Ectoparasiticide use in contemporary Australian livestock production

Edited by P.A. Holdsworth

Avcare

australian wool innovation limited

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Foreword

The word 'ectoparasiticide' is commonly used to describe a group of chemicals that assist farmers manage external parasites on ruminants. Ectoparasites of major economic and animal welfare concerns to cattle and sheep production in Australia are ticks, biting and nuisance flies, blowflies, lice and mites.

This publication contributes to the ongoing understanding and debate on ectoparasiticide use in contemporary Australian livestock production, by delivering a "snapshot" of current chemical use patterns, government registration/regulation programs for such products, the economic benefits to producers from using such products and, just as importantly, the animal welfare benefits of product usage.

I commend this publication to all who have an interest in the ongoing viability of the Australian livestock industry and the continued availability of vital production tools.

Senator the Hon Richard Colbeck
Parliamentary Secretary to the Minister for Agriculture, Fisheries and Forestry

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Chapter 1

History of ectoparasiticide use in Australian livestock production

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Introduction

Recent regulatory reviews into chemicals (and their associated products) used for ectoparasite control have warranted much debate not just from within the chemical industry itself but also, with the help of the media, from the general public. These reviews focus on occupational health and safety, environmental and trade-related issues, with specific evaluations targeting diazinon, chlorfenvinphos, carbaryl and a broader review of sheep ectoparasiticide use. The authors of the diazinon, chlorfenvinphos and carbaryl reviews have recommended some removals of, or restrictions on, specific use patterns for products at issue (NRA 2000; APVMA 2003, 2004b). The sheep ectoparasiticide review, while not completed, is likely to make similar recommendations. An additional study into acceptable disposal practices for used dip products will also potentially affect the use of certain ectoparasiticides.

In the review process it is important not to overlook the value of ectoparasiticides to productivity and animal welfare in the Australian livestock industry. For over a century, these products have enabled Australian primary producers to efficiently and economically manage ectoparasites on food and fibre-producing animals. In 2003, more than $60 million was spent in Australia on ectoparasite treatments for food and fibre animals (APVMA 2004a).

Given their long use in Australia, it is instructive to summarise the development of ectoparasiticide use in the primary production industry.

Inorganic compounds

Sheep-scab control was documented in nineteenth century England, involving treatment of individually infested animals with smears and salves based on arsenic or hellebore, mercury and lime (Page 1969). At the same time, Lord Sommerville, in Norfolk, England, was reported to have for the first time dipped sheep in a bath containing arsenic, soft soap and water (Page 1969). The first arsenic–sulphur dispersible powder was introduced in Britain in 1843 by William Cooper of Berkhamsted, Hertfordshire, and this product subsequently attained worldwide use. By 1863, nicotine–arsenic, arsenic and lime-sulphur dip products were also introduced as suitable for direct sale to farmers.

In the early twentieth century, sulphur/lime-sulphur based products (sold as dusts, dressings or aqueous formulations) and mixtures of arsenic and lime sulphur were effective treatments of sheep lice and mites. In the United States, wettable sulphur was recommended against lice and warble flies, and elsewhere as a fumigant against mange mites (Roberts 1952). These compounds were widely used in sheep farming areas of the world for some 140 years, but their use was overtaken by other ectoparasiticides. In Australia, sulphur was used for sheep itch mite control—in the form of ointments, as lime sulphur, or as potassa sulpha urata (Roberts 1952). Dressings incorporating boracic acid emerged (Freney et al. 1935, 1936; Freney and Graham 1939; Lennox 1941), with several formulations incorporating camphor oil, creosote, or orthodichlorobenzene and wetting agents that had blowfly larvicidal and antibiotic properties (Seddon 1967a). For many years, dressings containing 5% copper sulphate in water were used to treat individually blowfly-struck sheep (Seddon 1967a). Sodium fluoride and sodium fluorosilicate had application against lice (Roberts 1952), with sodium fluorosilicate in combination with phenothiazine and flour applied as a dust (Seddon 1967a). Magnesium fluorosilicate in combination with rotenone and sulphur is still used today to treat sheep lice, itch mites and ked infestations.

The first documented cases of arsenic use as a cattle dip acaricide were by a Dr Francis in 1894 and Mr Mark Christian of St Lawrence, Queensland, Australia in 1895, who used a 1% solution of Coopers dipping powder to kill cattle ticks (Angus 1998). Its success ensured that arsenic became a general treatment and was adopted worldwide as the treatment for one-host ticks (Seddon 1967b). In Australia, arsenic dips were marketed under various names (see Table 1) and were used for more than 50 years against ticks and, similarly, biting lice on cattle, horses and sheep (Roberts 1952).

Calcium arsenite and sodium arsenite were used as jetting fluids to protect against sheep crutch strike. While arsenic and its compounds were noted as stomach poisons, in the case of ticks they appeared to act mainly as a contact acaricide. Arsenic was not ovicidal or residual in activity, except in the case of the sheep biting louse. As such, frequent re-treatment of animals was necessary. Arsenic was also used to treat sheep keds (Lapage 1962), especially for sheep in longer wool, for which shower or plunge dipping using formulations of arsenic or butinide combined with rotenone was recommended (Seddon 1967a). Until the advent of dichloro-diphenyl-trichloroethane (DDT), arsenic was the most widely used compound against these parasites (Roberts 1952).

Before 1945, arsenic formed the basic constituent of most cattle tick and blowfly strike treatments, even though tick resistance to arsenic had developed by 1937 (Seddon 1967b). Until approximately 1946, arsenic was the main basic ingredient in sheep dips commonly used to control sheep biting lice and keds in Australia, due to its favourable cost, efficiency and residual effect in dealing with hatching louse eggs (Seddon 1967a).

Until relatively recently (1986), arsenic in combination with sulphur and rotenone was still available as a shower and plunge dip in Australia to treat sheep body lice, keds and itch mites.

Table 1. History of approved acaricide uses in Queensland, Australia since 1895[a]

Common name	Trade names (e.g.)	Year introduced	Chemical type
Arsenic	Maxidip, Agrico	1895	Arsenical
DDT	Rucide, Deetik	1946	Organochlorine[b]
BHC	Gamatik	1950	Organochlorine [b]
Toxaphene	Flit 222, Coopertox	1954	Organochlorine [b]
Diazinon	Neocidol, Nucidol	1956	Organophosphate
Dieldrin	Dieltix, Dielspray	1957	Organochlorine [b]
Dioxathion	Bercotox, Ruphos	1958	Organophosphate
Coumaphos	Asuntol	1959	Organophosphate
Carbophenothion	Dagadip	1961	Organophosphate
Ethion	Ethion, Coopathon	1962	Organophosphate
Carbaryl	Sevin	1963	Carbamate
Phosmet	Prolate, Bophox	1967	Organophosphate
Crotoxyphos	Parazon, Ciodrin	1967	Organophosphate
Chlorpyriphos	Dursban	1967	Organophosphate
Bromophos-ethyl	Nexagan	1967	Organophosphate
Chlordimeform	Spike, Fundex	1971	Formamidine
Clenpyrin	Bimarit	1972	Cyclic amidine
Chloromethiuron	Dipofene	1973	Thiourea
Promacyl	Promicide	1973	Carbamate
Amitraz	Taktic	1976	Amidine
Cymiazole	Tifatol	1979	Amidine
Cypermethrin/ chlorfenvinphos	Barricade S	1981	Synthetic pyrethroid/ organophosphate
Deltamethrin/ethion	Tixafly	1981	Synthetic pyrethroid/ organophosphate
Cyhalothrin	Grenade	1982	Synthetic pyrethroid/ organophosphate
Flumethrin	Bayticol	1985	Synthetic pyrethroid
Avermectin B1	Avomec	1985	Macrocyclic lactone
Ivermectin	Ivomec	1988	Macrocyclic lactone
Moxidectin	Cydectin	1994	Macrocyclic lactone
Fluazuron	Acatak	1994	Tick development inhibitor
Doramectin	Dectomax	1996	Macrocyclic lactone
Eprinomectin	Eprinex	1998	Macrocyclic lactone

[a] Table partly adapted from records of the former Standards Branch of the Department of Primary Industries and Fisheries, Queensland.
[b] Banned from use as acaricides in 1962.

Botanical compounds

Compounds such as pyrethrum, rotenone and nicotine have found use in parasite control. Pyrethrum (pyrethrin) sprays [sometimes containing DDT (pre 1962) and synergists such as sesame oil, piperonyl cyclenene and piperonyl butoxide], dusts or aqueous suspensions were used as insecticides to control lice and fleas and are still available in Australia to manage flies on cattle and pigs. Rotenone was formulated as a dust or aqueous suspension to control poultry lice, fleas, mites and ticks, as well as sheep keds and itch mites. Rotenone and pyrethrum were recommended for lice control on dairy cattle in the USA (Turk 1963). Rotenone is still used today to control itch mites on sheep through plunge and shower dips.

Nicotine, as nicotine sulphate, is a powerful contact insecticide but, owing to its volatility, is active for only comparatively short periods, resulting in the need for repeat treatment, which became an economic impediment to its use (Seddon 1967b). It was most frequently used against sheep scabs and chorioptic mange mites, but was also employed as a fumigant against poultry and cattle lice (Roberts 1952) and as a hand dressing to treat sheep foot lice (Seddon 1967a). Nicotine had no effect on louse eggs so two treatments at 14-day intervals were required (Roberts 1952).

Early organic compounds

Compounds such as mineral oils and tar distillates killed arthropods by smothering them and were employed to control lice, fleas and ticks. Coal-tar products such as phenols and cresols are contact insecticides that were used mainly against lice (Roberts 1952) and keds. For nasal bots, tar was originally smeared on sheep nostrils to prevent oviposition by female flies, but for infested sheep, mixtures of kerosene, benzol, acetone, sulphated castor oil, Trixon 100, oleic acid and lindane were introduced into each nostril and the treatment repeated 3–4 weeks later (Seddon 1967a). Other treatments included introducing into the sheep nasal cavity a mixture of liquid paraffin and carbon bisulphide, or liquid paraffin and tetrachlorethylene or a tetrachlorethylene emulsion (Seddon 1967a).

Cresylic acid was used to control cattle lice and ticks (Seddon 1967a). Bland oils such as castor oil or neat's foot oil were applied with a small brush to poultry to control fleas (Seddon 1967a). Alternatively, dressings such as petroleum jelly and sulphur (Byrne 1948; Ferguson 1923) or kerosene and lard (Byrne 1948; Cantello 1947) were used. Crude oils were applied to pigs as a hand dressing to manage lice infestations (Seddon 1967a).

Chlorinated hydrocarbons

Chlorinated hydrocarbons [DDT, benzene hexachloride (BHC), chlordane, heptachlor, aldrin, dieldrin, methoxychlor and toxaphene] were introduced from the mid 1940s (see Table 1), with DDT being the first compound to be used on a large scale to control cattle ticks (Seddon 1967b). High efficacy and good protection against tick reinfestation (Hitchcock and Mackerras 1947; Legg 1947) led to their widespread adoption. Control over buffalo fly, lice and bush fly infestations was also reported. While tick larvae were highly susceptible to DDT, nymphs were relatively resistant and adults were killed slowly (Seddon 1967b). DDT proved so successful that all clearing dips in Queensland were charged with it and good results obtained until its use was prohibited in 1962 (Seddon 1967b). However, since DDT was the most effective insecticide for buffalo fly control, its use as an overspray continued until 1973. In Queensland, water-soluble suspensions of DDT, in which birds were completely immersed, were effective against the stickfast flea although bird mortality could be significant (Roberts et al. 1947). DDT was effective in killing adult blowflies, relatively ineffective on young maggots and non lethal against older maggots (Seddon 1967a).

BHC was 10 times more efficacious than DDT against ticks, mites and larvae of the higher Diptera, but its residual effect was less and it was much less effective than DDT against buffalo flies (Roberts 1952). Ticks resistant to BHC are also resistant to other chlorinated hydrocarbons (Seddon 1967b). DDT and BHC gave 5–6 weeks' protection against blowfly strike, compared with nearly 4 weeks for arsenic. Similarly, BHC was effective against nymphs and adults of sheep foot lice but not against the eggs (Seddon 1967a).

The introduction of dieldrin and aldrin doubled the period of protection against fly strike while significantly reducing the cost of treatment (Seddon 1967a). Aldrin, dieldrin and BHC killed maggots on contact, with dieldrin at a 0.025% concentration and aldrin at 0.05–0.1% giving 8–9 weeks protection against crutch strike, 10–12 weeks against body strike and several months protection against poll strike (Seddon 1967a). BHC and DDT were effective in treating stickfast fleas on poultry and lice and sarcoptic mange on pigs, but both compounds tainted the carcasses and eggs of treated birds, resulting in a commercial disincentive for their use (Seddon 1967a).

Methoxychlor was similar to DDT in efficacy but not in residual activity (Roberts 1952) although it was recommended in the USA for lice control in dairy cattle (Turk 1963). Toxaphene had slow action, and a dose lower than that of DDT was required to kill most insects, but its residual effects were not as great as those of DDT (Roberts 1952). Toxaphene was effective against ticks but, as it was orally four times as toxic as DDT, its formulations were toxic to calves (Roberts 1952).

The use of chlorinated hydrocarbons was prohibited in 1962 because of their residues, which accumulated in treated food animal tissues (particularly the fat), and the need to comply with the pesticide residue standards set by countries importing Australian meat (Seddon 1967b). This prohibition covered all direct applications of dieldrin, aldrin, DDT and BHC to sheep and cattle (Seddon 1967a).

Organophosphates (OPs) and carbamates

Several OP compounds, including diazinon, dioxathion, carbophenothion, coumaphos and ethion, and one carbamate compound—carbaryl, appeared to be effective against ticks (Seddon 1967a). However, tick resistance to carbophenothion, diazinon and carbaryl was soon detected and when resistance to ethion and coumaphos subsequently appeared, dipping options became problematic in tick-affected areas. Chlorpyrifos and bromophos ethyl offered some temporary relief (Seddon 1967a).

For buffalo flies, where a satisfactory residual period is needed for control, the OPs were challenged. The carbamate carbaryl had some residual properties (although not as long as DDT) as a spray, giving 14–21 days protection, whereas carbaryl used as a dip gave 10–12 days and methoxychlor gave 10–14 days as a spray. OPs are used today in back-rubbers, ear tags and, in combination with synthetic pyrethroids (SPs), in dips and sprays. Ear tags require only one application to cattle per season, while dips or sprays may require up to 16 treatments per season and back-rubbers are a daily self-treatment of cattle (Spence 1994).

Many of the OP cattle preparations used against cattle ticks were also used to treat lice by plunge dipping or spraying. Crotoxyphos also found use in treating pig lice, as did fenchlorphos in treating lice, ticks, mites and fleas on poultry. OPs such as coumaphos, fenthion ethyl, propetamphos, dichlofenthion and phosalone have also been used in the past to control sheep lice, keds and blowflies, while fenthion was also used to control cattle lice.

For nasal bot infestations in sheep, mixtures of coumaphos and trichlorfon were recommended (Seddon 1967a). Similarly, a single intramuscular injection of a 50% solution of dimethoate at 25 mg/kg body weight was reported as efficacious in destroying larvae (Lapage 1962). Diazinon and maldison (malathion) were used to treat cattle lice (Seddon 1967a). Maldison has been used to control buffalo flies and ticks on cattle, as well as sheep lice and keds. Similarly, it had a role in controlling lice and mites on poultry and pig lice and mange mites. Maldison as a 5% dust was also effective in treating stickfast fleas on poultry. Diazinon was effective in dressings to treat flystruck sheep (Belschner 1959) as well as for pig lice and mange mites.

OP-based products are still successfully used today (Table 2). Following over 40 years of use against blowflies in Australia, fly populations with significant resistance to OPs have emerged. Diazinon resistance in blowflies was first reported in 1966, but 39 years later it remains a widely used blowfly strike preventative. There are few documented cases of OP-resistant field populations of lice.

Carbamates (carbaryl, promacyl) found use as dips and sprays in the past in controlling lice, ticks and buffalo flies on cattle, but the cattle tick use has ceased due to resistance problems. Carbaryl was also used in treating pig lice and mange mites as well as fleas, lice, mites and ticks on poultry. Butacarb also found use as a sheep blowfly jetting treatment. Bendiocarb is used today in a dust bag preparation to manage buffalo flies, and additional uses have emerged against biting and sucking lice on beef and dairy cattle through pour-on preparations.

Synthetic pyrethroids (SPs)

Cypermethrin, cyhalothrin, deltamethrin, alphacypermethrin and lambacyhalothrin are used to control lice on sheep in Australia. The long-time use of these chemicals in dips, through jetting and showering along with pour-on/back-line treatments, has resulted in SP-resistant lice populations emerging, but these populations are, at present, still OP-sensitive. There has been much debate in Australia as to whether this resistance has emerged primarily due to the inherent problems in one or more of the chemical application methods or to poor user adherence to application method and equipment maintenance. On cattle, SPs are used to control buffalo flies via sprays, pour-on formulations and ear tags, along with combinations of SPs and OPs as dips and sprays. Cattle require only one ear tag application per season, while dips or sprays may require up to 16 repeat treatments per season and back-rubbers are a daily self-treatment by cattle (Spence 1994). SPs are still successfully used to treat susceptible strains of ectoparasites on cattle (including ticks), sheep and goats (Table 3).

Table 2. Some approved uses of organophosphates in Australia

Active	Method of use	Host	Parasite
Azamethiphos	Spray	Poultry	Lice, red mites
Fenthion	Spot on	Beef cattle	Biting, sucking lice
Fenvalerate	Hand spray	Cattle	Buffalo flies
Phosmet	Pour on	Pigs Cattle	Mange, lice Biting, sucking lice
Maldison	Spray Spray, rinse	Poultry Cattle, pigs	Mites, lice, fowl ticks, mosquitoes Lice
Temephos	Dip, jet	Sheep	Body lice
Propetamphos	Dip, jet	Sheep	Lice, keds, assist in blowfly control
Propetamphos + dichlorobenzene	Hand dressing	Sheep	Blowfly strike
Propetamphos + dichlorobenzene + eucalyptus oil + cresol + butylated hydroxytoluene + light paraffin	Hand dressing	Sheep	Blowfly strike
Chlorfenvinphos	Jet, back-rubber, hand dressing	Cattle	Buffalo flies
Chlorfenvinphos + dibutyl phthalate	Aerosol spray	Sheep	Blowfly strike
Chlorfenvinphos + cypermethrin	Spray dip	Cattle Sheep, goats, deer	Lice, ticks, buffalo flies Ticks, flies
Chlorfenvinphos + cresol + eucalyptus oil + naphthalene + petroleum oil	Hand dressing	Sheep	Blowfly strike
Diazinon	Dip, jet, spray, ear tag, dressing	Sheep Cattle Goats Pigs	Fly strike, keds Lice, buffalo flies Lice Lice, mange
Diazinon + rotenone + piperonyl butoxide	Dip	Sheep	Lice, keds, itch mites, blowfly strike

Amidines

Amidines used in the past to treat cattle lice and ticks by plunge dipping and spraying included chlorphenamide and clenpyrin. Cymiazole also found use in treating cattle ticks. Amitraz is the predominant amidine used today. It is employed against pig mange mites; ticks on beef and dairy cattle; cattle ticks on sheep, goats and deer; lice, keds, itch mites and blowfly strike on sheep; and lice and mange on goats. Amitraz is formulated as dips, sprays and pour-ons.

Table 3. Some approved uses of synthetic pyrethroids in Australia

Active	Method of use	Host	Parasite
Deltamethrin	Pour on	Cattle Sheep Goats	Lice, flies, buffalo flies Lice, keds Lice, keds
Deltamethrin + ethion	Dip, spray	Cattle	Ticks, flies
Cypermethrin	Pour on, back liner Spray Dip	Sheep Cattle (non-lactating) Sheep	Lice Buffalo flies Keds
Flumethrin	Dip, spray	Cattle	Buffalo flies, ticks
Cypermethrin + chlorfenvinphos	Spray dip	Cattle Sheep, goats, deer	Lice, ticks, buffalo flies Ticks, flies

Macrocyclic lactones

Abamectin was the first compound in this chemical group with an ectoparasiticide claim approved for use on food-producing animals in Australia (see Tables 4 and 5). Ivermectin, moxidectin, eprinomectin and doramectin followed (Table 5).

Insect growth regulators (IGRs)/tick development inhibitors/spinosyns

IGRs emerged with cyromazine (a triazine) being introduced in 1979 in the form of a soluble powder concentrate to be used through dipping and jetting after dilution in water, or as dressings for blowfly strike control on sheep. In the 1990s, a ready-to-use pour-on formulation was introduced. More recently, it has been approved for use as an in-feed preparation to control larvae of nuisance flies affecting poultry.

Table 4. History of ectoparasiticide approval[a] in Australia since 1970

Common name	Trade name (e.g.)	Year federally cleared (NRA/APVMA registered from 1995)	Chemical type
Fenthion	Tiguvon	1970	Organophosphate
Chlorpyrifos	Dursban	1970	Organophosphate
Bromophos-ethyl	Nexaject	1970	Organophosphate
Chlordimeform	Spike	1971	Amidine
Famphur	Warbex	1971	Organophosphate
Carbophenothion/ rotenone	One Muster	1971	Organophosphate/ rotenone
Phosmet	Poron	1973	Organophosphate

Table 4. (cont'd) History of ectoparasiticide approval[a] in Australia since 1970

Common name	Trade name (e.g.)	Year federally cleared (NRA/APVMA registered from 1995)	Chemical type
Carbophenothion	Youngs Cattle Lice Spray	1973	Organophosphate
Promacyl	Promicide	1973	Carbamate
Amitraz	Taktic	1974	Amidine
Temephos	Lypor	1974	Organophosphate
Iodofenphos	Neporex	1974	Organophosphate
Methidathion	Somonil	1977	Organophosphate
Chlorfenvinphos	Supona	1977	Organophosphate
Diazinon	Neocidal	1978	Organophosphate
Permethrin	Stomoxin	1979	Synthetic pyrethroid
Azamethiphos	Alfacron	1979	Organophosphate
Coumaphos	Coral	1979	Organophosphate
Cymiazole	Tifatol	1979	Amidine
Cyromazine	Vetrazin	1979	Triazine
Cypermethrin	Barricade	1980	Synthetic pyrethroid
Deltamethrin	Clout	1980	Synthetic pyrethroid
Bendiocarb	Ficam	1980	Carbamate
Cypermethrin/ chlorfenvinphos	Barricade S	1981	Synthetic pyrethroid/ organophosphate
Deltamethrin/ethion	Tixafly	1981	Synthetic pyrethroid/ organophosphate
Cyhalothrin	Grenade	1982	Synthetic pyrethroid
Fenvalerate	Sumifly	1982	Organophosphate
Cyhalothrin/ rotenone	Grenade plus Rotenone	1982	Synthetic pyrethroid/ organophosphate
Tetrachlorvinphos	Rabon	1983	Organophosphate
Amitraz/diazinon	Amidaz	1984	Amidine/ organophosphate
Abamectin	Avomec	1985	Macrocyclic lactone
Flumethrin	Bayticol	1985	Synthetic pyrethroid
Cypermethrin/ diazinon	Bonus	1985	Synthetic pyrethroid/ organophosphate
Propetamphos	Ectomort	1986	Organophosphate
Alphamethrin	Duracide	1986	Synthetic pyrethroid
Chlorfenvinphos/ cresylic acid/ naphthalene/ petroleum jelly/ eucalyptus oil	Defiance S	1987	Organophosphate

Table 4. (cont'd) History of ectoparasiticide approval[a] in Australia since 1970

Common name	Trade name (e.g.)	Year federally cleared (NRA/APVMA registered from 1995)	Chemical type
Cypermethrin/ rotenone	Stockade 3 in 1	1987	Organophosphate/ rotenone
Cycloprothrin	Backlash	1988	Isostere
Ivermectin	Ivomec	1988	Macrocyclic lactone
Diflubenzuron	Fleececare	1993	Insect growth regulator
Triflumuron	Zapp	1993	Insect growth regulator
Moxidectin	Cydectin	1994	Macrocyclic lactone
Fluazuron	Acatak	1994	Tick development indicator
Doramectin	Dectomax	1996	Macrocyclic lactone
Eprinomectin	Eprinex	1998	Macrocyclic lactone
Dicyclanil	Clik	1998	Insect growth regulator
Spinosad	Extinosad	2001	Spinosyn

[a] Approval relates to Commonwealth clearance before state/territory registration being sought by the sponsor. This process existed until July 1991, when the National Registration Scheme came into being. This resulted in a single national registration of a product, through the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) in March 1995, which later became the Australian Pesticides and Veterinary Medicines Authority (APVMA). This registration is recognised by all Australian states and territories. Each trade name given here is for the first product approved/registered in Australia. Information in the table partially adapted from the records of the Technical Committee on Veterinary Drugs and the Veterinary Chemical Advisory Committee of the Department of Primary Industries and Energy (now the Department of Agriculture, Fisheries and Forestry).

Diflubenzuron (a benzoylphenyl–urea) followed cyromazine, with claims for efficacy against sheep body lice as well as fly strike through dipping and jetting. As for cyromazine, diflubenzuron is more effective against first-stage larvae than against second and third instars of blowflies. It is therefore recommended for use as a blowfly preventative. In 1995, cross-tolerance to diflubenzuron was anecdotally reported for some field strains of Australian blowfly resistant to OPs. Triflumuron (a benzoylphenyl–urea), as an off-shears, pour-on application, controls sheep body lice. It prevents the development of immature lice present in the fleece at application and those which hatch from eggs in the following weeks. Dicyclanil (a pyrimidine derivative) protects sheep from fly strike by spray-on application. It is available as a ready-to-use, 5% pour-on formulation and, in contrast to most other liquid formulations of blowfly products based on organic solvents, it is a suspo-emulsion containing more than 60% water. Fluazuron (a benzoylphenyl–urea) is a tick development inhibitor formulated as a pour-on for cattle to control cattle ticks. It is marketed as a ready-to-use pour-on containing 2.5% active ingredient. Applied topically to cattle, it acts systemically upon all developmental stages of ticks feeding on the host.

Spinosyns are a unique family of fermentation-derived natural products that have potent knockdown activity against a variety of arthropod pests (Kirst et al. 2002). Spinosad controls lice in short and long-wool sheep as well as treating and preventing blowfly strike. It also protects against blowfly strike in mulesing wounds of sheep for at least 8 days. It can be applied as a jetting fluid or as a blowfly strike dressing.

Table 5. Macrocyclic lactone uses in Australia

Active	Method of use	Host	Parasite
Abamectin	Subcutaneous injection Pour-on	Beef cattle (non-lactating) Cattle	Sucking lice, cattle ticks and biting lice Cattle tick, buffalo flies, lice (some products only aid in cattle tick control)
Ivermectin	Subcutaneous injection Pour-on Oral Jetting Subcutaneous injection Oral	Cattle Cattle Sheep Sheep Sheep Pigs	Sucking lice, mites, cattle ticks, aids in control of biting lice and chorioptic mange Lice, mites, buffalo flies, cattle ticks Nasal bots, itch mites, keds, aids in control of breech blowfly strike Prevents blowfly strike Lice Lice, mites
Moxidectin	Subcutaneous injection Pour-on Oral Subcutaneous injection	Cattle Cattle Sheep Sheep	Sucking lice, sarcoptic and chorioptic mange Lice, cattle ticks Itch mites Itch mites
Eprinomectin	Pour-on	Cattle	Lice, mites, buffalo flies, aids in control of cattle ticks
Doramectin	Pour-on Subcutaneous injection Intramuscular	Cattle Cattle Pigs	Lice, buffalo flies, mange mites, cattle ticks Sucking lice, cattle ticks chorioptic mites, aids in control of biting lice Sucking lice, mange mites

Conclusion

While insecticidal or acaricidal resistance, and possibly the outcome of the ongoing regulatory reviews, may dictate the long-term future of some of these chemicals and their related products, their value in primary production should not be undersold. The longevity of use of these chemicals is testimony to the paramount role they have played in the past in primary production, and their continued use today further reinforces their place. Such a statement does not detract from the value of the more contemporary chemicals such as insect growth regulators in ectoparasite control, but in fact reinforces the role for all these compounds as part of integrated pest control or quality assurance programs in the future. Issues such as arthropod resistance, pesticide levels in the national wool clip, export slaughter intervals and the value of generic products to sectors of the primary production industry will continue to drive the need for product alternatives in the choice of ectoparasiticides in Australia.

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Chapter 2

Regulation of ectoparasiticide use in Australia

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Introduction

Australia's agricultural and veterinary chemicals management system provides support that is essential to the success of Australian agriculture. The majority of primary producers rely on the supply of agricultural and veterinary chemicals to protect their crops and livestock from pests and diseases. Community concerns about the adverse effects of using agricultural and veterinary chemicals continue to increase worldwide (McLean 2000). People want to know that their food and clothing do not contain harmful chemical residues. Moreover, there is an increasing demand for information about the types of chemicals being used and how they are used, and assurance that agricultural and veterinary chemicals pose no danger to health, livestock and the environment (ARMCANZ 1998).

An agricultural or veterinary chemical is any substance administered to or applied in a situation to eradicate a pest or infestation, or treat or cure a disease or condition. Agricultural chemicals include herbicides, insecticides, fungicides, pest traps and barriers for pest control. Veterinary chemicals include vaccines, antibiotics, anaesthetics, worming products and external parasite treatments (ectoparasiticides). The chemical groups, dosage forms and delivery systems used in the management of ectoparasiticides on production animals are covered in other chapters of this book and have been reviewed elsewhere (Reeves 2002, 2005a). The subject of this chapter is the regulation of ectoparasiticides used on production animals in Australia. However, the regulatory framework described applies to agricultural and veterinary chemicals in general.

The regulatory framework

The National Registration Scheme (NRS), which sets out the regulatory framework for the management of agricultural and veterinary chemicals in Australia, is a partnership between the Australian, state and territory governments. The overall objective of the NRS is the safe use of chemicals to achieve the effective control of pests and diseases, thereby helping to ensure the high quality of Australia's primary production can be maintained while protecting the health and safety of people and animals, the environment and trade. The NRS has achieved a consistent, national approach to agricultural and veterinary chemicals registration, combining the separate schemes previously operating in each of the states.

The NRS was established in 1991 and has been administered and managed by the Australian Pesticides and Veterinary Medicines Authority (APVMA) since 1993. The APVMA is an independent Australian Government statutory authority within the portfolio of the Australian Government Minister for Agriculture, Fisheries and Forestry. The APVMA is responsible for the registration, quality assurance and compliance of agricultural and veterinary chemicals up to and including the point of retail sale. The responsibility for the control of use of agricultural and veterinary chemicals is with the individual state and territory governments. The agency responsible for control of use varies between states and is either the Department of Primary Industries, or Environment or Health.

The legislative arrangements governing the APVMA and its regulation of agricultural and veterinary chemicals are complex. The suite of legislation comprises seven Acts. Two of these, the *Agricultural and Veterinary Chemicals (Administration) Act 1992* and the *Agricultural and Veterinary Chemicals Code Act 1994*, are directly concerned with registration and will be discussed here.

The *Agricultural and Veterinary Chemicals (Administration) Act 1992* came into effect on 15 June 1993. It established the APVMA as a statutory authority, with responsibility for the evaluation, registration and review of agricultural and veterinary chemicals, and their control up to and including the point of retail sale. The states and territories retain responsibility for control-of-use activities under this Act.

The *Agricultural and Veterinary Chemicals Code Act 1994* was promulgated on 15 March 1995. It contains, as a schedule to the Act, the 'Agvet Code', which has the detailed provisions allowing the APVMA to evaluate, approve or register, and review active constituents and agricultural and veterinary chemical products (and their associated labels); to license the manufacture of chemical products; and to issue permits. The Agvet Code also contains detailed penalty provisions allowing the APVMA to regulate the control of agricultural and veterinary chemicals and has other provisions for ensuring compliance with, and enforcement of, the Agvet Code. The Code contains, in addition, provisions for data protection. The effect of the Agvet Code is that all products defined as agricultural or veterinary chemicals must be registered by the APVMA before they can be supplied, sold or used in Australia. Supply and use of unregistered products is an offence.

Any substance administered or applied to an animal for preventing, diagnosing, curing or alleviating a disease, condition or pest infestation is defined as a veterinary product under the *Agricultural and Veterinary Chemicals Code Act 1994*. The Act also refers to substances that modify the effect of another veterinary chemical product, such as, for example, the synergist piperonyl butoxide included in some ectoparasiticide formulations. Provisions in the Act enable the APVMA to evaluate, approve and control the supply of a proposed chemical product and a proposed active constituent in a chemical product, or to evaluate any proposed change to a chemical product or the active constituent that is present in an existing chemical product. Provisions in the Act relating to formulated products also enable the APVMA to evaluate, license and control the manufacture of chemical products.

The Act provides criteria that are at the core of decision-making by the APVMA when approving active constituents and labels, registering products or reviewing existing chemicals. The criteria are that the active constituent or product:

- should pose no undue hazard to the safety of people exposed to it during handling or using anything containing its residues
- would not be likely to have an effect that is harmful to human beings
- would not be likely to have an unintended effect that is harmful to animals, plants or to the environment
- would not unduly prejudice trade or commerce between Australia and places outside Australia
- should be effective when used according to label instructions.

The Agvet Code therefore provides that every decision the APVMA makes is subject to criteria that the agricultural or veterinary chemical product be efficacious, and not have an unintended effect that is harmful to animals, plants or other living things or to the environment. Information on data requirements and guidelines for applications to register or approve chemical products, labels, active constituents and permits is provided in the *Manual of Requirements and Guidelines* (MORAG). The MORAG for veterinary chemical products is accessible at <http://www.apvma.gov.au/MORAG_vet/MORAG_vet/MORAG_vet_home.shtml> on the APVMA website.

Animal welfare is not directly mentioned as one of the Agvet Code criteria. However, the combination of the criteria of efficacy and safety requires that, when the APVMA considers an application for registration of a veterinary chemical or reviews the registration of a currently registered veterinary chemical, it takes into account crucial elements of the welfare of target and non-target animal species. The result is that inefficacious products are not registered, and associated effects deleterious to animal welfare are avoided.

The APVMA has an animal welfare team that liaises with the Department of Agriculture, Fisheries and Forestry (DAFF). In addition, the APVMA is one of the stakeholders in the implementation of the Australian Animal Welfare Strategy (AAWS), details of which are given on the DAFF website at <www.daff.gov.au>.

The registration process for ectoparasiticides

Registration of an ectoparasiticide product involves rigorous scientific assessment aimed at ensuring the product will be effective for its intended use; safe for people and animals; and will not pose unacceptable risks to the environment or Australia's trade with other countries. Human exposure to an ectoparasiticide may occur through a number of means, including occupational exposure during manufacture or product use, the ingestion of residues in food or through household use. The latter may occur when ectoparasiticide products are applied to companion animals. However, for the general public, the most common route of exposure to ectoparasiticides is by ingesting foodstuffs containing their residues. Chemical companies submit extensive scientific data in support of applications for product registration.

During the evaluation of a new ectoparasiticide product, specialist staff in the APVMA assess the chemistry of the product and its manufacture, any residues in food and any trade implications. The APVMA also seeks specialist advice from a number of Commonwealth agencies including the following:

- The Office of Chemical Safety (OCS) in the Department of Health and Ageing
  - evaluates toxicology and metabolism studies, determines poison schedule classification and first aid directions, and establishes an acceptable daily intake (ADI) and acute reference dose (ARfD)
  - evaluates occupational health and safety aspects of an application, recommends safety information and occupational controls on use and advises on Material Safety Data Sheets.
- The Department of the Environment and Heritage (DEH) evaluates environmental data and recommends appropriate conditions on use to protect the environment.
- Food Standards Australia New Zealand (FSANZ) conducts dietary exposure assessments.

State/territory departments of agriculture, or primary industry, or independent reviewers, undertake efficacy and host animal safety reviews. Steps in the registration process applicable to ectoparasiticides are shown in Figure 1.

A brief outline follows of the risk assessments conducted during the registration of an ectoparasiticide product.

Chemistry risk assessment

A risk assessment of the chemistry of new and generic ectoparasiticides is performed before they are registered. A standard for the active constituent is established by APVMA chemistry evaluators as part of the risk assessment of a new chemical. A standard typically specifies the minimum purity of the active constituent, the ratio of isomers/diastereoisomers where relevant, and the maximum level of impurities, including those of toxicological significance. Subsequent risk assessments performed on generic chemicals consider the manufacturing process, and the purity and composition of chemicals to ensure compliance with the relevant standard. The assessment ensures consistent profiles relating to efficacy, public health and environmental issues for ectoparasiticides from different sources and between batches from the one source.

Toxicology risk assessment

The OCS assesses the hazards of the chemical. Toxicity studies are evaluated to characterise the inherent properties of the chemical to establish a no-observable-effect level (NOEL) and an ADI. The NOEL is the highest dose that does not cause any detectable effect in the most sensitive species of test animal. The ADI is the amount of chemical that may be consumed daily for an entire lifetime without causing an appreciable risk to health.

In addition, the APVMA Chemical Review Program assesses the short-term dietary toxicity of residues in food for new chemicals and for chemicals being considered. The maximum amount of a substance that can be ingested in food during one meal or one day without appreciable health risk to the consumer is estimated. This estimate is known as the ARfD of the substance.

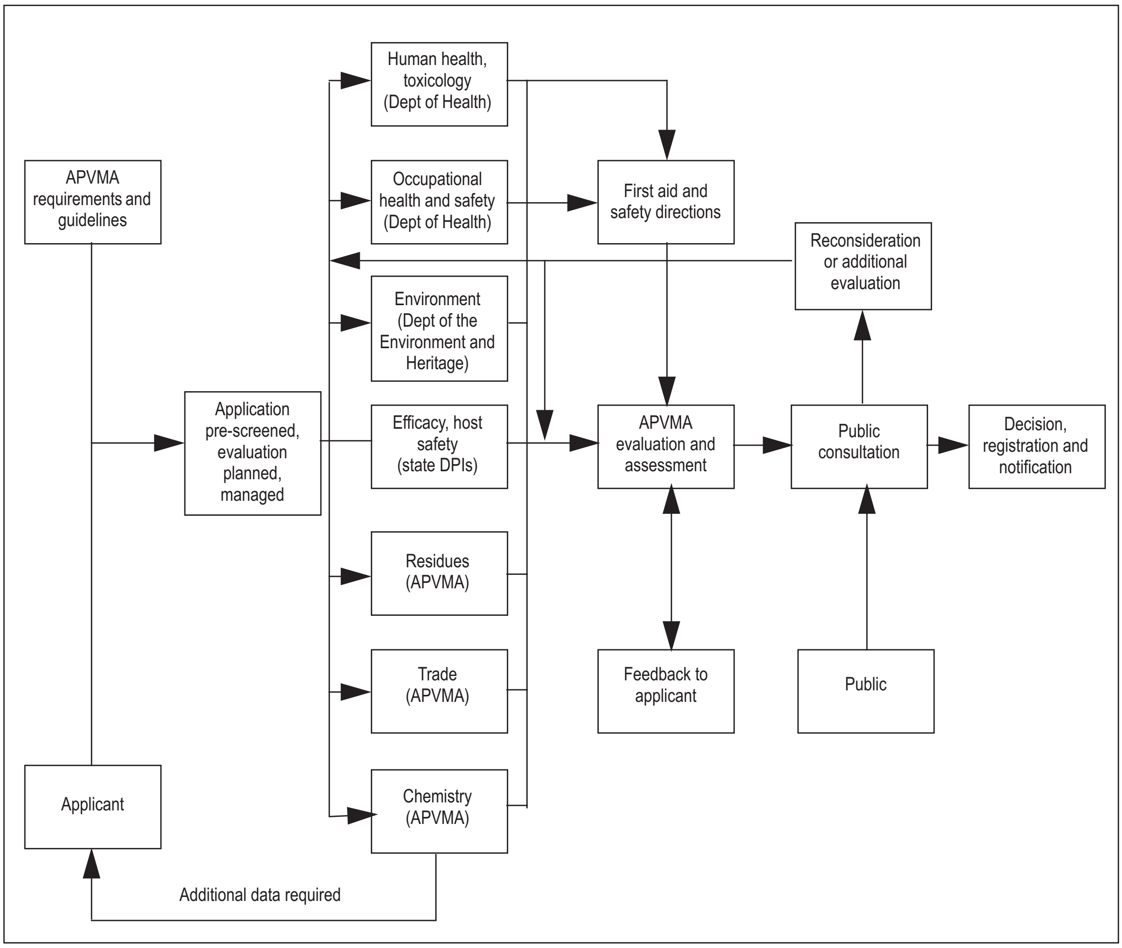

Figure 1. Registration process for ectoparasiticide products in Australia

The OCS also recommends first aid instructions and warning statements for chemicals, and safety directions for products. The National Drugs and Poisons Schedule Committee determines the poison schedule classification for the chemical, based on the toxicological evaluation produced by the OCS.

An ectoparasiticide will not be registered if human health and safety concerns identified in the toxicological evaluation cannot be surmounted by measures designed to reduce exposure to an acceptable level.

Assessment of residues in food

The safety assessment of chemical residues in food commodities was reviewed by Reeves (2005b). Potential residues of ectoparasiticides in food are assessed to ensure they are within safe limits. Maximum residue limits (MRLs) are set by APVMA residue evaluators through a comprehensive evaluation of data for chemistry, metabolism, analytical methodology and residue trials. The MRL is the highest concentration of a residue of a particular chemical that is legally permitted or accepted in a food or animal feed. MRLs are standards used to monitor that the product has been used as directed on the approved label. If a MRL is exceeded, it usually indicates a misuse of the chemical but does not normally present a public health or safety concern. The metabolic fate of the ectoparasiticide and the nature of the residue present in tissues and milk of treated animals are assessed and the target organ for residue accumulation is identified. Residue data are generated by the applicant in trials conducted in compliance with good laboratory practice, in which animals have been treated with the maximum dose rate of the ectoparasiticide permitted under good veterinary practice. Based on the assessment of the trial data, APVMA residue evaluators set MRLs for tissues. If the ectoparasiticide is intended for application to dairy cattle, a MRL for milk is set.

The APVMA residue evaluators may also assign a slaughter withholding period and, if the ectoparasiticide is applied to dairy cattle, a withholding period for milk. A withholding period is the interval between the last treatment with the ectoparasiticide and slaughter of the animal for human consumption or the collection of milk for human consumption. By observing the withholding period in the product labelling, farmers ensure that the residues in animal commodities fall to concentrations below the MRL.

Dietary exposure assessment

Once a MRL has been determined, the APVMA will perform a dietary exposure assessment that involves dietary modelling. The short- and long-term dietary exposures to chemical residues are estimated by calculating the national estimated short-term intake (NESTI) and the national estimated daily intake (NEDI), respectively. These estimates of predicted dietary exposure are reconciled with the permitted dietary exposure, namely the ARfD and the ADI, respectively. If there are very small amounts of chemical remaining in produce, the APVMA uses the toxicological evaluation and the dietary exposure evaluation to examine the potential occurrence of adverse effects on human health when the produce is consumed. The APVMA ensures that MRLs for ectoparasiticide products are set at levels that result in long-term human dietary exposure well below the permitted standards.

FSANZ then reviews the APVMA's dietary exposure evaluation and, once satisfied that the level of risk to public health and safety is acceptable, undertakes public consultation before incorporation of the MRL into the Food Standards Code.

Risk assessment of occupational health and safety

The OCS performs an assessment of occupational health and safety aspects of the product. The principal considerations are the hazard the chemical product poses to people exposed during its use or through the handling of treated animals; the occupational exposure; and the margin of safety the OCS may recommend. Measures such as the inclusion of safety directions on the product label, the use of personal protective equipment, or the need to comply with a re-handling period in respect of treated animals may be recommended to control occupational exposure. For an ectoparasiticide used on sheep, wool residue dissipation information on the product, a transdermal absorption study and a worker exposure study may need to be part of the assessment if it is necessary to refine the margin of safety.

Risk assessment of residues in wool

Residues of ectoparasiticides in wool are assessed by the OCS for occupational health and safety aspects and by the DEH for environmental aspects. To ensure residues of ectoparasiticides in wool are not an undue risk to the safety of shearers and wool handlers, the OCS may set a re-handling period. The re-handling period is the interval that must elapse between application of an ectoparasiticide and any handling of treated animals.

The assessment performed by the DEH determines whether harvested wool meets the prescribed environmental residue limits when the wool is processed. The wool harvesting interval (or wool withholding period) is the time that must elapse between treatment of sheep with an ectoparasiticide and collection of the wool (including crutching and fellmongering) to ensure environmental standards are met. By observing the wool harvesting interval, farmers ensure that the residues of the ectoparasiticide in the effluent from wool processing will comply with the permitted local environmental standards. Two wool harvesting intervals—an overseas wool harvesting interval and an Australian wool harvesting interval—are specified to account for differences between overseas and Australian wool-processing systems.

Risk assessment of environmental safety

The DEH assesses data on environmental chemistry and fate, and toxicity of the active constituent on non-target organisms including animals, birds, plants, soil organisms and aquatic life. Assessed are the extent of, and potential for, environmental exposure from use of the ectoparasiticide, and the environmental hazard from the disposal of spent or unused product. The DEH may recommend environmental statements and specific disposal instructions for inclusion on the product label.

Assessment of chemical residues in trade

An important objective of the trade assessment is to ensure that trade in animal-derived food and fibre between Australia and other countries will not be prejudiced unduly as a result of the ectoparasiticide product being registered. For food commodities, the APVMA evaluates information relating to:

- the commodities from treated animals that may be exported
- the countries to where these commodities are exported
- the proposed Australian use of the product
- overseas registrations and use patterns
- Codex Alimentarius Commission MRLs
- proposed Australian MRLs and permitted limits in importing countries
- potential risks to trade
- any action being taken to mitigate trade risks.

For trade in fibre commodities, chemical residues must meet applicable overseas environmental standards.

Assessment of efficacy and target animal safety

State and territory departments of agriculture or primary industry, as well as independent expert reviewers, undertake evaluations of efficacy and safety to the target species. Data from laboratory, pen and field trials including confirmatory efficacy trials conducted in Australia are assessed. Additional information on the data requirements relating to efficacy and target animal safety is available at <http://www.apvma.gov.au/MORAG_vet/MORAG_vet/MORAG_vet_home.shtml> on the APVMA website. The APVMA also accepts data generated in accordance with internationally agreed standards developed by the International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Medicinal Products (VICH) for the purpose of product registration. Information on these guidelines is available at <http://vich.eudra.org/htm/guidelines.htm> on the VICH website.

Public consultation

Whenever the APVMA evaluates a new product with a novel active constituent or a major new use of an existing product, it publishes a summary of its assessment and any conditions it proposes to apply to the use of the product. The APVMA invites public comment before making final decisions on these applications. When an assessment is complete, the APVMA may grant registration, refuse registration, or propose amendments to the draft label as a requirement of product registration and approval. The APVMA can approve or reject applications only on the basis of the provisions in its governing legislation.

The product label

Approval of the product label is an important element of the registration process. Every product registered by the APVMA has a unique number on its label. The process of approving labels for ectoparasiticides has been reviewed by Moffatt and Bennet-Jenkins (2001). Briefly, the Agvet Code requires that the APVMA must be satisfied that the label contains adequate instructions about:

- the circumstances in which the product should be used
- how the product should be used
- the times when the product should be used
- the frequency of use of the product
- the safe handling of the product and first aid in the event of an accident caused by handling of the product
- the withholding period for slaughter and milk after use of the product
- the export slaughter interval for the product
- the re-handling period for animals treated with the product
- the disposal of the product when it is no longer required
- the disposal of containers of the product.

The National Permits Scheme

The APVMA administers the National Permits Scheme. A permit allows a person, under certain circumstances, to possess and use an unapproved active constituent or unregistered product, or to use a registered product in a way not specified on the label and which would otherwise be illegal. Permits may be granted to exercise control over research chemicals, provide an emergency response to serious disease outbreaks or to approve chemicals for minor uses off-label. Permits for ectoparasiticides are most frequently issued to facilitate the conduct of efficacy and target animal safety trials for generating registration data. Permits are also issued for the off-label use of ectoparasiticides in minor species such as goats and alpacas.

Monitoring ongoing quality and safety of registered products

The APVMA manages four programs that monitor the ongoing quality and safety of registered products, including ectoparasiticides. Based on the findings of these programs, the APVMA may initiate regulatory action if the registration standards are not maintained or if new information becomes available that dictates the need to reconsider a product’s registration.

The four programs dedicated to maintaining the high standards of registration are:

- Chemical Review Program
- Quality Assurance and Compliance Program
- Adverse Experience Reporting Program
- Manufacturers' Licensing Scheme.

Chemical Review Program

The Chemical Review Program reconsiders the registration of agricultural and veterinary chemicals where potential risks to safety and performance have been identified. A review may be initiated when new research or information has raised concerns about the use or safety of a particular chemical or product. The review of a chemical may result in confirmation of its registration or it may support the continuation of registration but with some changes to the way the chemical can be used. In a small number of cases, the review may result in the registration of a chemical being cancelled and products being taken off the market.

Reviews may focus on one or more areas of priority (such as environmental safety, worker safety, public health, residues or trade) or may be comprehensive, covering all aspects of the product's registration. The review process draws on specialist expertise of APVMA staff and of other advisory agencies. The process includes extensive consultation with the chemical industry, users and the community. For a chemical to continue to be registered at the completion of a chemical review, the APVMA must be satisfied that the product remains safe and effective when used according to label directions.

Reports for chemicals reviewed in the program can be accessed at <http://www.apvma.gov.au/chemrev/chemrev.shtml> on the APVMA website.

Chlorfenvinphos and diazinon, two ectoparasiticides that are currently used on sheep and/or cattle, are being comprehensively reviewed at present. In addition, more focused reviews relating to specific aspects of products or their labels are progressing for temephos and a range of ectoparasiticide products used on sheep.

The review of diazinon

The APVMA is conducting a comprehensive review of diazinon. The review is examining all aspects of the approval of the active constituent and all registered agricultural and veterinary products containing diazinon. The regulatory action taken to date includes amendments to the active constituent approval and cancellation of registrations for a range of formulations involving unstabilised emulsifiable concentrates. Additional occupational health and safety data have been generated that will allow further assessment of worker safety aspects for diazinon-containing products applied to sheep. These additional data on occupational health and safety are under evaluation at the time of writing.

The sheep ectoparasiticide review

The APVMA is also conducting a focused review of a range of sheep ectoparasiticide products. The review is considering two main aspects: first, the use of approved products on sheep with more than six weeks wool growth, and second, the use of certain active constituents that are approved for use on sheep with short wool and, in particular, those chemicals demonstrating more persistent activity. Issues relating to occupational health and safety following application of the product to sheep, environmental safety and overseas trade are important considerations of the review. Additional background information on this review has been published (Ashton and Savage 2001). A preliminary review report is in preparation.

Quality Assurance and Compliance Program

The APVMA applies three compliance strategies to ensure that standards of registration are maintained:

- *prevention*, which involves promoting greater awareness and understanding of registration and compliance requirements
- *quality*, which includes publication of relevant standards and guidelines, and management of the Manufacturers' Licensing Scheme and the Adverse Experience Reporting Program
- *surveillance and enforcement*, which involves the APVMA investigation of alleged breaches of the Agvet Code and implementation of risk-based enforcement strategies. These activities can include prosecution, recall or negotiated compliance.

During 2003–2004, the APVMA review into diazinon products resulted in the voluntary recall of several diazinon products that did not contain an adequate stabiliser. One diazinon product was compulsorily recalled. The APVMA determined that diazinon products based on hydrocarbon solvents formulated without an adequate concentration of stabiliser could degrade to toxic breakdown products over time, particularly if the contents of the container were mixed with a trace amount of water. Such products were considered to be a risk to public health and animal safety.

Quality assurance programs conducted in conjunction with risk-based compliance strategies have been demonstrably effective in ensuring that registered products in the marketplace continue to meet acceptable standards.

Adverse Experience Reporting Program

The APVMA manages an Adverse Experience Reporting Program for agricultural chemicals and a similar program for veterinary chemicals. The latter is designed to provide the APVMA with feedback about the performance of registered veterinary chemicals, including ectoparasiticides, when used as directed on the approved label. The veterinary chemicals program is based on a requirement of the Agvet Code for product registrants to report any adverse effects resulting from the use of a product. Members of the general public, farmers and health workers are invited to report any adverse experiences. The APVMA assesses the reports received and determines whether the reported adverse effect is related to use of the product. In addition to the findings of the program reported on the APVMA website and accessible at <http://apvma.gov.au/qa/aerp1995_2003.pdf>, an overview of the APVMA's Adverse Experience Reporting Program for veterinary chemicals was recently published (Linnett and Dagg 2005).

Manufacturers' Licensing Scheme

The Manufacturers' Licensing Scheme requires all Australian-based manufacturers of veterinary chemicals to be licensed and to meet standards described in the Code of Good Manufacturing Practice (GMP). Compliance with the Code of GMP assures consistent quality standards across the industry, supports the export potential of veterinary chemicals manufactured in Australia, reduces the need for post-market surveillance and allows compliance efforts to be more targeted.

The APVMA also considers GMP compliance of overseas manufactured products as part of the registration process. Registrants must demonstrate that such products comply with quality standards comparable to those applying to veterinary chemical products manufactured in Australia.

Control of use responsibilities of states and territories

State and territory government legislation controls chemical use after sale and ensures compliance in chemical use. The states and territories operate through a variety of legislation for regulating poisons, pollution, food quality and water quality. Registered products must be used only for the approved uses specified on the label. The regulations cover basic training requirements for users, and licensing of commercial pest control operators and ground and aerial spray operators. These licensing schemes aim to minimise the risk to operators and bystanders by ensuring that access to such chemicals is restricted to those persons with the necessary competencies and equipment. Other measures to enforce the safe use of chemicals include the use of codes of practice, spraydrift guidelines and other initiatives to raise user awareness.

Monitoring of chemical residues in animal-derived foods

Residue testing programs undertaken by the states and territories and by agricultural commodity organisations identify instances of residues above MRLs. Some marketing organisations also conduct their own residue surveys as part of their quality assurance arrangements.

DAFF, in partnership with participating industries, conducts the National Residue Survey, which monitors chemical residues in raw food and fibre commodities.

FSANZ conducts the Australian Total Diet Survey, which screens food prepared to table-ready state. The survey estimates the dietary intake of a range of pesticides and contaminants, based on food consumption data from national dietary surveys. This provides the most accurate estimates available of our dietary exposure to agricultural and veterinary chemicals.

Prudent use of ectoparasiticides

An ectoparasiticide, to be effective and safe, must be used according to the product label instructions. It is important that users follow label information about directions for use, precautions, warnings, the use of personal protection equipment—including any need for protective clothing, and the expiry date. The product should be used only on the animal species for which it is approved and only at the label-approved rate. Poorly performed treatment operations may result in overdosing or underdosing with the ectoparasiticide. Overdosing may lead to poisoning of the treated animal or the user or both. Conversely, underdosing may lead to exposure of the target parasite to chemical at sublethal concentrations, resulting in treatment failure and the possibility of selecting for resistant strains of ectoparasites. With all approved use patterns, the responsible disposal of unused and spent chemical is critical to protecting the environment. The instructions relating to the disposal of ectoparasiticides included in the product labelling must therefore be complied with.

The slaughter withholding period and the export slaughter interval included on the product label must be adhered to. A failure to comply with the slaughter withholding period may result in chemical residues in meat and offal that exceed the legally permitted standard in Australia. Similarly, a failure to comply with the export slaughter interval may result in chemical residues in animal commodities exceeding the legal standard in the importing country. Non-compliance with a legal standard has the potential to disrupt market access and trade. With dairy animals, compliance with the withholding period for milk is necessary to ensure residues of the ectoparasiticide comply with the relevant MRL for milk.

Producers of wool must also use ectoparasiticides prudently. Chemical residues on wool must meet the standards applicable to worker safety and the environment, including overseas environmental standards when wool grown in Australia is processed overseas.

Conclusions

The regulatory framework for the management of veterinary chemicals in Australia provides primary producers with access to effective ectoparasiticides, while at the same time protecting the health and safety of people and animals, the environment and trade. It is important that farmers and other users of ectoparasiticides read the label carefully and follow the instructions, as these are based on a careful scientific evaluation of comprehensive data. The message for the prudent use of ectoparasiticides is ‘Use the right chemical—use the chemical right!’.

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Chapter 3

Modern chemical treatments for sheep infested with external parasites

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The Australian sheep flock

In 2003–04 there were 106 million sheep in Australia: 85% were merinos and the remainder meat and coarse wool producing sheep. Sheep are raised through the subtropical and temperate areas of Australia. There are 11,500 specialist sheep farms, with an average flock size of 3,500, and altogether 68,000 properties have sheep, with an average flock size of 1,580. Australian Wool Innovation estimates that 75% of all sheep are run in flocks of greater than 3,000. Some 55% of sheep are in the sheep–wheat zone, 33% on high rainfall country and 11% in the pastoral zone. On most farms, sheep are reared on pasture and need to be mustered and brought to a central sheep-handling area to be drenched, shorn, crutched, vaccinated or treated for external parasites.

External parasites of sheep in Australia and their effects on sheep

The main external parasites of sheep in Australia are biting lice (*Bovicola ovis*) and blowflies (*Lucilia cuprina* (Wiedemann)). Minor parasites are face lice *(Linognathus pedalis* (Osborne)), foot lice (*Linognathus ovillus* (Neumann)), itch mite (*Psorergates ovis* Womersley)*,* sheep ked (*Melophagus ovinus* (L.)) and mange mite (*Chorioptes bovis* (Héring)). It is quite likely that the widespread use of the macrocyclic lactone (ML) class of drench and modern insecticides has greatly reduced the incidence of the minor species.

Biting lice

Biting lice are obligate parasites of sheep, with limited ability to survive off the sheep. The main means of spread to new flocks is therefore on infested sheep. Following the introduction of a lousy sheep into a flock, it may be many months until other lousy sheep are seen within that flock (James et al. 2002). Lice are found in all the woolly areas of the sheep and feed on skin flakes and wool grease. The sheep develops an allergy to lice, which leads to irritation or itching. This in turn leads to rubbing and chewing, which cause derangement (Plate 1) of the fleece and loss of value of the wool, as well as discomfort and annoyance to the animal. In addition, blowflies may strike chewed and moist areas of wool. Lice are mechanically removed at shearing and numbers further reduced by exposure to environmental influences after shearing, especially in summer. The population of lice increases as the wool grows and also in the cooler months.

Blowflies

Lucilia cuprina, the blowfly that initiates strike, has been recorded throughout Australia (Norris 1990) and flystrike is seen wherever sheep are raised. Blowfly numbers typically rise in spring as soil temperature and humidity increase, and fall in the cooler months of the year. Hot, dry conditions can also reduce fly numbers. Gravid female *L. cuprina* are attracted to moist areas on the sheep's body, particularly where these are associated with a protein exudate such as caused by wounds, dermatitis, urine stain or faecal accumulation (dags) around the breech. The females generally imbibe protein and then lay their eggs on the skin where they hatch after 8–12 hours. The larvae grow to over 1 cm in length in 3 days. As well as physically abrading the skin with their mouth hooks, second and third-instar larvae secrete enzymes that break down the skin and cause serous exudation, which they then feed on. Existing strikes are, in turn, attractive to other gravid blowflies including a number of secondary strike species of blowfly. Multiple ovipositions cause the strike to grow rapidly causing fluid loss, shock, toxaemia and death (Plate 2).

Treatment of external parasites of sheep

General considerations

There are two approaches to the control of the external parasites of sheep: preventative treatment or treatment of existing infestations. An example of a preventative strategy would be to apply a cyromazine-based product to all susceptible sheep before an anticipated fly challenge. Alternatively, individual struck animals can be treated or a whole mob of sheep jetted in the face of an outbreak of flystrike ('fly wave').

A major factor in the treatment of sheep is delivering the chemical to the place on the body where the parasite resides. For lice, this means getting chemical to the skin over the whole surface of the sheep. For blowflies, chemical needs to be applied all over the body or to sites most prone to strike—the back, the breech, the poll for rams and the pizzle for wethers. For struck areas, localised treatment is required.

The fleece of sheep is greasy and naturally water repellent. Long wool provides a large and protective environment for lice and flies. It acts as a barrier to chemical treatments penetrating to the skin where most parasites are found. Therefore, external treatments of sheep must take wool length into account. All sheep are shorn at least once a year. Shearing reduces the barrier effect of wool to treatment, as well as the parasite habitat and parasite numbers. Therefore, timing chemical treatment to coincide with shearing makes good sense, particularly for lice treatment. To reliably eradicate lice, dipping is done within 6 weeks of shearing. This is because there can be certainty that each sheep has been thoroughly soaked to the skin with chemical and every louse has been exposed. Similarly, the pour-on treatments for lice control are applied immediately after shearing to give the chemical a maximum chance of penetrating to the skin at the site of application and to maximise the spread around the sheep. In addition, if all shorn sheep are treated with a visible treatment, untreated and unshorn sheep can be easily identified and treated. Treatment of the whole flock is essential for lice eradication.

Treatments given to sheep with long wool require high-pressure jets of water or prolonged soaking in a shower dip to move chemical into the fleece and down to the skin. Water-soluble chemicals such as cyromazine move into the fleece when it rains, enhancing their efficacy. Some ready-to-use back-line treatments can be applied to long wool to give temporary control of lice, and the physical barrier the long wool presents is overcome by using large amounts of chemical. Long wool protects chemicals from the environment, to give sustained insecticidal levels preventing new infestations or continuing to reduce existing infestations.

Plunge dips

The oldest and perhaps most effective way of applying chemicals to sheep is by dipping. This involves swimming sheep through a long body of water–chemical solution 2–6 weeks after shearing. Many sheep farms around Australia have an old concrete dip, 12 m long buried in the ground near a set of yards, often contaminated with residues of arsenic or other, now obsolete chemicals. Today, trailer-mounted, portable dips are commonly brought onto a sheep farm by a contract dipper (Plate 3). Sheep are driven along a race, then up a ramp or onto a sheep-handling conveyor belt and fall into a U or S-shaped dip. The dip will be wider than the shoulder and hip of the largest sheep, 1.5–2 m deep and 6.9–13.3 m long (Downing 1994). The contractor and staff then push the head of the sheep under the dip at least twice to ensure that the head and neck are fully wetted. Downing (1994) showed that dry areas on the sheep declined with a longer swim length and more head dunks. Lund et al. (1998), working with a straight in-ground dip, found that a swim length of 9 m gave significantly better wetting than 6 m. They also showed that two head dunkings gave significantly better fleece wetting that none or one dunk, but that three dunkings gave no extra benefit. They therefore recommended two dunkings in addition to the head-wetting that occurs when the sheep enter the dip. A recent innovation in sheep-dip design has been an immersion cage mobile dip in which sheep are run into a cage then completely immersed in dip wash for a specified period. They then drain in an adjacent area whilst the next load of sheep is dipped. This method has the advantage of totally immersing all sheep for a set time and eliminates variation due to sheep and operator differences. This approach is likely to be widely adopted.

The other main factor determining efficacy is the need to maintain a concentration of chemical sufficient to kill parasites. Many chemicals used on sheep are lipophilic—that is they bind avidly to lipids such as wool grease in preference to water. Therefore, running sheep with a greasy fleece through a dip strips chemical out of the dip at a greater rate than water is removed from the dip. To counter this, chemical companies have provided a quite complex set of instructions for charging the dip, recharging it to restore the water level and reinforcing to bring the concentration of chemical back to the initial concentration. Work done by Sherwood et al. (1999) showed that intermittent replenishment led to substantial rises and falls in chemical concentration during the dipping process. They showed that charging and constantly replenishing a 3,360 L plunge dip with 100 ppm diazinon gave a steady concentration of 30–40 ppm of dip chemical. A further study showed that, by charging the dip with 30 ppm diazinon and matching the stripping rate of chemical with the concentration of chemical in the constant replenishment stock, a steady concentration of chemical could be maintained in the dip wash, presumably associated with improved efficacy. These findings were utilised in the recommendations for Extinosad®, a dip chemical product recently registered in Australia, which contains the active ingredient spinosad. On the label of Extinosad® the initial charge concentration of the dip is 10 ppm with a constant replenishment rate of 15 ppm. No reference is made to reinforcement or topping up. In contrast, diflubenzuron, which is not lipophilic, does not strip (Levot and Lund 2004) and replenishment and initial charge concentrations are the same.

Shower dips

A sheep shower dip is a large, enclosed pen, usually circular (Plate 4), in which sheep are held and sprayed with a large volume of insecticidal wash at low pressure from overhead circulating arms (Sinclair 1995). Spray nozzles on the floor of the shower can also be used. Dip wash runs from the floor of the shower into a sump and is recirculated. Sinclair (1995) recommended that sheep be held in the shower for 4–10 minutes. Higgs et al. (1994) showed that sheep sprayed for 5 minutes from the top nozzles and 1 minute from the bottom nozzles had dry areas, especially on the neck, and that some formulations of insecticide dip did not eradicate lice in groups of sheep. Lund et al. (1998) investigated mechanical influences on fleece wetting in a Buzzacott 60 R shower dip. They showed that using a pump able to give a flow rate of 18 L/second and a boom speed of 5 rpm gave better wetting than that obtained using the manufacturer's recommendations. They found a linear decrease in fleece dryness as time in the shower increased and recommended that sheep be left in the shower for 12 minutes under the top nozzles only—much longer than standard practice.

Lund et al. (1998) found that the concentration of insecticide in the shower dip declined markedly—to as low as 7 ppm—during showering, after starting with 100 ppm. Sherwood et al. (1999) held sheep for 6 minutes in a Buzacott 30 R shower charged with 100 ppm diazinon and constantly replenished with 100 ppm diazinon. They showed that chemical was stripped from the wash much more rapidly from shower dips than from plunge dips. In the constant replenishment system, the concentration of diazinon in the dip wash rapidly fell during the treatment of the first batch of sheep, rose whilst the dip was empty and then fell even further during showering of the second and third batches of sheep. With all sump volumes, the concentration of diazinon remained below 20 ppm nearly all the time and with large sump volumes a steady-state concentration of less than 10 ppm was reached. Top-up and replenishment directions brought the concentration of chemical back towards 100 ppm, but it rapidly fell during dipping, and the batch treated just before replenishment would presumably be exposed to low concentrations of chemical. Levot and Lund (2004) obtained similar results and suggested that the shower dip should be reinforced and topped-up after each batch of sheep to ensure that each sheep got an effective dose of diazinon. In many field situations this would be impractical, calling into question the utility of shower dips for diazinon. The Extinosad® label recommends charging the shower dip with 20 ppm spinosad and constantly replenishing with 40 ppm spinosad to ensure adequate treatment of sheep. Assuming that each sheep plunged or shower-dipped withdraws the same volume of dip wash from the system, shower-dipped sheep need nearly three times the amount of spinosad per head as do plunge-dipped sheep to overcome the lower effectiveness of shower dips.

Jetting

Jetting is the application of chemical into the fleece of sheep using high-pressure jets of fluid. It can be used to treat lice in sheep with greater than 6 weeks of wool growth or to prevent and treat flystrike. Because of the large parasite habitat available on sheep with long wool, and the physical barrier to treatment that the wool presents, the aim of jetting is to 'control' lice populations, by which is meant reducing the population below the level associated with fleece damage or economic loss. Eradication of parasites by jetting is not feasible in sheep with long wool.

Hand jetting

In traditional practice, sheep are mustered, brought to the sheep yards and packed fairly tightly into a race. Jetting chemical is mixed with water in a large tank and connected to a pump. One or two long hoses lead from the pump to the race. Attached to the end of the hose is a jetting wand that has an on/off mechanism and several outlets for jetting fluid to enter the fleece. The jetting wands are either curved or have a flat metal shroud over the nozzles to control splash back and facilitate saturation of the fleece (Dutjet; Plate 5). Some end in a T-piece shape, with a comb like row of nozzles on the end. The water runs out under high pressure (100 psi) to allow liquid to penetrate the fleece. Half a litre of jetting fluid is applied to adult sheep per month of wool growth and a lower volume to lambs. The wand is passed over the areas that need to be treated—back, neck, sides and breech. Application along the back line deposits a reservoir of jetting fluid that drains through the wool along the natural drainage lines of the body. These same sites are susceptible to body strike, so this method of application provides protection to the most vulnerable sites. Rams can be treated on the poll, and wethers or rams on the pizzle. It takes 20–40 seconds to treat each sheep and is laborious.

Automatic jetting races (AJR)

Several machines have been developed to automatically jet sheep and reduce the labour required. This usually entails sheep running along a race and entering an area with a number of nozzles facing onto the back and belly of sheep. In some races, nozzles also treat the sides and breech of the sheep. The devices usually have a mechanical lever or electric eye that activates liquid flow when the sheep is in the machine.

Plate 1. Lousy sheep with severe fleece derangement

Plate 2. Blowfly struck sheep

Plate 3. Sheep-dipping in mobile plunge dips

Plate 4. A shower dip

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Plate 5. Jetting sheep using a Dutjet wand

Plate 6. Sheep treated with a pour-on formulation straight after shearing

Plate 7. A home-made fly remedy in a bottle and some shears to remove wool from the strike

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James and Russell (1980) compared the fleece-wetting ability of hand jetting, AJR (Harrington machine) and shower dipping. Hand jetting gave the best fleece penetration and movement of wash to the skin along the back line, pizzle and breech. The AJR gave better breech wetting than shower dipping, but poor penetration to the skin along the back line. James and Russell (1980) reported that hand jetting was by far the most effective treatment method, but took much more time than the other methods. Since 1980, further work has been done to improve the performance of AJRs. Lund and Kelly (1994) described how to improve AJRs by increasing the pump size, using larger nozzles giving a solid stream of liquid, aligning the spray nozzles along the length of the race and increasing the volume administered per head. Levot and Sales (1998a) measured organophosphates (OPs) and cyromazine residues in wool after hand jetting, standard AJR or modified AJR application. They showed that the modified AJR was less efficient in delivering pesticide than hand jetting, but was much more effective than the standard AJR. Electrodip, a New Zealand company, has developed an AJR with nozzles on the side, high-pressure pumps and the ability to deliver a large volume of liquid into the fleece. Other high-volume machines are available, some of them able to recirculate liquid not absorbed by the fleece. Some deliver so high a volume of liquid per head in seconds that they are more akin to a sheep shower dip than a jetting race. The author has seen one such machine in use in the Southland of New Zealand in which Romney ewes received more than 10 L of dip wash per head as they ran through the spray curtain.

Pour-on for lice control

Dipping sheep for the control of lice is a laborious process and requires capital investment in a dip or the use of dipping contractors. In 1980, the Wellcome chemical company developed a solvent-based, pour-on formulation of the synthetic pyrethroid (SP), deltamethrin (Clout®), to overcome these difficulties. Animals were treated immediately after annual shearing. A narrow strip of product, 2–15 mL was applied along the back line, using a drench-gun-like device, with the product carried in a pack on the operator's back. Bayvel et al. (1981) list many advantages of a pour-on treatment for lice: ease of application, labour saving, ready to use, no water supply needed, dose volume readily measured, no fleece wetting, no spread of bacterial infections in the dip wash, no effluent disposal, no environmental contamination of waterways and groundwater, can be used off shears, no re-mustering, dye added to identify treated animals (to help treating 100% of the flock), and easy treatment of small groups. It is not surprising then that Clout®, Clout-S® (a water-based formulation) and other pour-on formulations of SPs were widely adopted by farmers and many old plunge and shower dips fell into disuse.

Unfortunately, Boray et al. (1988) found that resistance-associated failure to eradicate lice in the field was being reported. Levot and Hughes (1990) characterised the resistance in the laboratory. Johnson et al. (1995) investigated the spread of deltamethrin following back-line treatment of sheep. They showed that most of the chemical applied stayed at the site of application and that the concentration of deltamethrin declined markedly away from the back line. They also showed that the chemical stayed on the tip of the wool staple as it grew away from the skin. Hennessy (1997) has likened this effect to a 'canopy' of insecticide that the lice could re-establish beneath. Johnson et al. (1995) also showed that samples of wool collected more than 16 days after treatment were ineffective at killing lice, whereas samples collected soon after treatment containing the same concentrations of deltamethrin were effective. This indicated that the bioavailability of the chemical declined after administration. There is little doubt that the poor distribution of chemical around the sheep from the back line allowed some lice on some sheep to survive and selected for resistance. James (2002) suggested that the high prevalence of lice experienced in most states during the early and mid 1990s was associated with spread of resistance to SPs used in back-line applications, which at that time comprised approximately 70% of louse control treatments.

Griffin (1993) reported the introduction into the market in Australia of a new class of pour-on chemicals for lice control. This was the insect growth regulator (IGR) triflumuron, Zapp®. The applicator for this chemical has a wide boom with several jets to ensure a broad application of material to the back line and to improve distribution. Since it was a member of a new class of chemicals, there was no resistance, and it was both efficacious and easy to use. Triflumuron chemical and other pour-on IGRs (Plate 6) have taken the market by storm and far outsell other lice-control products. Their use has been linked to a fall in louse prevalence (James 2002).

It is worrying that there are reports of resistance to the IGRs in the field (James and Levot 2005). The situation seems akin to the situation with SP pour-on products in the 1980s. It may be that the pour-on mode of application of chemicals to sheep is an inherently inefficient way to apply an effective dose of chemical over the whole skin of the sheep to eradicate lice. Pour-ons, by their nature, may select for resistance. Perhaps wet dipping, using modern portable plunge dips and effective chemicals, may be the best way to get an even application of chemical to the skin, eradicate lice and protect the chemical from the development of resistance.

Spray-on for fly control

As with lice control, for fly control there has been a substantial swing from hand jetting and jetting races to convenient, ready-to-use spray-on formulations—especially cyromazine (Vetrazin® and generic products) and dicyclanil (Clik®). These products are applied, using special applicators, to the back line, the breech and other areas where flies are likely to strike sheep. Dicyclanil gives at least 19 weeks protection against flystrike (Nottingham et al. 2001). Fortunately, laboratory research using artificially induced mutagenesis has shown that only low-level resistance to cyromazine arises and that some types of resistant flies are less able to survive in the wild than are susceptible flies (Yen et al. 1996). The Australian fly population has therefore remained susceptible to cyromazine despite widespread use since 1979.

Blowfly dressings

In the early days of the wool industry, before effective preventative chemicals were invented, farmers had to catch struck sheep, shear the wool off the struck area and apply ‘tar’ products to kill the maggots and prevent re-strike. To this day, shearers refer to the dressings applied to struck sheep as ‘tar’. These products contained creosote, paraffin, eucalyptus oil, phenol and whatever else farmers found to be effective. In the 1940s, the organochlorine class of chemicals was developed and released for fly control in Australia, followed in the 1950s by the OPs. The OPs were very popular and were widely used to prevent and treat flystrike. Powder, paste and liquid ready-to-use formulations were developed to treat individual animals (Plate 7). The jetting and dipping formulations could also be diluted in water for individual animal use. More recently, aerosol formulations of an OP and spinosad (Rothwell et al. 2005) have appeared. Ivermectin has been released as a dressing and jetting product.

Unfortunately, by 1965 OP resistance had been detected in the field, and by 1970 95% of all field populations of flies were resistant to the OPs (Levot 1995). This naturally raised concerns about the effectiveness of the OP dressing, and laboratory studies showed that resistant maggots could survive therapeutic concentrations of OP (Levot et al. 1999). A study by Levot and Sales (1998b) showed that OP fly dressing were still useful, but only to prevent re-strike. The recommendation from this work was to closely shear the wool from the stuck areas to mechanically remove maggots, then apply the dressing to prevent re-strike. Alternatively, the flock could be jetted with cyromazine after shearing the struck animals. Nowadays, ivermectin (Thompson et al. 1994) or spinosad (Rothwell et al. 2000) can be used as jetting treatments without shearing first or as an individual animal treatment. Even with these newer products, however, prudence suggests that shearing or clipping of the wool over a strike before treatment is desirable.

Systemic

There are some minor external parasites of sheep that live within the skin or suck blood, for which a parenteral or systemic route of administration is useful. Sheep itch mite (*Psorergates ovis*) is susceptible to drenches of MLs such as ivermectin, moxidectin and abamectin. The widespread use of this class of drenches for worm control is probably responsible for the low prevalence of itch mite in Australia today. The MLs also have registered claims against chorioptic mange (*Chorioptes bovis*) in cattle and undoubtedly have some effect against chorioptic mange in sheep. Similarly, the ivermectin capsule (Ivomec Maximizer®) has a claim against the sheep ked (*Melophagus ovinus*) and the MLs, together with widespread treatments for lice, have virtually eradicated sheep ked from Australia.

Chemicals used

Insect growth regulators

Cyromazine
Diflubenzuron
Triflumuron
Dicyclanil

Pyrethroids

Deltamethrin
Cypermethrin
Alphacypermethrin
Pyrethrin
Lambda-cyhalothrin

Organophosphates

Diazinon
Chlorfenvinphos
Propetamphos

Macrocyclic lactones	**Others**
Ivermectin	Spinosad
Abamectin	Rotenone
Moxidectin	Magnesium fluorosilicate

A full list of brand names can be found on the found on various agricultural websites such as that of the NSW Department of Primary Industries site at <http://www.agric.nsw.gov.au/reader/sheep-external/dai78-v4.pdf?MIvalObj=24622&doctype=document&MItypeObj=application/pdf&name=/dai78-v4.pdf>.

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Chapter 4

Pesticides used against ectoparasites (ticks, flies, lice) of cattle in Australia

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Introduction

Cattle ectoparasites are damaging to the health and welfare of Australian cattle and add substantially to production costs. Loss due to cattle ectoparasites was estimated at $131m per annum in 1995 (McLeod 1995) and this is likely to have increased in the past 10 years. The figure includes loss in production due to the parasites and the cost of pesticides. It does not include costs related to diseases transmitted by the ticks (babesiosis, anaplasmosis) or to welfare issues that can be difficult to assess or cost. For the cattle tick (*Boophilus microplus* (Canestrini)), each female causes a loss in production of approximately 2 g or 7 mL of milk (Sutherst et al. 1983; Jonsson et al. 1998). This becomes important when thousands of ticks are feeding on each animal. It also causes irritation and stress on animals, as witnessed by their constant grooming and rubbing at the tick attachment sites.

A good example of the welfare issue is the buffalo fly (*Haematobia irritans exigua* De Meijere). Effects on production are difficult to quantify and some trials show no measurable losses. The buffalo fly is a serious ectoparasite of cattle in northern Australia. This small, dung-breeding, blood-feeding fly was accidentally introduced into Australia at Darwin from Asia in 1838. Since then it has gradually spread south, becoming established throughout most of the northern humid (i.e. high rainfall) parts of Australia including the Northern Territory, Western Australia, Queensland and New South Wales. More than 10–15 million cattle in Australia are subjected to parasitism from buffalo flies. Although scientific research has not consistently demonstrated weight gain improvement resulting from buffalo fly control treatment[1], most personnel involved with cattle in tropical areas are in no doubt, that buffalo flies are capable of inflicting inhumane levels of suffering on their hosts (Plate 1).

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Plate 1. Buffalo fly infested cattle in northern Australia

Cattle can suffer intense discomfort and irritation from high populations of buffalo fly and this may be partly due to the filarial worm (*Stephanofilaria* sp.) transmitted by the fly. Badly affected cattle exhibit restlessness and defensive behaviour as they seek to dislodge flies. Continual interruption (day and night) to normal grazing and resting behaviour results from buffalo flies biting and feeding on blood. While it may be quite difficult to accurately count the number of buffalo flies present on individual heavily infested animals (due to movement of flies and the affected animal), certain animals may carry burdens of more than 4,000 biting flies, which is certainly not conducive to wellbeing. Most treatments would be aimed at reducing stress rather than preventing production loss.

Three main species of lice are found on cattle in Australia: the long-nosed cattle louse (*Linognathus vituli* (L.)), the most common; the short-nosed cattle louse (*Haematopinus eurysternus* (Nitzsch)); and the biting louse (*Bovicola bovis* (L.)). The biting louse is the one usually involved in very heavy infestations. Biting and sucking lice are the most common ectoparasites of cattle in temperate zones of Australia (Holdsworth 2002). *Bovicola bovis* is found on cattle at all ages and when numerous is capable of causing considerable annoyance and irritation. *Linognathus vituli* is found mainly on dairy cattle, with *H. eurysternus* on calves (Holdsworth 2002). Lice irritate cattle while sucking blood

[1] In Queensland beef cattle, a range of losses in production due to a moderate infestation of 200 buffalo flies has been recorded. The losses averaged 15 kg over a 100-day fly season (L. Turner, Buffalo fly in beef cattle. Losses in production. Department of Primary Industries and Fisheries, Queensland, Agnote 20 July 2005.)

or feeding on epithelial debris. Affected cattle relieve the irritation by rubbing or scratching. Affected animals become anaemic and unthrifty, and death may occur (Seddon 1967)

It is still popular to criticise the use of pesticides, but without them the ectoparasites would make it difficult to produce cattle in many parts of Australia. The use of pesticides on cattle is probably increasing with the recognition that the European *Bos taurus* L. breeds and their crosses to *Bos indicus* L. are more marketable, but are generally more susceptible to parasites.

Cattle tick

Treatment

It should be remembered that, with the arrival of the cattle tick and the tick-borne diseases (TBD), cattle production in northern Australia would have been almost impossible without the introduction in 1895 of arsenic for tick control. The standard dose of arsenic was 0.2% arsenic tetroxide. Resistance was slow to develop but was suspected in Australia in 1937 and confirmed in 1955 by Hitchcock and Roulston. Fortunately, DDT at 0.5% became commercially available in 1946 and was soon followed by the other organochlorines (OCs)—BHC (benzene hexachloride or hexachlorocyclohexane), toxaphene, dieldrin, aldrin and chlordane. Unfortunately, and unlike arsenic, resistance to BHC emerged quickly (Hitchcock 1953), and worse, this tick strain was cross-resistant to all the other chlorinated hydrocarbons but less so to DDT. Resistance to DDT was confirmed by Stone in 1957. The use of all the chlorinated hydrocarbons was banned for tick control in 1962, because of residues in meat, milk and the environment.

Fortunately, the organophosphates (OPs) became available: diazinon (in 1956), dioxathion (1958), coumaphos (1959), ethion (1962) and chlorfenvinphos, bromophos-ethyl and chlorpyrifos at later dates. The carbamate, carbaryl, became available in 1963. A complex series of resistant strains of tick then emerged, starting in 1963 with a strain (Ridgelands) resistant to the earlier OPs but against which coumaphos, ethion and carbaryl still gave adequate control. The Biarra strain then emerged, which was resistant to the newer acaricides but could still be controlled by chlorpyrifos and bromophos-ethyl. A number of other resistant strains were eventually identified (Mt Alford, Gracemere etc.) and, from 1970 onwards, there was a rather rapid decline in the usefulness of the OP and carbamate acaricides in tick control. This has been well documented by Wharton and Roulston (1970) and Roulston (1980). Dates of introduction of the different acaricides are given in Table 1 of Chapter 1. In 2005, coumaphos is the only OP registered for tick control. Chlorfenvinphos and ethion are registered only as synergists in combination with synthetic pyrethroids (see below). It is worth mentioning at this point that, as resistance overtook the OP and carbamate compounds, there was again a threat of no chemicals available to control ticks. Roulston (1980) commented that the Queensland cattle industry was in serious trouble when arsenic resistance took hold and OPs had not yet been introduced.

Once again, when OP resistance threatened tick control, fairly desperate steps were considered necessary. When coumaphos resistance was detected (Biarra strain), quarantine and eradication measures were enforced in the Brisbane River valley area where this strain was identified This attempt at containment failed for various reasons (Nolan and Roulston 1979), but the introduction of the new acaricide chemicals (amidines and synthetic pyrethroids (SPs)) saved the day. Chlordimeform, the first amidine introduced (1970), was used to spike OP dipping vats to control the OP-resistant strains. Clenpyrin (1972), chloromethiuron (1973), amitraz (1975) and then cymiazole (1979) followed. For various reasons, most of these compounds were not used extensively at this time and chlordimeform was withdrawn from the market. Once problems of amitraz breakdown were resolved by adding lime to the dipping vats to increase pH, amitraz was used extensively for a short time before the introduction of the highly efficacious SPs.

It is also worth considering here the benefits to the cattle industry of chemical company research, development and marketing. For example, the availability of new acaricides for control of resistant tick strains was very valuable. Unfortunately, there are no estimates of the benefit to producers (or the animals) from this company work but, in 1980, CSIRO's Division of Entomology commissioned a benefit–cost analysis (Marsden et al. 1980) of its research on acaricide resistance diagnosis and its assistance to chemical companies in developing effective acaricides (a foretaste of the now ubiquitous benefit–cost analyses). Benefits in 1975 values were $6.8 million (at a 10% discount rate), which would be substantial in 2005 values. Updated analyses of benefits and costs of ectoparasiticide development and use would be valuable.

There was an indication of amitraz resistance developing (Ulam strain) in 1980 (Nolan 1981), but with the introduction of the SPs—cypermethrin (1981), deltamethrin (1981), cyhalothrin (1982) and flumethrin (1985)—tick control was again secure. The SPs when first tested actually gave lower percentage control of the existing DDT-resistant strain. To overcome this problem, they were introduced at higher than originally planned concentrations (cyhalothrin) or in combination with OP synergists (Nolan and Bird 1977). Unfortunately, this secure tick control situation did not last long. In 1987, a strain (Lamington) resistant specifically to flumethrin and another strain (Parkhurst) resistant to all SPs were identified by the Queensland Department of Primary Industries (QDPI; now the Department of Primary Industries and Fisheries, Queensland (QDPIF) and CSIRO. There was a rather rapid spread (or perhaps repeated emergence) of these resistant strains, no doubt due to a number of factors, including the popularity of the SPs as tickicides. As a result, the sales of SPs for tick control are now low.

Before moving on to discuss newer acaricides that controlled SP-resistant strains, some comment is needed on changes in formulation and delivery of acaricides. The introduction of flumethrin pour-on was the first departure from the older procedures of dipping and spraying. The pour-on was quicker and easier to apply and this formulation also gave longer residual protection (14 days) than the older acaricides (0–7 days). All of this was popular with the producers. The reasons for the success of this newer technology were never fully publicised but various suggestions can be made. One possibility is that, although vehicle oils for the pour-on may be relatively standard, the extremely high toxicity of the trans-Z flumethrin isomer meant that enough of the flumethrin spread over the animal to tick attachment sites to be toxic to ticks. Another possibility is that the vehicle allowed transdermal passage of the flumethrin, which then acted systemically. A reservoir site inside the animal may have allowed prolonged release of the flumethrin into the circulation. Whatever the explanation, this prepared the way for the newer delivery techniques of pour-on, injectable, and injectable slow-release that are now used with more recent acaricides such as the macrocyclic lactones (MLs).

Returning to consideration of SP resistance in the ticks and the decline in SP use: one outcome was that, in the early 1990s, many producers returned to amitraz for tick control, especially for control of SP-resistant strains. At that time, amitraz had 50% or more of the acaricide market. This has probably declined, partly because the resistance first detected in 1980 has increased following increased amitraz use, and partly because new, easier to use, longer-acting acaricides have been introduced. Data from QDPIF and, up to 1999 from CSIRO, suggest that there are now 200 or more properties with amitraz-resistant ticks. In the 30 years since the introduction of amitraz, this has been a remarkably slow increase in resistance compared to experience with DDT, BHC, OP and SP resistance. It is difficult to explain this result, but lack of use of amitraz is not a likely answer. More likely is a continued lack of fitness of the amitraz-resistant tick strains. There are two recognised strains. As mentioned earlier, Ulam strain was identified in 1980 and this could still be controlled with SPs but, in 1992, the Ultimo strain was identified which had resistance to amitraz and all SPs (QDPIF). Actually, the strain does have some OP resistance as well: in other words, combined Ulam and Parkhurst resistance. It is now known that a similar strain has become a serious problem in Latin America.

Newer acaricides will control the Ultimo strain and this is one reason why MLs and fluazuron (Acatak) now have an increased share of the market. Certainly, they are more costly than amitraz but they are easier to apply (e.g. pour-on and injectable) and give longer protection. Avermectin was the first ML approved in 1985, followed by ivermectin (1990), moxidectin (1994), doramectin (1996) and eprinomectin (1998) (see Table 1 of Chapter 1). These chemicals also have the added advantage of worm and fly control. Treatments with MLs can give some excellent improvements in the production and appearance of cattle.

Companies will continue to develop and market new acaricides. The strategies currently being investigated can be grouped as follows:

- new formulations of existing compounds into more user-friendly products, such as pour-on formulations that previously were dip or spray formulations
- combinations of different classes of acaricides into a single pour-on formulation, so that the resulting product has better knock-down characteristics and provides control of a broader spectrum of parasites

- new formulations of existing classes of acaricide to provide longer residual protection (e.g. Ivomec Gold®)
- new classes of acaricides undergoing evaluation.

The cattle tick has developed resistance to most of the earlier classes of acaricides. Fortunately, to date no resistance to MLs has yet been detected in Australia. In the light of earlier observations, it would be optimistic to think this will never happen. In fact, ivermectin resistance has been detected in *B. microplus* in Colombia and Brazil, where MLs have been used more extensively for tick control than they have in Australia.
In northern Australia, it is the dairy industry that is at greatest risk, because amitraz resistance is more common and MLs are more relied on since fluazuron cannot be used on milking cows due to residues in milk. For milking cattle, control of the Ultimo amitraz and SP-resistant ticks can only be with moxidectin and eprinomectin pour-ons, which have short or nil withholding periods. Emergence of ML resistance would be a serious problem for these producers.

When talking of acaricides, the impression might be of a litany of disappointments because of the emergence and spread of resistance. It must be remembered, however, that the acaricides have kept the cattle industry viable in the tick-infested zones of northern Australia for 110 years. Nevertheless, we need to look briefly at means of avoiding and managing resistance. Given that the discovery and development of new acaricides for livestock is not progressing rapidly, there is a good argument for trying to keep our existing acaricides viable. For example, saving or rescuing the MLs from resistance is worthwhile. Knowing the best control methods against *B. microplus* is a difficult decision for nearly all cattle producers (and also researchers). In most cases, producers have many other important problems to think about (e.g. cattle feed), so it is a good idea to present them with the best practical advice on tick control. Of course, it is a subject of heated debate between researchers and companies who themselves can often disagree. There is a need to provide up-to-date information and good practical advice for producers. The standard advice on tick control is that farmers should use registered acaricides at concentrations detailed on the product label. Seasonal control strategies recommended for each region should be followed (consult QDPIF literature), and acaricides used economically so that the cost is worth it in terms of improved cattle production and health. Producers should make sure that they understand and follow advice on withholding periods, especially for cattle destined for export to countries such as Japan, the EU and USA, which have strict regulations as defined in export slaughter intervals. Good property biosecurity is needed to ensure that resistant ticks are not introduced with new cattle.

These are the clear and easy parts of the advice on tick control, but there are other suggestions that could be taken up by producers to try to preserve the efficacy of acaricides. Where acaricide control fails, it is good practice to get the ticks tested for acaricide resistance at QDPIF in Brisbane. If resistance is confirmed, use an acaricide of a different chemical group. This is easy advice, but the problem is that recommendations are needed on what chemicals to use, which would be valuable information to add to resistance test reports. Where ticks can have combined resistance to OPs, SPs and amitraz, they can be controlled by MLs on beef cattle and some MLs (e.g. Cydectin, Eprinex) can even be used on milking dairy cattle. Fluazuron (Acatak) can also be used on non-milking dairy cattle and beef cattle to control these resistant strains of tick. Other newer acaricides are mentioned below but are not yet registered in Australia (e.g. fipronil and spinosad). MLs, fluazuron and the newer acaricides tend to be more costly but some give longer protection so reducing the net cost of treatments.

Acaricide resistance avoidance and management has been discussed over many years, but based on very little information, and strategies proposed should be treated with caution. Rather than discuss again in detail the various resistance management strategies, let us stick with one consistent field observation by various authors: reducing treatment with one particular acaricide chemical group, e.g. OP, SP, ML etc., to a maximum of five acaricide applications per season will help to delay resistance. This information comes from repeated use of chemicals such as OPs, SPs and amitraz that are used five times at approximately 3–4 week intervals. For long residual protection acaricides (some MLs, fluazuron), this is equivalent to a total of approximately 4 months or two tick (*B. microplus*) generations.

Conclusion

In summary, the main barriers to effective acaricide control of ticks are too-frequent acaricide use, higher costs of newer products and introduction of resistant ticks with newly purchased cattle. Resistance management has the potential to delay emergence of resistance, and the best strategy seems to be reduced acaricide use. Tick-resistant *B. indicus* cattle are a solution in some circumstances, especially in tropical climates where they have other advantages. It is also possible to select tick-resistant animals within almost any breed. This takes time but it may be easier in the future because there is current research to find gene markers for resistance in different cattle breeds. It will be some years, however, before this technology becomes available.

It is likely that any new technology will have to be integrated with acaricide use. Another biocontrol strategy with the potential to reduce the need for acaricides is the TickGARD® vaccine, an improved version of which is currently under development.

We can now suggest additions to the standard advice on tick control given earlier.

1. If acaricide resistance has been detected, change to an acaricide group to which your ticks are not resistant.
2. If amitraz resistance has been identified, rotate amitraz use with a different acaricide group at a minimum of 2-month intervals (tick generation time).
3. Use *B. indicus* or *B. indicus* cross-bred cattle that are more tick resistant, or select your own animals that are more resistant.
4. Use TickGARD® vaccine if available.
5. Use any other means to reduce frequency of acaricide applications to five per tick season (equivalent of 4 months or two tick generations).

What is the future for discovery, development and introduction of new acaricides that will resolve the resistance and residue issues? It has been argued that the incentives for the development of new veterinary drugs are low compared to the incentives for making new human drugs. The introduction of new chemical groups of acaricides has been rather slow since the mid 1990s, but probably no slower than in some periods in the past (see Table 1 of Chapter 1). It is fortunate that resistance to the newer products (fluazuron and the MLs) has not apparently emerged in the 10 or more years since their introduction. This can be explained in part by the slow spread of serious amitraz resistance and the continued high use of this product. As discussed earlier, it is unlikely this favourable situation will last.

For many years, companies have been extensively screening for new chemicals that will control ticks. What appears surprising are the relatively few targets that have been identified or, in some cases, suspected from information on targets in insects. Omitting arsenic because its mode of action in ticks may be complex and is not fully known, that leaves acetylcholine esterases (organophosphates and carbamates), chloride ion channel (suspected target of DDT), GABA receptor (organochlorines), chloride ion channel proteins (SPs), octopamine receptor or monoamine oxidases (suspected target of amidines), GABA receptor but not the same site as the organochlorines (suspected target of MLs), chitin synthase (suspected target of fluazuron), GABA receptor (fipronil) and nicotinic GABA receptors (spinosyn). Possibly only seven proteins are targeted. This has led to some predictions that genomics, bioinformatics, robotics, combinatorial chemistry, parasite cell culture, RNAi etc. will rapidly find many more protein targets and open the way for development of many new antiparasite drugs against these targets. As pointed out by Geary et al. (2004), these new techniques must be applied, but finding single, new, antiparasitic agents is a difficult task even using high throughput methods. Buehler (2004) has similar comments about new drug discovery for human medicine. Many proteins occur in protein families that contribute to a biochemical or physiological pathway. There is redundancy or backup in the system and single drugs to block these pathways may be rare, hence the few targets discovered so far. However, provided this is recognised, the new technologies are sufficiently powerful to identify a family of drugs that will be effective rather than the single drug we have been accustomed to in the past. The future for discovery of new acaricides is promising, but we also need to take practical steps to conserve the excellent acaricides we already have.

Buffalo fly

Treatment

The history of insecticide use for buffalo fly control on cattle overlaps to varying degrees with the history of tickicide use in Australia. This is not surprising, given that buffalo flies and cattle ticks occupy similar geographic and climatic distribution and that the preferred hosts of the two pests are the same major economic species of cattle. It was common practice over 50 years ago to treat cattle with a pesticide product that targeted and controlled both ticks and flies, and the same situation exists today. Only in the past

20–30 years have products that specifically target one pest and not the other become available. For reasons of convenience and expediency, however, products that control cattle ticks and buffalo flies simultaneously will continue to be developed by manufacturers and sought by cattle producers.

In the late 1940s, when the OCs replaced arsenic (0.2% arsenic tetroxide) as the preferred treatment for cattle ticks, the use of DDT to control cattle ticks was found to simultaneously provide good control of buffalo fly (Norris 1947). Seddon (1967) reported:

> DDT is so potent that when a buffalo fly alights on a treated beast even after the spray has dried, it picks up on its appendages sufficient DDT to kill it. It is unnecessary to spray the entire body surface of the animal, a patch over the shoulders being sufficient. As flies move from beast to beast, treatment of only 30 per cent to 50 per cent of the herd resulted in the almost immediate disappearance of flies, even from the untreated beasts, and comparative freedom for weeks.

The use of a 1% DDT emulsion (or suspension) thoroughly sprayed over the shoulders kept animals free of buffalo flies for approximately 2 weeks and numbers well below pest level for 4 weeks (Seddon 1967). The other OC that was widely used for buffalo fly control was methoxychlor, a pesticide with similarly low acute-toxicity characteristics but with shorter residual effect and less tendency to accumulate in fatty tissues than DDT.

In May 1962, the use of DDT for control of cattle tick was prohibited. It remained permissible to use DDT as a dressing for buffalo fly control [one pint (about 570 mL) of 0.5% solution per head was allowed every 3 weeks] in Queensland. The rate was subsequently reduced to half a pint per head, and DDT was finally removed from registration for any use on cattle in 1973.

No reports of field failure of DDT treatment due to suspected or diagnosed resistance in buffalo flies are known.

With the removal of DDT and other OCs from registered use against cattle ectoparasites, a range of OP pesticides was registered and marketed to fill the gap. Seddon (1967) observed that these OP preparations gave good knock-down of buffalo flies on dipped cattle, but they had no lasting residual effect, and serious re-infestations usually built up in 4–7 days after treatment. The carbamate pesticide carbaryl was reported to keep flies below pest proportions for 7–10 days. The first insecticidal ear tags for cattle targeting buffalo flies were RABON tags containing the OP tetrachlorvinphos (first introduced in 1980).

The 1970s saw the introduction of the first SP pesticides. Compared with the OPs, the SPs gave dramatic levels of pest control, mainly in length of effective residual control, similar to the results seen with the use of DDT. Fenvalerate was introduced in April 1978 and, used as a 0.1% overspray, it provided control of buffalo flies for 20 days (Schnitzerling et al. 1982). Fenvalerate was so effective and convenient that RABON ear tags (marketed by Shell Chemicals who also marketed fenvalerate) did not enjoy market success in the early 1980s. In 2004, RABON tags offering 90 days of buffalo fly control were again marketed to cattle producers.

The effectiveness of the SP insecticides against buffalo fly was not to last, however. In 1980, the first case of SP resistance in buffalo fly, in the Mackay area of north Queensland, was reported by Schnitzerling et al. (1982):

> Dosage mortality tests on flies indicated a moiety that was 45×, 29× and >1000× more resistant respectively, to fenvalerate, cypermethrin and DDT, than a moiety in a reference population of flies which had not been subjected to control by fenvalerate.

It was also reported that field failure of fenvalerate sprays in 1979 (only 2 years after its introduction) followed 2 consecutive years of monthly use. The authors postulated that previous exposure of buffalo flies to DDT had prepared them for development of SP resistance.

Industry research on buffalo flies conducted in north Queensland (Holroyd et al. 1984) and at Belmont in the south (Bean et al. 1987) failed to unambiguously establish the economic impact of buffalo flies on cattle. Dissatisfaction with the buffalo fly situation (presumably aggravated by increasing SP resistance) prompted a producer survey throughout central Queensland in 1990 (O'Sullivan 1990). This survey of 300 producers/graziers indicated that the buffalo fly was regarded as the most important ectoparasite of cattle, with the main reason for their concern being the worry and annoyance that flies caused cattle. Interestingly, the main method of control being used at the time of the survey was spraying pesticides containing SPs. There was a large number of available SP sprays on the market in the late 1980s and price competition was making them relatively cheap to use. Periods of protection that producers reported they were achieving from their SP sprays varied widely between 1 and more than 20 days. This would appear to confirm (even allowing for different levels of personal observation accuracy and performance expectation) the establishment of SP resistance throughout central Queensland.

In 1994 and 1995, a Meat and Livestock Australia (MLA) sponsored field survey (and questionnaire) of pesticide resistance in buffalo flies throughout Queensland and northern New South Wales was carried out by Agrisearch Services. There was particular interest and concern about how to manage buffalo fly shown by cattle industry personnel in northern New South Wales because of the relatively recent incursion and establishment of buffalo fly populations (in 1982 buffalo flies were first observed at Coffs Harbour) in that state. Graziers further north in Queensland were found to be somewhat more fatalistic, accepting that there were few reliable options for total and effective control of flies. A small, though apparently increasing number of northern graziers, reported that they had decided to discontinue or minimise insecticide treatment specifically for flies due to the poor control (plus high cost) typical of many of the treatments available, plus the recent memory of meat residue scares. A common observation in all areas was that there are treatments available for ticks that leave the animals tick-free for several weeks but there is nothing on offer (excluding ear tags) that will keep flies away for more than a few days.

In the 1994 and 1995 MLA survey, flies were assayed for resistance to a range of commercially available SP, OP and carbamate insecticides. As expected, very high levels of SP resistance were detected, as was, less well expected cross resistance between all SPs in fly populations in all areas. The exception was remote western Queensland, where flies are less endemic and therefore receive less insecticide spraying. Little or no resistance to the OP insecticides was detected, despite this chemical group having been in use for at least 10 years longer than the SPs. Questionnaire information gathered in the survey also revealed some deficiencies in knowledge. For example, certain graziers believed that they were managing resistance by rotating pesticides products when, in fact, they were only rotating brand names containing the same SP active ingredient. Treatment application techniques were also revealed to be to be a cause for concern, with an over-reliance on inaccurate overspraying of large groups of cattle.

Following the survey there was little consensus among industry participants about the best way to manage resistance, apart from a renewed educational campaign targeting graziers and their understanding of insecticides and correct usage.

The early 1990s saw the introduction of the first ML endectocide products (e.g. abamectin, ivermectin). ML-based products were registered to give control of buffalo flies and parasitic roundworms, and to aid in the control of cattle ticks. These products are relatively expensive and are rarely therefore used primarily for fly control when cheaper SP and OP sprays and pour-ons are available. The 1990s also saw a new generation of insecticide-impregnated ear tags (e.g. diazinon-impregnated ear tags such as SPIKE and OPTIMIZER), and these were registered for buffalo fly control only. They became widely used from the early 1990s and, for the first time, graziers had products that were effective against buffalo flies for more than 3 months. High adoption rates of the diazinon ear tags also brought the prospect of diazinon resistance development. Although diazinon had been in use for more than 30 years, until the ear tag products it was used primarily as a short-term knock-down spray, with little likelihood of there being resistance selection pressure. Indeed, while the MLA survey of 1994 and 1995 did not detect any diazinon resistance, a smaller MLA resistance survey conducted in 2000, did detect low levels of diazinon resistance, particularly in buffalo flies in northern New South Wales. In subsequent years, further anecdotal reports (i.e. not confirmed and published) suggest that diazinon-impregnated ear tags are now much less effective against buffalo flies than 10 years ago.

Several other pesticide-impregnated ear tags have also come on to the market over the past 10 years. These products contain various SP/OP/synergist combinations. The YTex company is recommending a resistance management strategy of rotating their PYTHON (SP/synergist) ear tag with their OPTIMIZER (OP) ear tag to prevent continuous exposure of flies to one pesticide group. Ear tags will probably remain popular in areas where cattle can be mustered and handled conveniently, and while cattle prices are relatively high. The cost of treatment with ear tags is several dollars per head, which is comparable to the MLs (though these are not used solely for buffalo flies) but much higher than the sprays, treatment with which costs less than a dollar per head.

The cheapest, but not necessarily least-effective treatment for buffalo flies, is the back-rubber device. In the pre-DDT days, use of back-rubbers was common, employing hessian soaked in creosote. With the removal of DDT and its long-acting oversprays, back-rubbers came back into use, particularly with only the new OPs pesticides available. Self-dosing by animals that learn the value of the back-rubber was suited to shorter residual OPs. Back-rubbers have remained in effective use until today with the thorny questions of correct dosage and potential residues remaining unanswered.

Conclusion

The control of the buffalo fly has not received the same level of coordinated research effort as has been accorded the cattle tick. In the 1990s, particularly before the advent of the pesticide-impregnated ear tags, there was a growing dissatisfaction among graziers about lack of attention to the buffalo fly problem. Buffalo flies ranked above cattle ticks in terms of seriousness and this frustration was no doubt exacerbated by the heavy reliance of graziers on SP insecticides for buffalo fly (and cattle tick) control, combined with high levels of SP resistance in buffalo flies and poor understanding of resistance management. These barriers are being gradually overcome by newer chemistry and by education via MLA and state departments of primary industry, as well as by the pesticide manufacturers. It should also be noted that the cattle industry in buffalo fly infested northern Australia is a particularly far flung and a fragmented set of individual producers, a factor which would not easily allow for coordinated resistance management strategies, let alone education campaigns. But, to paraphrase Charles Darwin, the individuals who will survive and prosper are those that can adapt best to a change in their environment.

New chemistry has been the backbone of the ectoparasite-control industry over the past 100 years. Although it is unwise to expect that a constant supply of new pesticides is going to be available, particularly for difficult pests that continually develop resistance, there will always be a large and lucrative marketing opportunity for effective new pesticide products. We hope that, with time and experience, we will learn how to best manage the new chemistry for sustainability.

Lice

Treatment of cattle for lice usually occurs as part of a treatment regime targeting all internal and external parasites. Because of this need for broad-spectrum control, MLs are commonly used (Holdsworth 2002). Treatment of cattle with MLs for lice usually commences before winter when lice numbers increase. In addition, the annual treatment programs for internal parasite control using ML pour-on formulations will also control lice species on cattle (Holdsworth 2002). In late autumn or early winter, when worms and lice become a problem, the use of ML pour-ons (*B. bovis*, *L. vitul* and *H. eurysternus*) or ML subcutaneous injection (*L. vituli* and *H. eurysternus*) formulations are the best options (Holdsworth 2002).

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Chapter 5

Economics of ectoparasiticide use in Australia

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Introduction

For the purposes of this chapter, ectoparasiticides are defined as registered and externally applied chemical products that prevent loss of animal productivity according to a specified response rate and a usage cost tied to the chemical product's cost to purchase, prepare and apply. The difference between the production loss prevented and the cost of usage determines the overall economics. Large opportunity savings and low costs are likely to confer 'good' economics, whilst small opportunity savings and high costs are likely to confer 'poor' economics.

The literature reveals a certain preoccupation with estimating the national cost of parasites (e.g. Beck et al. 1985; McLeod 1995). The cost of lice on sheep, for example, has been estimated by summing the cost of actual treatment (including labour and chemical) and production losses that still occur, with or without treatment. It should be noted, however, that the cost inflicted by a parasite is not the same thing as the economics of using an ectoparasiticide to achieve control. The economics of controlling lice take into account both gains and losses. In this case, the economics are given by the opportunity losses avoided, less the cost of treatment. By way of difference, the cost inflicted by lice is simply the sum of treatment costs plus residual production losses. The conceptual difference can be summarised as follows:

Cost of parasite = cost of treatment + residual production losses

Economics of controlling parasite = losses avoided by treatment[1] – cost of treatment

Knowing the total cost inflicted by a parasite is of limited value unless the exercise is repeated at regular intervals to reveal linkages between treatment methods and results. A revealed history of the linkages between treatments and results will eventually allow management strategies to be developed and applied.

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1 This figure has to be provided by 'experimentation' that quantifies the yield response to specified treatments. Yield in this case might be weight of wool grown or live weight.

The economics of ectoparasiticide usage are inherently important because manufacturers, primary producers and the larger community are all interested to know the details of how and why dollar benefits are generated and if the economic impacts are confined to the direct users or there are flow-on impacts that affect other parties, including consumers and the environment. In practice, however, there has been comparatively little work done on the farm or regional-scale economics of using ectoparasiticides. This situation is largely due to the difficulties associated with demonstrating the opportunity gains that could be expected to apply in general. A short list of the difficulties associated with arriving at generally applicable conclusions about economic outcomes includes the following:

- *The imperfect relationship between killing a parasite and gaining an economic benefit*: Whilst the chemical might always do what the product label says it will do, the size of the associated economic benefit will depend on many factors. These include: interactions with pasture management; the parasite burden at the outset; the ability of the animal to respond after treatment given the prevailing feed quality and climatic conditions; the level of dependency between the animal treated and the sale animal (e.g. cows and weaners); and the capacity of the animal's physiology to respond as determined by condition of the intestinal system, and its age and genetics. In addition, there can be temporal changes in input costs and output prices that will affect economic performance quite apart from the physical response rate.

- *Coping with variation*: Some of the above variation that makes it hard to predict economic performance will be due to adventitious events and some will be due to poor management. Removal of the extreme results associated with the former (that might bias impressions) can be achieved only by applying the treatment regime to a large enough sample size and over a long enough time frame. In practice, the livestock manager will require a sound knowledge of the cost/benefit situation applying to ectoparasiticides in order to formulate a rational usage strategy. Finally, the difficulties of comparing different chemical products that do essentially the same job are a further barrier to objective analysis.

- *Treatment options*: Livestock producers have at their disposal many techniques for controlling parasites; ectoparasiticides are just one option. In practice, several control measures might be used in combination, with substitution among them possible at the margin; that is, the point at which the expected difference in performance is minimal. Integrated pest management (IPM) requires that producers use a combination of control measures and also vary the 'mix' depending on conditions at the time. Under these circumstances, it will be difficult to predict what part of a total benefit is due to each part of a multi-input, integrated system.

Fortunately, however, it is not necessary to rely on 'economics' for all the answers. Over the last decade in particular, regulatory measures have been used to meet concerns associated with environmental externalities, the safety to users and the technical efficacy of particular chemical products.

In some cases, the justification for treating parasites relies on imperatives that transcend economics. Thus, animal welfare concerns will increasingly require that livestock producers administer treatments for various external parasites regardless of the apparent economics. Mulesing of sheep, for example, is destined to be outlawed on animal welfare grounds, despite the fact it is an economic means of controlling flystrike. In any event, it will be reasonable to assume in contemporary Australia that new ectoparasiticides pose minimal risk to the environment because of the scrutiny they have borne to achieve registration.

Moreover, there are many informal mechanisms that serve to protect the interests of users and the community. For example, the 'marketplace' serves to protect users from poor products through its ability to make anecdotal judgments about a product's effectiveness and then communicate these judgments to all interested parties. These assessments are greatly assisted by the ongoing evaluation work performed by scientists employed within the state and national agricultural institutions. In practice, products that under-perform in the paddock tend to suffer loss of market share without the need for any formal demonstration of their economics.

Demonstrating the economic case

On this occasion, it is most appropriate to demonstrate the economics of using ectoparasiticides by reference to farm-level cases, for which it should be possible to indicate the rewards associated with treating or not treating with a particular chemical product doing a particular job.

Break-even analysis

The simplest approach to 'proving' the economics of using ectoparasiticides is break-even analysis. This approach is used in the cattle parasite atlas recently published by Meat and Livestock Australia (MLA 2005). For the North Coast of New South Wales, the atlas provides the following analysis under the heading 'economics':

- The annual cost of *Ostertagia* control in a 100-cow herd is $1,240; that is, $12.40 per treated weaner.
- Yearling or sale stock must gain an extra 8.2 kg in weight to break even on drench costs.
- Worm control can increase weight gains by 2–6 kg/month for up to 12 months after weaning.
- Positive returns are likely in cattle sold when they are less than two years of age.

The above guidelines are useful, since they suggest that a treated weaner could gain an additional 40 kg in the course of 12 months but would need to gain only a little over 8 kg to cover the costs of the treatment. To arrive at the break-even additional weight gain, the analysis assumed a sale price of about \$1.50 per kg; that is, \$12.40 / 8.2 = \$1.51. Whilst these figures are not unrealistic they serve to remind us that the break-even weight gain will be sensitive to both the cost of the treatment and cattle prices. Thus, we should expect that the economics of treating worms in young cattle would deteriorate during periods of strong inflation in chemical prices or falling cattle prices.

Partial budget

Some producers will want to know the total margin between costs and returns, either for a single treatment or for multiple treatments over a set period such as a year. In this case, they should use a partial budget that captures the full implications of additional costs and returns. The appropriate profit equation could be represented thus:

Additional margin = (Additional returns) – (Additional costs)

Using the data presented above (for the break-even analysis) and assuming that the cattle are sold 6 months after weaning[2], the additional return due to treating weaners for *Ostertagia* could be estimated as follows:

Additional margin = (4 kg/month × 6 months @ \$1.50/kg) – \$12.80

= \$23.20 per head

The additional margin of \$23.20 per head is effectively a return of the time and effort associated with treatment. It will be appreciated that the partial budget technique is much more informative that the break-even analysis—especially where it is used to compare different treatments.

Whole-farm budget

A weakness of both the break-even and partial budget is their narrow focus on the short-term and one turn-off. Increasingly, producers are being encouraged to view pest management as one part of their overall farm operation with flow-on implications for every facet of management. Where producers practice IPM, for example, they are likely to be rewarded with complementary gains; that is, a production relationship where there are positive gains due to interactions between inputs. If IPM is indeed effective, it will be reasonable to assign premiums to the normal response that might be applied to treating animals.

Controlling flystrike in sheep using IPM might be expected to involve the following combination of treatments:

- mulesing

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2 If the cattle are sold 6 months after treatment, the seller foregoes some of the benefit from treatment since we must assume that the market will not make a distinction between treated and untreated weaners at time of sale. In a perfect market, the treated animals should attract a higher rate, as they should exhibit higher growth rates for a further 6 months if run in a parasite-free environment.

- tail docking to the correct length
- selecting for resistance to body strike
- preventing scouring by controlling internal parasites
- strategic use of fly traps
- moving the flock to low-risk paddocks in the event of a fly wave
- timing of crutching and shearing to avoid high-strike periods
- strategic use of jetting.

The economics of the above IPM approach to flystrike control could be compared with routine jetting of the whole flock. The IPM approach would involve many small costs compared with one relatively large treatment cost for jetting. Assuming that total treatment costs were similar in both cases, the economics would come down to the system that most suppressed flystrikes. With the IPM approach there might be cumulative gains because the animals are bred for strike resistance and therefore become increasingly less susceptible to strike through time.

Conclusions

The farm-level economics of using ectoparasiticides are complex, resulting in only crude measures of profitability being applied in practice. This situation will not change until data become generally available on the opportunity costs likely to arise from not using particular strategies that incorporate chemical treatments. Generation of these data will be expensive since it will entail controlled experiments under a range of circumstances likely to emulate conditions applying in the real world. The answer might lie in routine modelling of individual ectoparasiticide performances by some independent organisation. The end result would be better-informed producers and a much healthier and more productive livestock population.

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Chapter 6

The effects of ectoparasites and their control on the welfare of livestock

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Introduction

Animal farming systems are increasingly under scrutiny for their potential to adversely affect the welfare of the animals (Phillips 2005), and those in Australia are additionally exposed to criticism on the grounds of their potential threat to the local flora and fauna, as well as potential environmental degradation. Extensive livestock production is more common in Australia than in other major livestock production areas of the world, which allows the animals to have greater freedom of movement and opportunity for natural behaviour such as grazing than have livestock in intensive units. However, it also exposes animals to climatic extremes, and intervention is often necessary to limit exposure to ectoparasites. Whereas in the past bodily reconstructions, otherwise known as mutilations, have been utilised to reduce welfare problems, such as blowfly strike in sheep, feather pecking in poultry or tail biting in pigs, controlled by mulesing, debeaking and teeth clipping, respectively, these are increasingly seen as unacceptable due to the painful procedures involved.

Ectoparasites are a problem in both extensive and intensive livestock production. They feed on the animals' blood, body tissues, lymph, tears, sweat, skin debris, hair or feathers. They live on the surface of the animals, which exposes them to the environment in a way which most endoparasites would find very challenging. The skin of animals is not only the largest organ, it is the most susceptible to parasite invasion, being open to the environment. The entry points for endoparasites, principally the gastrointestinal and respiratory tracts, can be well defended by virtue of their narrow aperture to the environment. Buffalo fly (*Haematobia irritans exigua* De Meijere), sheep blowfly (*Lucilia cuprina* (Wiedemann)), and the sheep body louse (*Bovicola ovis* (Schrank)) are all important pests of the Australian livestock industry. *Lucilia cuprina* feeds on skin and skin debris and creates a large oedematous lesion.

Effects of ectoparasites on behaviour and physiology of livestock

Ectoparasites have several direct effects on behaviour. They disrupt normal behaviour, such as feeding, and produce abnormal behaviours, including stereotypies. In addition, there may be indirect effects due to the impact of the parasites on nutritional and immune status.

Flies are the greatest ectoparasite threat to livestock behaviour. Cattle break off from grazing to form a stockade, often on high ground where there will be more wind to disrupt the flies' feeding patterns (Phillips 2002). Their heads will be turned inwards towards the centre of the circle, protecting them and their legs from fly attack. Dominant cattle will usually be in the centre of such a group, demonstrating their priority of access to high-quality space (Kabuga 1993). This bunching of the cattle can induce heat stress in high ambient temperatures, which will reduce their growth (Wieman et al. 1994). If possible, they will move into long grass to give their heads protection whilst they graze (Albright and Arave 1997).

Ectoparasites will reduce grazing time, but cattle may compensate by grazing more in the evening or morning when flies are less active (Dougherty et al. 1994, 1995). And although their biting rate at pasture is often considerably reduced, bite size increases in an attempt to compensate. This suggests less-selective grazing, which may penalise cattle nutritionally because they depend on selecting herbage of higher quality than average. Thus, the quality of herbage ingested by cattle contaminated by flies might be reduced, but this has yet to be examined.

As well as disrupting maintenance behaviours, cattle also employ tail swishing, skin twitching and leg raising and repositioning to disturb the flies. In one study of beef cattle infested with flies in high ambient temperatures (Wieman et al. 1994), reduced weight gain was mostly (72%) due to heat stress and bunching, but partly (26%) due to the energy loss in fighting the flies. The following body movements of cattle were recorded in Canada in response to stable flies (*Stomoxys calcitrans* L.): moving their heads (8 times per minute), lifting their front legs (8 times per minute) and hind legs (3 times per minute), ear movements (12 per minute), tail movements (69 per minute) and skin twitches (25 per minute) (Dougherty et al. 1994, 1995). Most of these movements are an attempt to dislodge the flies, with foot stamping commonly used to attempt to dislodge flies on the legs. The distribution of the flies was 65% on the front legs, 29% on the hind legs and 6% on the trunks. In this experiment, the cattle were able to compensate for reduced biting rate with increased bite size, so the rate of herbage dry matter intake was not affected by the flies. In another experiment, Rousing et al. (2004) demonstrated that ticks caused dairy cows to step more during milking, which was associated with human avoidance in an approach test.

The tail is important in protecting the hindquarters of the animal, and tail docking prevents this natural behaviour. Tail docking is common in both sheep and dairy cattle to prevent it becoming soiled, especially when the animals are consuming high-energy foods that result in faeces with a low dry matter content or if they are living in wet and dirty conditions. Tail docking is prevalent in dairy cattle in Victoria, Australia and New Zealand, but the practice is subject to pressure from animal activists, who have recently been instrumental in achieving a ban on tail docking of dogs in Australia. Soiled and moist tails attract flies (French et al. 1994) and any ban on tail docking in livestock could necessitate increased use of ectoparasiticides. Sheep are at high risk of attack by the blowfly if their hindquarters are soiled, since this preserves moist areas where the flies can lay their eggs. A good dairy stockperson will remove any contamination of the tail of dairy cows at milking time, but an easier option is to remove the tail.

Another target area for flies is around the eyes, where moisture provides them with very favourable conditions. It is the inability of cattle to protect this area adequately that often attracts flies. Cattle autogroom their face by rubbing against posts, branches or similar protrusions, but these can become a point of transmission of the ectoparasites between animals. This area and the rest of the forequarters are also the subject of much allogrooming (Sambraus 1969) and flies and ticks will be removed during this mutual process. However, this has little impact on the total infestation rate (Barker et al. 1990).

Autogrooming on posts etc. can spread sheep scab in the United Kingdom (Corke and Broom 1999). This disease causes irritation of the skin, resulting in restlessness, rubbing on fence posts, biting at the flanks, and scratching at the body and ears with the hind feet. An allergic response to the faecal antigen of the sheep scab mite, *Psoroptes ovis* (Hering), causes scabs to develop, which produces discoloured areas of fleece and wool loss, starting as displacement of small amounts of wool from the shoulders and flanks, but eventually it may progress to affect large areas of the body (Corke and Broom 1999). Limited wool loss may even be beneficial, since it exposes the scab mite to the external environment and the desiccation and destruction by sun that is likely to ensue. However, if the wool loss is extensive it threatens the survival of the sheep and increases the potential for transfer to conspecifics. Corke and Broom (1999) observed some potentially stereotyped oral behaviours, mouthing and biting, during an infestation, which may indicate reduced welfare and constant irritation in affected animals. They used an endectocide (moxidectin, Cydectin®, Fort Dodge Animal Health) for sheep scab treatment, and they suggested that, since no skin washing occurs with the endectocide treatment, the antigen remains in contact with the skin for longer than dipping the animals, and as a result pruritis may persist.

Although animal behaviour and temperament vary considerably between individuals, there appears to be little correlation between tick resistance and temperament (Fordyce et al. 1996; Burrow 2001), although individual animal behaviour may contribute to resistance.

Effects on immunocompetence

The response of an infected animal to ectoparasites is to activate the systemic and humoral immunity to reject the parasite and avoid tissue damage by the wound (Nash et al. 1996). Within 6 hours of infestation, there is an influx of leucocytes into the area, characterised by neutrophils, eosinophils and MHC II positive cells (macrophage/ Langerhans cells). At this stage the epidermis remains intact. Then, macrophages and eosinophils continue infiltrating the area, although they concentrate in the mid-dermis rather than the disrupted epidermis. There is also an up-regulation in CD1 expression in Langerhans cells at the site of the lesion. These responses appear to be generalised for different ectoparasites, having been observed for blowfly, ticks, lice and keds (Nash et al. 1996). After approximately 24 hours, there is an influx of CD4 and T cells into the site of the lesion, and this lasts for about 24 hours. These immunoregulatory responses probably incur an energy cost, which can reduce learning rate, as found in mice (Kavaliers et al. 1995). Cattle attempt to control ectoparasite feeding behaviour through their immunoregulatory responses—an antifeeding effect produced by immune responses has been identified with the African cattle brown ear tick (*Rhipicephalus appendiculatus* Neumann) (Losel et al. 1992). This effect reduces the typical feeding pattern in these ticks. In return, a large number of immunoregulatory factors, including prostaglandins, immunosuppressive or anti-inflammatory protein molecules and antimicrobial peptides are produced by parasites to control the immunocompetence of their host (Liang et al. 2005). The nutrient and, in particular, amino acid requirements of increased immunocompetence are not well understood, and they need further research if host animal defences are to be utilised to maximum effect (Sykes and Greer 2003). Also, blood loss in animals that are parasitised by haematophagous insects can be considerable, creating a further strain on nutrient resources.

Treatment with ectoparasiticides

Treatment of flies with impregnated ear tags is generally effective—in Argentina 13 g tags with 30% chlorfenapyr were found to control horn fly (*Haematobia irritans* (L.)) infestation in cattle for about 10 weeks (Gugielmone et al. 2000). Increased feed intake is a common response to treatment for control of buffalo fly. This has been demonstrated following fitting of diazinon-impregnated ear tags (Spradbury and Tozer 1996). Weight gain in this 20-week study was increased when the ear tags were used from approximately 60 to 90 kg. Attempts to demonstrate a correlation between individual animal ectoparasite resistance and growth have not been successful (Fordyce et al. 1996; Burrow 2001).

In dairy cattle infested by buffalo fly and the closely related horn fly, a moderate infestation results in a reduction in daily milk yield of 520 mL and in daily growth rate of 28 g, as determined in a meta-analysis of literature data by Johnsson and Mayer (1999). No effect on individual animal productivity could be detected for an infestation rate of 30 or fewer flies. The stress reduction by fly control must be balanced against the stress induced by regularly treating the animals, particularly those kept in extensive rangeland conditions.

The effectiveness of ectoparasiticides requires definition. In the view of the European Medical Agency, ectoparasiticides, to be effective, must achieve an 80–100% reduction in the parasite load if the parasites are permanently on the animal, dependent on the species, but for parasites that complete only part of their life cycle on the animal a 100% kill is usually required (EMA 2004).

Alternatives control mechanisms to ectoparasiticides

Vaccination

The initiation of antigen-specific immunity in the host, suggested by the similarity in molecular and cellular events at the sight of infection and in the lymph, may foster the development of efficacious vaccines for ectoparasites such as the sheep blowfly (Dalton and Mulcahy 2001). This development would bring major improvements in sheep welfare in exposed populations, such as in Australia. The first genetically engineered *Escherichia coli*-expressed Bm86 vaccine, TickGARD®, has been produced by Biotech Australia, together with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The vaccine is directed against the cattle tick *Boophilus microplus* (Canestrini). Its activity relies on the uptake with the blood meal of antibody directed against a critical protein in the tick gut, with eventual adverse effects on the reproductive capacity of the females (Willadsen 1995). It is recommended that it be used in conjunction with acaricides because some cattle are not effectively immunised by the vaccine. However, a few acaricides are producing resistance in ticks, and there is a concern, which remains to be realised, that neither vaccines nor acaricides will provide effective control in the long term. Before the recent attention paid to vaccine development for ectoparasites, the high efficacy, low cost and ease of use of acaricides meant that there was little incentive to develop alternative control methods.

Breeding for disease resistance

The breeding for resistance is a particular challenge in situations in which resistance to ectoparasiticides has become established and in which vaccines have not yet been developed. This is the case with trypanosomiasis, which is a disease caused by the trypanosome parasite transmitted by the tsetse fly, which inhabits most of central Africa (Phillips 2001). Genotype clearly affects tick infestation susceptibility—bulls of 50% *Bos indicus* content are twice as susceptible to tick infestations as those with 75% content (Fordyce et al. 1996; Burrow 2001). The negative genetic correlation between fly (but not tick) infestation and growth rate suggests that selection for growth in the Australian tropics may result in reduced resistance to some ectoparasites (MacKinnon et al. 1991). Reliance on trypanocidal drugs and vector control has diminishing effectiveness, which is prompting considerable interest in breeding disease-resistant stock.

The trypanosome parasite causes intermittent fever, listlessness, progressive emaciation and eventually death. The distribution of the tsetse fly controls the livestock distribution in Africa, with only wild game and trypanotolerant cattle breeds inhabiting the heavily infected areas, such as wet, swampy regions. In the open savannah, the tsetse flies prefer the wild game, but increasingly these have been replaced by cattle, as these are more valuable for food production. The desirability of controlling cattle trypanosomiasis has led to an extensive search for means of controlling the tsetse fly.

The disease is a particular constraint to the productivity of recently imported, exotic cattle in Africa. Over several thousands of years, breeds of local cattle, such as the N'Dama and West African Shorthorn, evolved their own resistance, but these are not as productive as modern European cattle. Wildlife are carriers and do not suffer severe clinical symptoms, but they do provide a constant reservoir of disease organisms, rendering eradication of the disease impossible. The potential exists to transfer the resistance of the local cattle to more productive European cattle. If quantitative trait loci for trypanotolerance can be identified, it should be possible to transfer the relevant regions of the genome and produce novel genotypes with favourable disease resistance and production characteristics. The major challenge, however, is to understand the physiological basis for trypanotolerance, because it is only this understanding that can reduce the virulence of the disease in the long term. Clearly, the trypanosome haemoprotozoans are capable of commensal relationships in some cattle and wild animal genotypes, and this should be the objective of current breeding programs for more productive cattle.

Pain sensitisation

Host animals exhibit a variety of stress and anxiety responses to biting arthropods. However, following exposure for a short period, perhaps as little as one hour, pain or, more specifically, nociceptive responses are reduced (Colwell et al. 1997). This analgesic effect is produced only when the arthropods have intact mouthparts, or when animals have previously been exposed to arthropods with intact mouthparts but are then challenged with arthropods without intact mouthparts. Thus, it appears that livestock exhibit both anticipatory analgesic responses to the presence of ectoparasites, as well as immediate analgesic effects in response to the bites. Indeed, the odours of parasitised conspecifics are sufficient stressors to induce analgesia (Kavaliers et al. 2003a), which is therefore a conditioned response. This is associated with elevated corticosteroid concentrations in blood, particularly if the animals cannot escape (Kavaliers et al. 2003a). The presence of parasites reduces the attractiveness of the odours of a male mouse to females (Kavaliers et al. 2003b). Detection of the parasite status of a potential mate is clearly of major significance if this ability has evolved in mammals. Ticks themselves are attracted by odours, but more specifically in this case to the volatile products from rumen fermentation, carboxylic acid, phenol and indole byproducts of fermentation (Donze et al. 2004). Odours are therefore of key significance in the battle between ruminants and their ectoparasites in their quest to prevent each other from recognising their presence. Furthermore, the recent identification of haemorphin-like opioid peptides in ticks suggests that this may be another way in which they attempt to escape identification by the host and prevent behavioural attempts to dislodge them (Liang et al. 2005).

The analgesia induced by biting flies is opioid-mediated in only medium to long-term exposures (30 minutes plus) and, at least in rodents (Kavaliers et al. 1998), may be greater in males than females. Stable fly feeding on cattle lasts about 5 minutes, which appears to produce a non-opioid mediated analgesia (Kavaliers et al. 1998). This pain relief can be beneficial in animals with concurrent diseases. The analgesic effects of tick-borne encephalitis can successfully reduce pain in patients with simultaneous rheumatic fever (Meyerova 1991), but the extent of such pain relief is not well understood.

Pathogen transmission

As well as direct effects of ectoparasites on the welfare of livestock, described above by the effects of the sheep scab on epidermal damage, many ectoparasites transmit diseases that potentially pose a risk to the welfare of both the animals and humans that contact or eat them. These are principally the blood-sucking arthropods, mosquitoes, haematophagus flies and ticks (Pruett 1999). For example, the mastitogenic pathogen *Actinomyces pyogenes*, which is highly infectious, of environmental origin and resistant to antibiotics, is transmitted to dairy cattle by the head fly, *Hydrotea irritans* (Fallèn). It is best controlled by fly elimination with impregnated ear tags or sprays (Byford et al. 1992).

Diseases can also be introduced indirectly through the effects of ectoparasites on the immune system. Tick pyaemia is a serious condition of this nature in sheep, caused by the *Staphylococcus aureus* bacterium, which is found on all farms (Henderson 1990). Lambs initially infected with tick-borne fever experience a high temperature and damage to their white blood cells, allowing the staphylococci to enter, usually via the navel cord or castration or tail docking wounds, or a cut around the mouth. The bite of the tick can also transmit the staphylococci. Once in the body, the staphylococci migrate to the joints and cause severe lameness, which is usually permanent. Abscesses also occur in various parts of the body, causing ill-thrift and a number of site-specific symptoms including, for example, paralysis or blindness from brain abscesses. Control is best achieved by the pour-on insecticides or walk-through dips, sometimes in combination with use of long-acting tetracyclines. However, in addition to the issue of development of resistance, regular use of antibiotics will render the animal very susceptible to fever if the treatment is terminated at any time. Since the rescinding in 1992 of legislation that required compulsory dipping of sheep, usually using organophosphates, for control of sheep scab, the proportion of the United Kingdom's sheep flock that is dipped regularly has declined considerably (French et al. 1994).

Effects on animal welfare

Animal welfare is a concept that has not been satisfactorily defined, and the definition of welfare may have an influence on the extent to which ectoparasites are perceived to have an impact. There are four main concepts that have been discussed in considering animal welfare: an animal's ability to cope with its environment; its feelings; its ability to perform natural behaviour; and a description of its freedoms (which to some are 'rights') that is now gaining considerable support by both activists and scientists alike. The 'freedoms' approach provides a practical and tangible method of evaluating an animal's welfare, whereas the more abstract concepts are satisfactory for philosophical debates but of little value as a tool to aid assessment. The 'Five Freedoms' that originated in the United Kingdom have been adopted in many situations (FAWC 1994). They are described here together with considerations of how the effect of ectoparasites on the specific freedom may impact on the welfare of the host animals.

1. *Freedom from thirst, hunger and malnutrition—by ready access to fresh water and a diet to maintain full health and vigour*

This is challenged by the nutrient requirements of the infestation, in particular greater energy requirements for the increased activity in attempts to remove the ectoparasites, and also increased amino acid requirements for the elevated immune status. The close association of some essential elements, in particular magnesium (McCoy and Kenney 1992), with mammalian immunocompetence suggests that adequate mineral status should be a high priority if ectoparasitisation is likely. This is particularly true for extensively grazed stock for which mineral supply from herbage is often deficient and supplementation difficult.

2. *Freedom from discomfort—by providing an appropriate environment including shelter and a comfortable resting area*

This will be challenged by the discomfort of biting insects and the stress that their presence induces.

3. *Freedom from pain, injury and disease—by prevention, or rapid diagnosis and treatment*

This is probably the major challenge to animal welfare induced by ectoparasites. However, it is important to parasites that they maintain their hosts in viable condition to enable them to replicate and disperse to new hosts. The use of insecticides/acaricides in effectively reducing the ectoparasite challenge to the animal may be considered an essential part of good husbandry in livestock that are likely to receive a considerable challenge. The redirection of animal law towards a duty of care on the part of the animal manager, and away from prohibition of cruelty (Phillips 2005), is likely to encourage the regulatory authorities to require ectoparasite control in livestock. Cruelty prosecutions usually rest on unnecessary pain having been inflicted on animals, and it is possible to argue that ectoparasite damage to an animal is an unavoidable component of extensive farming. However, the duty-of-care legislation often embraces an animal's needs as a fundamental requirement for animal management (which may be framed around the Five Freedoms), and it is incumbent on the animal's carer to provide prophylactic medicine or to otherwise ameliorate the risk if necessary. Recent cases in Australia have included failure of animal managers to obtain the attention of a veterinary surgeon in situations where this has been necessary, and this should signal to the managers that they have a duty for effective health care for their animals.

4. *Freedom to express normal behaviour—by providing sufficient space, proper facilities and company of the animal's own kind*

The impact of ectoparasites in disrupting normal animal behaviour, in particular grazing, and in stimulating abnormal animal behaviour, in particular attempts to remove the parasites from their skin, is well established. It could be argued perhaps that the latter is part of normal antipredator behaviour, but the question of what is normal behaviour is far from resolved in this respect.

5. *Freedom from fear and distress—by ensuring conditions and treatment which avoid mental suffering.*

It is clear that there is a stress response to fly infestation, which will lead to distress if it is sufficiently large and long-lasting to cause clinical signs of damage. The avoidance of parasitised males by females is further evidence of fear of parasitisation by mammals. The welfare impact of producing efficacious treatment for cattle and sheep by testing the products under experimental and field conditions cannot be ignored (Morris 2000, 2003). The inclusion of a control treatment, where animals are deliberately left untreated, is particularly difficult to justify.

Conclusions

Ectoparasites present a serious challenge to the welfare of livestock, in particular to animals kept under extensive grazing conditions. Their nutritional adequacy, immunocompetence and behaviour will all be adversely affected by ectoparasites. Despite the fact that there are concerns about parasites becoming resistant to ectoparasiticides, the requirement for animal managers to adequately care for their animals now means that sufficient prophylactic treatment is likely to be required by law until alternative methods of ameliorating the risk of parasitisation, such as vaccination or breeding, are guaranteed to be effective.

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