residues, even though they may be well within acceptable limits, can severely affect the marketability of produce. As a major exporter of livestock products such considerations are crucially important to the Australian economy. It is in the interests of all livestock industries to develop parasite control strategies which avoid chemical residues in livestock, products..

In addition, strategic use of ectoparasiticides is important for the following reasons:

1. Pesticide resistance - Already resistance has caused problems for the control of many ectoparasite species (Drummond 1977). When resistance develops, higher concentrations of pesticide are required to achieve control and the chance of residues is increased, With stricter controls and burgeoning costs to develop and register new products it is likely that there will be a reduction in the rate of release of new pesticides onto the market. It is important that usage patterns be adopted to minimise selection for resistance and maximise the effective life of those pesticides presently available,

2. Occupational exposure to pesticides - Farm workers applying treatments as well as personnel employed in other sectors of the industry such as shearers, stockmen and slaughtermen may be exposed to pesticides. Protocols are currently being developed for the assessment of hazard from pesticide residues in raw wool (Reed *et al. 1989).*

3. Environmental considerations - Effects on non-target organisms, accumulation of residues in the environment and disposal of pesticide

* *Department of Agriculture, G.P.O. Box 1671, Adelaide, S.A. 5001.*

wastes are increasingly topics of public concern.

4. Economic considerations - Optimising the effect of each treatment will reduce both the number of treatments required and the associated labour and chemical costs.

Ways in which the use of pesticides can be optimised and the chance of pesticide residues minimised are discussed in this paper.

RESIDUES FROM CURRENLY REGISTERED ECTOPARASITICIDES

Prior to registration of a pesticide for the treatment of livestock, maximum residue limits (MRLs), which incorporate a large safety factor, are carefully established for residual levels in meat, milk and eggs. MRLs should no be exceeded if pesticides are applied according to label directions and the withholding periods are observed. Most ectoparasiticides currently registered, if absorbed into body tissues at all, are rapidly detoxif Fed and excreted. A number have zero withholding periods.

Table 1 Residues of chemicals which are currently registered for the treatment of ectoparasites on domestic livestock - National Residue Survey July 1988 to June 1989

Species	Chemical	Number of samples tested	Number with residues	Number with residues exceeding the MRL
Beef	Organophosphate	9932	41	
	Avermectin/Ivermectin	432	5	2 (Ivermectin)
	Cyromazine	351	0	
Sheep	Organophosphate	8258	17	
	Avermectin/Ivermectin	377	2	
	Cyromazine	312	0	
Pork	Organophosphate	2425	3	
	Avermectin/Ivermectin	411	1	1 (Avermectin)
	Cyromazine	140	0	
Goats	Organophosphate	223	0	
Poultry				
Meat	Organophosphate	826	0	
Eggs	Organophosphate	206	1	1 (Fenitrothion)
Milk	Organophosphate	67	0	
Fat products	Organophosphate	241	0	

Data in Table 1 show the residues detected in livestock meats, eggs and milk in the National Residue Survey during the 1988/89 year that could possibly have resulted from treatments for ectoparasite control. Of a total of 25,706 samples tested, only 4 (0.016%) exceeded permissable MRLs while 0.26% contained detectable levels of residues below the MRL. Seneviratna and Baton (1989) note that sheep fed grain treated with fenitrothion or chlorpyriphos, which are extensively used to protect grain from store product pests, can show violative levels for organophosphates if slaughtered within a few days of feeding, Some residues for organophosphates may have resulted from ingestion of contaminated food rather than from use of ectoparasiticides, Of the samples which exceeded MRLs, those for ivermectin and avermectin resulted from the use of these pesticides on species for which they were not registered whereas the violation for fenitrothion is most likely to have resulted from feeding poultry with treated grain. These figures underline the safety of most of the currently registered ectoparasiticides. Presently the National Residue Survey does not test for amitraz, promacyl or rotenone which are also used in ectoparasite treatments. Testing for synthetic pyrethroid residues has commenced recently,

It should be noted that the United States has no MRLs in meat for some organophosphates which are used as ectoparasiticides in Australia, cyromazine, cypermethrin, deltamethrin, promacyl or rotenone. Where levels have not been set an effective MRL of zero *is* taken. This represents a serious potential threat to meat exports (Pryor 1987).

Maximum residue limits have not been developed specifically for pesticide residues in raw wool, lanolin or other livestock fibres. Manufacturers of pharmaceuticals and cosmetics are particularly sensitive to the presence of residues in lanolin although these concerns have been addressed to a large extent by the development of processing techniques to remove pesticides from wool grease and the commercial availability of British Pharmocopceia specified "pesticide reduced" and "pesticide free" lanolin (Reed *et al.* 1989.) In addition, there is increasing concern in Europe about the presence of pesticides, in particular pyrethroids, in wool scouring effluent (Evans 1988). The possibility of hazards from occupational exposure of shearers and farm workers to pesticides in wool grease has also been noted (Reed *et al.* 1989). Effective methods of controlling parasites which minimise the levels of residues are necessary to avoid possible future problems.

USE OF NON-CHEMICAL METHODS OF CONTROL

Physical and cultural controls

Physical methods can be effective in controlling parasites and are often long lasting or permanent in their effect. However sometimes their usefulness is under valued and they are often not used to their full potential, This may in many cases be because of the ready availability of pesticides as a 'quick fix' back-up.

Mulesing, docking tails to the correct length, crutching, shearing and pizzle dropping are cultural methods used to reduce susceptibility of sheep to flystrike. Many believe that by judicious use of these techniques, breech strike can be controlled in all but the worst seasons, Morley and Johnstone (1984) conclude from a review of the development and use of the Mules operation that levels of adoption of mulesing are well below optimum, particularly in non-Merino breeds, despite abundant evidence of the benefit of the operation to these breeds. Similarly, though the importance of docking tails to a medium-long length to prevent wool staining and subsequent flystrike has been recognised since the work of Gill and Graham (1939), surveys summarised by Morley and Johnston (1984) suggest that, in some areas, more than 50% of producers dock tails too short. These authors suggest that new extension approaches may be needed to increase adoption of correct tail docking and mulesing procedures.

The use of trapping to reduce populations of livestock pests has been attempted with many species. Bait bins used early in the season as sheep blowflies *(Lucilia cuprina)* emerge from over wintering, *or* placed at strategic sites where populations of flies persist, may be effective in reducing strike incidence in pastoral areas (Anderson 1990). However, traps are likely to have little effect once strike waves have begun, or in wetter areas where fly populations are higher, unless used at impractically high densities (Mackerras *et al.* 1936). Traps for buffalo flies *(Haematobia irritans exigua)* may be effective in maintaining fly numbers below economic thresholds on dairy cattle which walk through the trap each day (Roberts 1952; Anon. 1986). As the cattle walk through, brushes dislodge the flies which then fly up to a transparent dome where they are killed. Traps have been reported to reduce the levels of worry caused by various species of biting flies attacking cattle in the United States (Wilson 1968; Meifert *et al.* 1978) although Drummond *et al.* (1988) conclude that their usefulness as a practical technology is still to be determined. Sticky traps, baits and "electrocutor" type traps are sometimes used in integrated programmes to control flies in intensive pig and poultry houses and dairies.

Careful sanitation and removal of waste from around dairies and areas where animals are housed removes breeding sites for house flies (*Musca domestica)* and biting flies such as stable flies *(Stomoxys calcitrans),* thus reducing the need for pesticide treatments. Conditions which allow rapid drying of poultry manure 'are unfavourable for fly of larvae but favourable for the various predators and parasites of fly eggs, 'larvae and pupae (Axtell 1986).

Barriers such as screens, plastic strips and airlocks on entry doors can be used to exclude flies in animal housing areas and barriers of dense vegetation have been shown to impede the spread of biting flies (*Tabanus nigrovittatus)* from salt marsh breeding sites to cattle grazing areas in the U.S.A. (Morgan and Lee 1977).

Wilkinson (1964) showed that moving cattle into a paddock which had not been stocked for 4 months in May, when ticks produced few progeny, and subsequently alternating them between paddocks at 4 monthly intervals controlled cattle ticks (*Boophilus microplus).* Harley and Wilkinson (1971) reported a modification of this technique which used small tick-free disinfection paddocks to house cattle until all ticks had dropped from them; the cattle were then moved to the main grazing paddocks before they were reinfested by the progeny of the dropped ticks. Both of these methods reduce the need for chemical treatment but, as appears to be the case with most physical and cultural methods, are not used to their full potential (Elder *et al.* 1980, 1985).

Biological control

Two categories of biological control can be distinguished, classical or innoculative biocontrol in which an introduced biological agent is expected to persist in the ecosystem keeping the target pest at low levels,and innundative biocontrol where very large numbers of the agent are applied as a 'biological pesticide', Innoculative control programmes, once established, are cheap and reasonably permanent, They do not result in eradication of a pest but may reduce it to below economic levels, either through their own effect *or* as a part of an integrated programme. However, the possibilities for using innoculative bio-control against ectoparasites with no off-host phase are limited as the control agent must either be very closely associated with the target, such as with a vertically transmitted micro-organism, *or* must have very sophisticated host locating mechanisms. Those parasites with an off-host phase, such as dung breeding *Diptera,* are more likely to be amenable to innoculative biocontrol.

The most wide ranging biological control programme undertaken in Australia for the control of livestock pests is the introduction of dung breeding insects and mites to control buffalo and bush flies (Bornemissza 1976). The project was initially undertaken following the partial success of a similar project to control horn flies *(Haema tobia irri tans irritans),* which are closely related to buf falo flies, in Hawaii. Fifteen species of beetle and a mite, which-attacks the immature stages of the buffalo fly, are now established in northern Australia, and seven species are established in south-western Australia. Dung dispersal by the beetles has reached high levels in some areas, and buffalo fly numbers are significantly reduced at times of the year when beetle activity is high (Anon. 1986). Hughes and Morton (1985) failed to detect any significant difference in the number of bush flies over wintering in southern Queensland before and after the introduction of dung beetles. However, Ridsdill-Smith and Mathieson (1988) noted an *88%* reduction in bush fly numbers in January following the introduction of summer active dung beetles into south-western Australia. Programmes to introduce spring active dung beetles to prevent early season build-up of bush fly numbers are underway (Ridsdill-Smith pers. corn.),

Biological control is an important component of integrated programmes to control flies in poultry houses. Hymenopterous pupal parasites, predaceous beetles, mites and entomophilic nematodes which attack fly eggs, larvae and pupae have been identified. In most programmes in Australia bio-control is achieved simply by the adoption of manure management programmes which allow sites for naturally occurring predators and parasites to carry over, Release of parasitoids to augment natural populations is used on some North American poultry farms although Axtell (1986) notes that this is not always successful. Entomophilic nematodes, which can be reared in large numbers and can be applied to manure as a spray, have been used to control flies breeding in poultry manure with some success in Canada (Belton *et al.* 1987), but results have been less favourable in other environments (Geden *et al.* 1986).

In the early 1900s, at which time it was believed that the majority of *L. cuprina* bred in animal carcasses, a number of parasites and predators including a pupal parasite *(Nasonia vitripennis)* a larval parasite *(Alysia manduca tor)* and a number of predaceous beetles were introduced (Anon. 1933). As the majority of *L. cuprina* breed on live animals and few emerge from carcasses (Waterhouse 1947), these methods were doomed to failure.

The use of *Bacillus thuringiensis,* a bacterium which has been successfully used to control a range of agricultural pests, is presently *being* investigated for the control of sheep blowflies and lice. Initially the aim is to use it as an innundative biocontrol agent, but in the longer term it is hoped to incorporate the plasmid, which codes for the toxic principal in *Bacillus thuringiensis*, into bacteria which grow in the fleece during fly risk periods (Pinnock 1988). In addition, the potential of an introduced protozoan pathogen *Octosporea muscaedomesticae*, for reducing blowfly numbers is under investigation (Cooper *et al.* 1985).

An entomophilic nematode, *Heterotylenchus autumnalis,* was released in California to reduce populations of the face fly (*Musca autumnalis)* (Anon 1969). A similar nematode parasitizes bush flies in Australia, but does not seem to exert a major regulating effect on bush fly numbers (Nicholas and Hughes 1970). Wharton and Norris (1980) note that *B. microplus* is predated by birds, scavenging rodents, poultry and ants, but conclude that the potential for innoculative bio-control is poor. Various pathogens ranging from entomophilic nematodes to fungi, bacteria and viruses have been investigated overseas for the control of mosquitoes, black flies and biting midges which can cause losses amongst livestock and can transmit diseases (Lacey and Undeen 1986; Molloy 1981; Platzer 1981). These have *been* at best partially successful but may assist control when used in integrated programmes.

Breeding livestock for resistance to parasites

Variation in resistance or tolerance to ectoparasites both amongst breeds and amongst individuals within breeds has been recognised for many livestock species. Sometimes this has a physical basis. For example sheep with wrinkly breeches are more susceptible to breech strike (Seddon and Belschner 1937) and cattle with darker coloured coats have been observed to be more attractive to various species of blood feeding flies (Taschiro and Schwardt 1953; Holroyd *et al.* 1984). Often there also appears to be an immunological basis.

The most spectacular use of between breed variation to reduce problems caused by ectoparasites in Australia is the use of *Bos indicus* cattle in crosses with *B. taurus* to increase resistance to *B. microplus* (Utech *et al.* 1978). In south-eastern Queensland, *B. taurus* cattle require six spray treatments at 21 day intervals or four pour-on treatments at 35 day intervals commencing in spring whereas *B. indicus* breeds need only one pour-on or two dip or spray treatments in autumn when their natural resistance begins to wane (Kearnan 1988). Genetic gains in resistance can also be made by selecting the more resistant bulls and cows within herds (Hewetson 1972). In south-eastern Queensland from 1977-78 to 1982 the proportion of producers running pure or crossbred *B. indicus* cattle increased from 47.8% to 60% (Elder *et al.* 1985). However, there was no difference in the number of ticks tolerated before animals were treated between owners of *B. taurus* and *B. indicus* cattle. Thus in many instances increased use of *B. indicus* cattle was not translated to reduced chemical treatment.

There are well documented variations between strains of Merino in resistance to fleece rot and bodystrike (McGuirk *et al.* 1978) and estimates of the heritability of liability to fleece rot suggest that genetic gains will be made from selecting within strains (McGuirk and Atkins 1984; James *et al.* 1987). Sandeman *et al.* (1986) present evidence which suggests that the type and extent of immune response to *L. cuprina* larvae is genetically determined.

Nelson et *al.* (1970) divided cattle into three groups on the basis of their response to infestation by the shortnosed sucking louse (*Haematopinus eurysternus*) : (a) susceptible animals carrying high louse burdens which increased to a point where acute anaemia developed and action had to be taken to save the lives of cattle; (b) carriers that had chronic infestations year round but seemed to suffer no ill effects and (c) resistant animals with few lice despite being housed with louse-infested cattle. Nelson and Baron (1982) suggest that breeding may be a suitable method for improving resistance to sucking lice on livestock and to the sheep ked (*Melophagus ovinus*). Hall and Goss (1975) present evidence of genetic variation between strains of cockerels in susceptibility to northern fowl mite (*Ornithonysus sylvarium*).

Treatment with insecticide masks expression of natural variation in susceptibility and reduces the opportunity for selection of the more resistant animals. This was well demonstrated in Zimbabwe where, prior to independence, a very intensive programme for tick control in cattle operated. This allowed development of tick susceptible strains of cattle and when the programme ceased, it resulted in widespread tick infestation and endemic disease (Allen 1979).

It is seldom that absolute resistance or tolerance to ectoparasites would result from selection. However, increased resistance delays the time until economic thresholds for treatment are reached, thereby reducing the number of chemical applications required.

Immunization

Vaccination to protect against ectoparasites is presently the subject of intensive research world wide, Vaccination of cattle with a crude extract of partially fed adult cattle ticks reduced the number of ticks developing on cattle by in excess of 90% in some studies and reduced the size and egg producing potential of ticks that did complete feeding (Johnston *et al.* 1986). Vaccination stimulates a different immunological response to that induced by natural tick infestation and so does not simply substitute for naturally acquired immunity (Kemp *et al.* 1986). Field trials to test a recombinant vaccine are presently underway in Queensland (K. Bremner pers. com.).

O'Donnell et *al.* (1981) demonstrated that circulating antibodies were produced in response to administration of an extract of ground up *L. cuprina* larvae, but no protection was conferred against larval implants. Sandeman *et al.* (1986) showed that resistance was induced in approximately half of a group of sheep exposed to four or more consecutive infections with *L. cuprina* larvae. Possible mechanisms for this resistance are discussed by Bowles *et al.* (1987). Whereas these researchers are investigating the secretory and excretory products of *L. cuprina* larvae for antigens that could form the basis for a vaccine, CSIRO Division of Tropical Animal Science is using a 'concealed antigen" approach. This approach aims to find an antigen in the blowfly larvae to which the sheep is not normally exposed, similar to the antigens in the guts of ticks which are the basis for the cattle tick vaccine. Similar methods are being utilised towards developing a vaccine for buffalo fly (K. Bremner pers. corn.).

Burrell (1985, 1989) showed that immunisation with an experimental *Pseudomonas aeruginosa* vaccine prevented exudative fleece rot and subsequent flystrike. Field trials are continuing to test whether vaccination can protect against the range of serotypes and species of bacteria which can predispose sheep to bodystrike in the field.

Nelson and Baron (1982) conclude from studies with sheep ked and sucking lice that resistance is locally mediated in the skin and that circulating antibodies to parasite secretions, though often present, are of little importance. Acquired resistance appears to be locally mediated and operates by causing constriction of the blood vessels on which the keds are feeding. As it appears that non-immune systems are most important in the development of acquired resistance to keds, these authors suggest that genetic selection of livestock for resistance may be a more feasible non-chemical approach to control than immunization. However the concealed antigen approach to developing a vaccine may also be a worthwhile avenue for research with these species (K. Bremner pers. corn.).

Genetic control of insect populations

Genetic control, or manipulation of a pest's genome for its own destruction, has been investigated for use against a number of species of livestock pests since the unparalleled success of the sterile male technique in eradicating the new world screw worm *(Cochliomyia hominivorax),* a major pest of livestock industries, from Curacao, the Virgin Islands, Puerto Rico and the U.S.A. (Graham and Hourrigan 1977). The sterile male technique consists of flooding the wild population with successive releases of sterilized male flies until the chance of a fertile female locating and mating with a fertile male is effectively reduced to *zero.* The technique would be economically impractical for use in the eradication of most livestock pests in Australia because of the large areas involved, although it could be useful for regional suppression in some instances.

In an attempt to overcome this problem the CSIRO Division of Entomology have developed a number of strains of genetically altered sheep blowflies which transmit genetic defects to succeeding generations (Whitten *et al.* 1977). The most successful strains have been the FKS or "field female killing system" strains, The males of these strains are semi sterile when mated to normal sheep blowflies and transmit a number of mutations that result in blindness of females in subsequent generations, The blind females fail *to* survive to reproductive age while the male progeny continue to mate with normal females and spread the genetic defect.

In a trial on Flinders Island in South Australia, release of the FKS strains reduced sheep blowflies to negligible levels at the end of the 1985/86 season and fly numbers increased only slowly again the next year. Further trials are presently underway on Flinders Island in Bass Strait. Results of computer simulation studies suggest that it will be possible to eradicate sheep blowfly from Tasmania and other physically bounded areas using this system but that on the mainland a strategy of ongoing releases aimed at suppression in selected high risk areas may be a more cost-effective approach (Foster *et al.* 1988).

Eradication quarantine and legislative control

Eradication of a pest is the most permanent method of control if it is supported by effective quarantine procedures. A number of instances of successful eradication of livestock pests using the sterile male technique have already been cited and others are reviewed by Graham and Hourrigan (1977). The most successful instance in Australia is eradication of the sheep scab mite *(Psoroptes ovis)* prior to 1896 (Seddon 1964). A programme which aims to eradicate sheep lice *(Damalinia ovis)* is currently underway *in* Western Australia (Wilkinson 1986). Eradication of sheep lice would eliminate the major reason for application of ectoparasiticides to sheep in Australia (Reed *et al.* 1989).

Tick-free areas are maintained in both Queensland and New South Wales and strict legislative requirements are enforced for the movement of cattle into these areas. Movement of animals into tick-free areas, whether for sale or slaughter, requires a number of pesticide treatments at short intervals, and there have been instances of pesticide residues resulting from this practice. Reid (1987) recommends that the chance of residues occurring can be minimized by using low risk chemicals such as synthetic pyrethroids at the maximum interval of 7 days before clearance. Although regulatory control and eradication programmes may depend on intensive use of pesticides, in the longer term they significantly reduce insecticide usage.

Quarantine requirements are often imposed following eradication, not only to prevent the re-introduction of the pest but also the introduction of other pests. The importance of quarantine procedures to containing costs of production and maintaining markets, but also to reducing pesticide usage, cannot be overstated. For example, the invasion of the screw worm fly (*Chrysomyia bezziana*) or re-introduction of sheep scab would wreak havoc with Australia's livestock industries and significantly increase the use of pesticides.

STRATEGIC USE OF PESTICIDES

At the peak of reliance on the use of pesticides for pest control, treatments *were* applied at the first sign of a pest, when conditions were suitable for a pest outbreak, or sometimes preventatively on a calendar basis at regular intervals, regardless of the presence of pests. Pesticides are now generally used more strategically. Applications may be timed when levels of an infestation exceed an economic threshold, when it is predicted from a knowledge of'the pests population dynamics that economic thresholds will be exceeded if treatment is not conducted, or at a strategic time in the life cycle of the pest to gain a lasting effect. Treatments must also, as far as possible, be planned to minimise residue levels at the time of sale.

Application with regard to economic thresholds

Little formal work based on cost benefit analysis has been carried out to establish economic thresholds for livestock pests. However, Sutherst *et al.* (1983) calculated economic thresholds for the treatment of *B. microplus* for a range of tick damage coefficients, beef prices and treatment costs. An economic threshold of 79 ticks per side was calculated for *B. indicus* x *B. taurus* steers assuming product values current at that time,

Haufe (1981) noted two different biological responses to horn flies that affected productivity of cattle, one at 12 and one at 230 flies *per* animal, Between 12 and 230 flies per animal, growth rate was depressed by a relatively constant 17% to 20%, while numbers above 230 depressed growth rate by up *to* 45%. He concluded that it was necessary to virtually eliminate an infestation to prevent the 17-20% loss in potential growth rate. Results of studies of the effect of buffalo fly on weight gain have been less conclusive. However, Reid (1989) recommends that buffalo fly treatments should be applied when the *number* of flies exceeds 200 per side on beef cattle and 100 per side on dairy cattle.

Arends and Robertson (1986) describe a monitoring system for flies in poultry houses using white cards. Chemical control is commenced when the number of spots per card per week exceeds 50. However, the authors' point out that this ie an arbitrary figure and that thresholds should be established based on the individual farm's needs.

It appears that in many instances *Damalinia bovis* and *Linognathus vituli,* the major species of cattle lice in Australia, cause little production loss (Arundel and Sutherland 1988). Treatment may be warranted to prevent damage to hides and fences and other fixtures which can result from cattle rubbing. *H. eurysternus* can have more severe effects and may even cause anaemia and death (Nelson et *al.* 1970). However, Scharff (1962) found that the proportion of cattle severely affected was less than 2% and that treatment was seldom justified in more than 5%. It may be prudent to cull highly susceptible animals which are a continuing *source* of infection to avoid having to continually re-treat with insecticides.

In most instances itchmite in sheep (*Psorergates ovis)* cause little production lose. Normally special treatments for itchmite will not be warranted (Johnson pers. corn.). Where itchmite become a problem, treatment will be *beet* timed to coincide with treatment for other parasites, for example a drench of ivermectin for internal parasite control, or when dipping post shearing for louse control. Johnson *et al.* (1989) indicate that better control is obtained when this treatment is carried out in spring rather than in autumn.

Though current estimates suggest that between 20% and 30% of the nation's flocks are infested, treatment for sheep lice is conducted routinely after shearing by approximately 85% of wool growers (Anon. 1988). Approximately 180 million chemical treatments are applied for louse control each year (Reed *et al.* 1989). This seems to be an inefficient exercise involving considerable unnecessary use of pesticides. Routine treatment of all sheep post-shearing has been necessary in the past for 3 main reasons:

1. Until recently there was no registered method of controlling mid-season infestations other than shearing and treating.

2. It is extremely difficult to detect very light infestations and thus to determine which sheep are infected and which are not.

3. Post-shearing treatment for lice has been a legal requirement in most States of Australia until comparatively recently.

The availability of products for long wool louse control (Rundle and Forsythe 1984; Sherwood and Page 1988) has allowed treatment of sheep between shearings if infestations develop. Wilkinson (1988), compared the costs of a programme of routine annual treatment with those for a strategic programme consisting of treatment of all sheep at introduction to the property and emergency treatment when infestations developed. In a 1000 sheep flock purchasing an average of 100 sheep per year and assuming a prevalence of lice of 20%, he calculated a potential advantage of $1.00 per sheep for the strategic programme if all stray sheep could be excluded from the property. Obviously changing the assumptions changes the margins but the strategic programme generally retains an advantage. The major unknown in this estimate is the effect on the national prevalence of lice if the majority of producers ceased annual dipping. Strategic treatment programmes will only be a practical option on properties which are not subject to frequent reinfestation.

However, treating sheep with long wool increases the chance of unacceptable residues in the fleece. The effects of different treatment regimes for louse control and the timing of treatments on levels of residues in wool clips require clarification.

In many organic horticultural enterprises, especially where damage ie mainly cosmetic, insecticide treatment is withheld and a level of lose is accepted. Often the increased losses are at least partially compensated for by a premium for organically grown product in the market place. Animal welfare considerations make this approach unacceptable in many livestock enterprises. However, it is important before treating animals to carefully balance the costs of treatment, as well as the indirect costs of selection for resistance and the possibility- of-residues, against the economic benefits resulting from treatment.

Strategic timing of insecticide applications

A detailed knowledge of the insect's life history is necessary to determine the optimal time for the application of pesticides. Sometimes best effect ie gained by applying insecticides at a strategic point in the pest's life cycle rather than from waiting until an infestation becomes apparent. This approach can sometimes avoid the necessity for repeated chemical treatments later in the season.

Two chemical treatments applied to cattle within 21 days of each other can give a prolonged reduction in buffalo fly numbers (Reid 1989). Treatments at this interval mean that those buffalo flies which are undergoing the dung breeding phase during the first treatment are killed by the next. In southern Queensland one programme of two treatments may be sufficient for the whole season while in northern areas the programme may have to be repeated two or three times. As buffalo flies usually do not migrate long distances, the effect will be maximised if these treatments are synchronised with similar treatments on neighbouring properties.

As most *L. cuprina* breed on live sheep, Hughes and Mackenzie (1987) suggest that jetting all sheep before flies begin to emerge from overwintering will remove breeding sites for early season build up in *L. cuprina* populations and will thus have a prolonged effect in reducing strike. This approach will also reduce selection for resistance. For best effect all properties within an area should undertake early treatment. Field trials to date have shown promise for this approach (Hughes and McKenzie 1987). When struck sheep are treated it is important to ensure that all larvae are killed and do not escape to pupate in the soil and provide flies for the next generation (Anderson *et al.* 1987).

Monzu et *al.* (1983) describe an early warning system which uses the presence of *L. cuprina,* susceptible sheep and environmental cues to predict periods of body strike risk. Variability between properties necessitates the use of the system on an individual property basis. This system reduces the chance of unnecessary jettings and of high losses which can occur if body strikes are not recognised early enough and treatments are applied too late.

The other major type of strategic pesticide application is that which could be termed quarantine application. An estimated 55% of infestations of *D. ovis* are introduced to properties with new sheep (Wilkinson 1988). Treating all sheep at introduction and keeping them isolated from the rest of the flock until it is certain that they are free of lice can reduce the need for subsequent insecticide applications.

Treatment of animals before introduction into intensive animal areas such as feedlots or intensive piggeries is often preferable to risking a major outbreak which requires treatment of all animals. Treating animals at the time of introduction usually also gives the maximum period of time between treatments and sale, thus minimising the chance of residues.

Strategic treatment with regard to insecticide residues

Withholding periods are established so that if pesticides are used in accordance with directions, MRLs in food products (meat, milk, eggs) should not be exceeded. Nevertheless, if animals must be treated it is sound practice to maximise the period between treatment and sale of produce and to use a chemical with a short withholding period. When application is by water medication, in the diet, or by controlled release or self treatment devices, such as backrubbers, it is important that administration cease in time to satisfy the required withholding period for the chemical being used.

There are presently no clear guidelines with regard to residues in raw wool for the use of pesticides on sheep. However, when possible, treatment of sheep close to shearing should be avoided. If emergency treatment for flystrike control close to shearing is necessary, from the point of view of residues, cyromazine (Vetrazin(R)) is the chemical of choice as there ie currently little concern about residues of this chemical in raw wool. However, it is preferable not to treat lambs which may be destined for export to the U.S.A. with cyromazine close to slaughter as there is currently no MRL for cyromazine in that country. Thus the MRL is effectively *zero* and any detectable residues could lead to rejection of meat shipments.

Elder *et al.* (1985) found that 20% of producers used chemicals in tick control programmes that were ineffective, presumably because of the development of resistance. Use of effective chemicals reduces the number of treatments required, and thus, in most cases, the potential for residues. Monitoring of the resistance statue of pest populations ie extremely important in determining efficient pesticide usage strategies.

Spacially strategic treatment

Often chemical applications can be placed so as *to* reduce the possibility of residues. In poultry or pig sheds, external walls where flies rest can be treated or pesticides can be applied in baits which attract flies to them. Area spraying of housing or the animals themselves should seldom be necessary thus minimising the likelihood of direct contamination of livestock or of contamination of food or drinking water. It is extremely important in poultry fly control programmes that manure not be sprayed with insecticide as this will lead to death of most predators and parasites. As flies breed more quickly than the beneficial species, direct spraying of manure can lead to a resurgence in fly numbers following treatment.

Sometimes it ie possible to gain control of parasites by treating only certain areas on an animal. Buffalo flies are intimately associated with cattle, moving around the animals' bodies and leaving only to oviposit. The highest numbers of flies are carried on the back and shoulder. Good control is achieved from oilers or backrubbers or by spraying just along the backline. Whole body treatment ie not necessary. Insecticidal ear tags and tapes have given control of parasites which infest animals near the head including ear ticks, head flies and face flies (Ahrens *et al.* 1977; Knapp and Herald 1981; Appleyard *et al.* 1984) and may be of use for the control of poll strike in rams (James unpublished).

Many pesticides including some organophosphates, methoprene, diflubenzuron, cyromazine, various preparations of *Bacillus thuringiensis* and azadiractin, which are excreted in the faeces, have been shown to control dung breeding pests when administered orally or by injection (Miller and Miller 1984; Miller and Chamberlain 1989). This mode of application can reduce the total amount of insecticide used in the control of pests such as horn fly or buffalo fly but the effect on tissue residues would also depend on many other factors, The effect on beneficial dung breeding fauna would also need to be considered (Wall and Strong 1987).

Though no chemicals are registered specifically for this usage in Australia, avermectins and ivermectin are registered for the control of internal and some external parasites of sheep and cattle. Ridsdill-Smith (1988) concluded that as long as Australian farmers continue to use single injections of avermectin B1 for parasite control, the long term effects on dung beetles should not be very harmful. However, he cautions that the administration of avermectins or ivermectin in slow release systems, so that these compounds are excreted in the faeces over a long period of time, could have devastating effects on dung breeding fauna (Ridsdill-Smith pers. corn.). This requires testing.

Application method

Trends in the application of pesticides for the control of ectoparasites are toward a gradual reduction in the amount of material applied (externally from dips and sprays to pour-ons, spot-ons and insecticidal ear tags) increasing use of products with systemic action administered orally or percutaneously and towards methods which lengthen the residual effect of treatments (Drummond 1985). The effect of these changes on the likelihood of pesticide residues will depend on the interaction of many factors.

The volume of formulation applied with pyrethroid offshears backline treatments for lice ie much less than applied by dipping, but the amount of insecticide applied is up to 15 times greater (Boray *et al.* 1988). Low volume long wool lice treatments apply very high amounts of active ingredient closer to shearing than dipping or backline treatments and thus increase the possibility of residues in raw wool.

Whether the active ingredient is systemic (that ie it enters the treated animals' general circulation) or is applied topically and does not cross the skin barrier, will affect the partitioning of residues between the tissues and the fleece. Tissue residues are more likely with systemic treatments than with topical treatments that are not absorbed, but the chance of residues in the wool or fibre coat is generally lower. Many other factors, in particular the type of insecticide and the formulation will also influence the chance of residues.

Similarly, the trend towards sustained release systems to lengthen the period of protection can work in various ways. Traditional application methods achieve prolonged effect by applying insecticides at levels well above that required for immediate effect so that control is achieved until the insecticide degrades to below active levels. Soon after treatment the potential for residues in livestock products ie high. Sustained release systems aim' to supply steady levels of active ingredient over a prolonged period of time. Thus low level residues are possible for a longer period of time but the chance of high residue levels ie seldom as great as from application by traditional methods. The rate of breakdown or detoxification and excretion following release will have a large effect on the relative potential for residues from different methods of administration. Application of insecticides in sustained release systems has been implicated in the development of resistance, particularly in horn flies (Sparks *et al.* 1985). However, the use of sustained release systems need not necessarily increase selection for resistance. For example, systems which maintain insecticides at high concentration and then give rapid residue decay (Hughes and McKenzie 1987) and systems which maintain high levels of insecticide through the parasite season and then decay when no parasites are present could reduce the rate of resistance development.

Examples of slow release systems for parasite control include slow release ear tags which have been widely used for control of various fly and tick species on cattle in the United States and Europe and which were briefly registered for buffalo fly control in Queensland, and slow release rumen capsules for control of internal parasites (Anderson *et al.* 1980). A controlled release capsule to deliver cyromazine for flystrike control (Hughes and McKenzie 1987), controlled release boluses which deliver methoprene (Miller *et al.* 1979) and diflubenzuron (Miller et *al.* 1986) to control horn fly and face fly larvae breeding in dung, and the use of a subcutaneous implant containing ivermectin to give prolonged protection against ticks (Nolan et *al.* 1981) have been tested experimentally with some success but the effect of these methods on tissue residues was not reported.

Alternative chemicals

Most modern chemicals currently used for the control of ectoparasites have low mamalian toxicity, are rapidly metabolised if absorbed into body tissues and do not give unacceptable residues if used according to directions. Many have zero withholding periods. Amongst newer families of chemicals being investigated are growth regulator compounds, such as cyromazine, dimilin and methoprene, which target specific growth processes peculiar to insects, oviposition suppressants for sheep blowfly, which act against the adult fly rather than the larvae, the avermectins and azadirachtin, the main active compound from the seeds of the Neem tree *(Azadiracta indica)*. Azadiractin which is being investigated for use against sheep blowflies and lice (Rice pers. corn.), is effective against a wide range of insect species but has very low mammalion toxicity and has shown no mutagenic activity in tests to date (Jacobsen 1986).

I-RATED PEST MANAGEMENT

Integrated pest management in the integration of two or more control tactics which aims to reduce pest populations below economic injury levels at the lowest possible cost and with minimum hazard to man or desirable components of his environment. It has evolved with the realization that sole reliance on one method of control, particularly involving the use of pesticides, can in the longer term be counter-productive. Integrated programmes usually include the use of chemicals, but aim to use them strategically to maximise the benefits from a minimum number of applications and to minimise any undesirable side effects. Most control strategies for livestock pests are integrated to some degree. However, in many instances, as has been demonstrated, there is considerable scope *for* increased use of non-chemical methods and more efficient application of pesticides.

EDUCATION

A facet which should be addressed in regard to the current concern about pesticides is education, both of personnel involved in the sale, handling and application of pesticides and of consumers. Training of pesticide resellers, who often advise on the use of farm chemicals, ie currently being addressed by the Farm Chemical Industry Training Course which ie offered by tertiary education institutions around Australia and which leads to accreditation by the Agricultural and Veterinary Chemicals Association. Most agricultural training programmes contain sections on the application of pesticides.

However, education of consumers and the general public ie also extremely important. Further effort is needed to stress the exhaustive testing that takes place for carcinogenicity, mutagenicity, teratogenicity and other undesirable effects to ensure the safety of a pesticide before it ie registered for sale. In fact the requirements are so rigorous that it has been suggested that if some vegetables had to fulfil the same criteria they would never gain registration. Chemicals presently registered for the control *of* ectoparasites often do not penetrate the epidermis of treated animals and if they do, they are rapidly broken down and excreted. It is currently estimated that the ratio of natural to artificial carcinogens ingested in our diet (that ie all carcinogens not just pesticides) ie in the order of 10,000:1 (Ames 1989).

Despite these facts, the presence of residues in farm produce is a particularly emotional issue and it is extremely important that the livestock industries maintain responsible usage practices and develop pest control strategies which minimise the possibility of residues. This will enhance the reputation of Australia as a producer of clean produce, both at home and abroad, and increase the marketability of our products.

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