

# TARGETED TREATMENT STRATEGIES FOR SUSTAINABLE WORM CONTROL IN SMALL RUMINANTS

BESIER, R.B.

*Department of Agriculture and Food Western Australia,  
444 Albany Highway, Albany WA 6330 Australia  
Email: [bbesier@agric.wa.gov.au](mailto:bbesier@agric.wa.gov.au)*

**Abstract.** Sustainable worm control strategies are based largely on ensuring that a source of worms not exposed to anthelmintics (“in refugia”) remains after treatments are given, so that resistant worms do not become a dominant part of the total population. In environments with seasonally poor survival of worm larvae on pasture, this may require withholding treatments from a proportion of animals when the whole group would normally be treated. The “targeted treatment” approach involves using anthelmintics on an individual animal basis according to indications of parasitic effects, regardless of parasite burdens. For *Haemonchus contortus*, the FAMACHA system, based on the easily-visualised index of anaemia, has proved effective provided that labour is available for frequent inspections. For non-haematophagous nematodes, recent research indicates the potential of production parameters such as body weight change (sheep) and milk yield (dairy goats), providing that parasitic effects can be differentiated from nutritional and other factors. Continuing investigations are necessary to indicate the most appropriate indices for different situations, so that the refugia effect is maximized for the least risk of disease and production loss. Of prime importance, targeted treatment strategies must be practical to implement if they are to achieve widespread adoption.

## INTRODUCTION

Helminth parasitism is globally considered the most important form of transmissible disease in sheep and goats, with animal mortalities, ill-thrift and the cost of treatments imposing a massive annual cost on livestock owners. Although parasitic disease is a significant problem in all countries, it is especially serious in developing countries where objective control information and the resources to combat parasitism are not always available (Krecek & Waller, 2006; Vatta & Lindberg, 2006).

However, despite the availability of initially highly effective anthelmintic compounds, resistance by nematodes, in particular, compromises their effectiveness.

Anthelmintic resistance has been reported from virtually all sheep and goat farming countries, and involves all major nematode species and anthelmintic classes (Sangster & Dobson, 2002; Kaplan, 2004). In particular, increasing levels of multiple drug resistance by the ubiquitous nematode *Haemonchus contortus* and the major temperate parasite *Teladorsagia circumcincta* sound a warning to livestock owners.

Alternative approaches to helminth control have met with limited success. While it is undoubted that the provision of adequate nutrition (Coop & Kyriazakis, 1999) and the avoidance of parasite intake through pasture management or zero grazing tactics are important elements in parasite management, it is rarely possible to implement these on all

occasions. Other alternatives which potentially reduce the reliance on anthelmintics have either not been developed for commercial use (eg, nematophagous fungi, anti-helminth vaccines) or have found limited adoption (eg, the breeding of worm-resistant animals) (Jackson & Miller, 2006; Besier, 2007a).

The obvious solution is the provision of new classes of anthelmintic, but until recently it appeared that the high costs of research into new compounds and relatively low financial returns had prevented the commercial development of new compounds (Geary *et al.*, 2004; Besier, 2007a). Very recently it appears that some new anthelmintics are likely to be progressed as commercial products, although even should this eventuate, neither the timeframe nor the affordability in different situations is yet known. Effective and sustainable helminth management requires the integration of a wide range of strategies, with realistic attitudes to acceptable levels of animal production, to ensure that both existing and new anthelmintics are preserved for as long as possible (Waller, 2006).

#### **THE CAUSES OF RESISTANCE: THE KEY TO MANAGEMENT**

The key to preventing the development of resistance to anthelmintics is to identify the major causal factors for particular environments and enterprises. Although the chief factors involved have long been recognised (Prichard *et al.*, 1980), it is evident that their importance varies greatly between situations, and some are more easily addressed than others (Besier & Love, 2003). For instance, underdosing with anthelmintics can be remedied by ensuring that livestock managers are aware of the need to dose according to animal weight, although inadvertent underdosing can occur where products containing less than recommended level of active ingredient are sold (Waller, 1997). The use of persistent anthelmintic products may also contribute to the development of resistance in some situations, but the potential can be reduced if these are used according to recommendations which

minimise the selective effect (Dobson *et al.*, 2001).

A major causal factor is an excessive frequency of treatment, which usually reflects heavy parasite challenge, especially where *H. contortus* is dominant. While frequent monitoring of worm egg counts usually permits a reduction in drenching, this may not be sufficient to prevent the continued development of drench resistance. Also, in developing countries in the tropics where intensive treatment is the major factor promoting resistance (Chandarwathani *et al.*, 1999), worm egg counting services are not always readily available or affordable. Strategies to permit sufficiently frequent treatment without adverse consequences for anthelmintic resistance are urgently needed where unremitting parasitism threatens the viability of the enterprise.

Also requiring modification are strategic control programs which employ treatments to prevent pasture contamination with nematode larvae at epidemiologically critical times, to provide a prolonged period of low worm larval intake. Although long considered a theoretical risk (Martin, 1981), the unintended consequence of heavy selection pressure for anthelmintic resistance has now been recognised as a major cause of resistance in recent years. In situations where the survival of non-resistant worms in the population is insufficient to dilute worms that survive strategic treatments, the level of resistance can rise rapidly, and this mechanism is believed to largely explain widespread multi-drug resistance in Australia to *T. circumcincta* (Besier & Love, 2003).

#### **REFUGIA-BASED RESISTANCE MANAGEMENT STRATEGIES**

Although different factors may explain the development of anthelmintic resistance in different situations, the underlying biological basis concerns the proportion of resistant worms in relation to non-resistant genotypes. Where the selection pressure in favour of resistant worms continues, it is inevitable that they will contribute disproportionately to the



total worm population, and control with anthelmintics will be increasingly less effective. The concept of “refugia” from anthelmintic treatment of non-resistant (or less resistant) nematodes in the population so that they may dilute resistant worms is the basis of current resistance management strategies (van Wyk, 2001).

The need to provide refugia through modification of worm control programs depends largely upon the environment and importance of local factors in drench resistance. Where environmental conditions promote the continual survival of worm larvae on pasture, a substantial pool of larvae in refugia (not exposed to drenches) is usually available on the livestock property involved. This presumably explains the relatively lower levels of anthelmintic resistance in non-*Haemonchus* species in temperate countries. However, where the treatment interval is close to the pre-patent period of the nematode species involved, non-resistant worms do not have an opportunity to contribute to the population, and resistance can develop rapidly. This almost certainly explains the high levels of resistance in the *H. contortus*, where the need to combat a highly pathogenic nematode has created a conflict with the sustainability of anthelmintic use.

Where strategic control programs based on the seasonal absence of worm larvae on pasture explain high levels of anthelmintic resistance (Besier & Love, 2003), it may be necessary to deliberately allow the survival of some worms not recently exposed to anthelmintics. In Western Australia, where the commonly-used “summer drenching” program provides excellent worm control but is associated with high levels of resistance in *T.circumcincta* and *Trichostrongylus* spp., the tactic of leaving a proportion of the flock undrenched when strategic treatments are given has reduced the development of resistance (Besier, 2001). However, the failure to suppress worms in summer has been shown to increase the risk of winter parasitism, especially in immature, worm-prone, animals. More recently, transferring the routine summer treatment of mature sheep to autumn, so some pasture contamination is ensured, has proved successful, providing worm egg counts are

adequately monitored (R. Woodgate, personal communication).

The concept of leaving a proportion of animals untreated (“targeted treatment” or “targeted selective treatment”) aims to provide a continual source of worms in refugia, providing that a reliable and practical basis for treatment decisions is available. In high-value animals, the individual measurement of parasite burdens as the basis for treatment may be justified, such as in gastrointestinal nematodes in horses in South Africa (Krecek & Guthrie, 1999), and lungworm in dairy cattle in Sweden (Höglund, 2006). In small ruminants, the urgent need to develop easily-applicable refugia-based systems for resistance management has led to the investigation of a variety of “targeted treatment” approaches for different nematodes (van Wyk *et al.*, 2006), with the emphasis on easily-applied indicators for the need for treatment.

#### **FAMACHA: TARGETED TREATMENT FOR *HAEMONCHUS CONTORTUS***

The large variation between individual sheep in nematode burdens has been the basis of breeding programs for many years (Woolaston & Baker, 1996), but over the past decade, this observation has been successfully exploited by South African researchers for a targeted treatment approach for *H. contortus*. The FAMACHA system utilises inspection of the ocular membranes to indicate the degree of anaemia, categorised on a 5-point scale, so that treatment can be restricted to individuals identified as at risk of haemonchosis (summarised in van Wyk *et al.*, 2006). Research has indicated that on any “routine” treatment occasion, only a small proportion of animals require drenching, and over the course of a year, no treatment at all may be justified in the majority of a flock (Malan *et al.*, 2001).

As well as in South Africa, FAMACHA has been successfully used in numerous countries where *H. contortus* is the dominant parasite (eg, Molento, 2004; Burke *et al.*, 2007), and has the significant additional benefit of a reduction in the cost of anthelmintics compared to whole flock treatments. This is especially important in

resource-poor communities where the imperative is chiefly to prevent animal deaths. Additional benefits of FAMACHA are that treatments are given to the animals excreting the largest number of worm eggs (hence reducing pasture larval contamination), and animals repeatedly identified as requiring treatment can be removed from breeding programs (van Wyk & Bath, 2002). Where other non-anthelmintic approaches to reducing parasitism can be used, such as the use of nematophagous fungi (Maingi *et al.*, 2006), the benefits of the FAMACHA system are likely to be increased.

A requirement of FAMACHA is the considerable labour and time input for the frequent yarding of flocks and individual animal restraint and inspection. This has not proved a drawback where either labour is relatively inexpensive or flock sizes are small. A tactic to increase the efficiency of the labour effort is to monitor a small randomly selected number of animals at frequent intervals once the “*H. contortus* season” commences, so whole-flock inspections are confined to identified danger periods and flocks at risk (JA van Wyk, personal communication).

However, in *H. contortus* zones where large flocks and small labour forces are usual, such as in Australia, it is often impractical to implement FAMACHA. An alternative is to target specific flocks for treatment, rather than treating all flocks once the danger of haemonchosis has been identified on the property. Using a worm egg count-based decision guide, drenches can be given only to at-risk flocks, so that a source of refugia for non-resistant worms is provided in the flocks judged as not requiring treatment (Kahn, 2006).

#### **TARGETED TREATMENT STRATEGIES FOR NON-HAEMONCHUS SPECIES**

The application of a targeted treatment approach to non-haematophagous helminths presents the significant challenge of identifying a suitable indicator of parasitism in individual animals. The typical signs of pathogenic non-haematophagous species are ill-thrift and diarrhoea, but both present problems: ill-thrift

is often the result of poor nutrition rather than parasitism, and diarrhoea indicates the failure of worm control, and in any case is not specific to parasitism. In practice, the main indices of non-*H. contortus* parasitism which has been pursued concern the failure of individuals to achieve acceptable production levels in comparison to others in the flock. This represents the major aim of anti-parasite treatment: to ensure optimal production while avoiding the occurrence of overt parasitism.

#### **Dairy goats, France**

Investigations with dairy goats suggest a role for a selective or targeted treatment approach based on comparative milk yields. Initial studies indicated that the categories most susceptible to parasite infection are the highest producing and multiparous goats (Chartier & Hoste, 1997; Hoste & Chartier, 1998). These patterns were repeatable between years, suggesting the basis for a targeted treatment approach to animals at greatest risk of *T. circumcincta* and *Trichostrongylus colubriformis* infection (Hoste *et al.*, 2002a). In a 2-year study in which all goats in a group were treated, or treatment was given only to those in first lactation or adults with highest milk production, similar levels of production were seen despite a substantial difference in drenching (Hoste *et al.*, 2002 b). Similar benefits of the targeted treatment approach were obtained when extended to a series of 11 goat dairy farms, with an average reduction of 40% in anthelmintic use (Hoste *et al.*, 2002 c). It appears that although a proportion of goats continued to excrete worm eggs for the duration of the grazing season, this did not lead to excessive larval intake and continued effects on production.

#### **Merino sheep, Western Australia**

In this highly seasonal Mediterranean environment, where relatively few annual treatments are necessary, approaches to reducing the selective pressure for resistance must centre on modifications to treatment practice, rather than frequency (Besier, 2001). Recent research has involved a targeted treatment index based on short-interval weight gain in young Merino sheep (Besier, 2007b). At each visit to trial properties, a small

proportion of the worst performing sheep were selected for drenching, and compared to control groups given whole-flock treatments according to a strategic control program. Although there was little reduction in the overall number of individual sheep treatments (approximately 2 to each group in a year), computer modelling of trial indicated that resistance to the drenches used increased at a significantly slower rate in targeted treatment groups (R.Dobson, personal communication), due to the timing of drenching in relation to larval survival patterns. However, there was no reduction in the incidence of diarrhoea, and sheep weight gains were decreased by some 5% in the targeted treatment groups. It appeared that relatively few immature sheep were able to both grow and maintain optimal production without timely removal of worm burdens.

While the reduction in resistance development may justify the production loss to some farmers, the main disadvantage of this strategy is the need for frequent weighing where economies of scale require the minimal amount of sheep handling. Current research therefore involves an index to indicate the proportion of animals likely to be suffering significant sub-optimal performance for a given level of parasitism, based on mean flock worm egg counts, sheep age and body condition score. The individuals treated will be those visually identified as “poor doers”, ie, poorest body condition score and clinical appearance. This approach is being assessed in different environments throughout Australia, with sheep in varying nutritional condition and exposed to different levels of parasite challenge.

#### **Meat-breed lambs, Scotland**

A different approach has been taken in experiments conducted at the Moredun Research Institute in Scotland, where current-year lambs typically face significant nematode challenge prior to turn-off for slaughter. An index for targeted treatment decisions was developed based on the difference between the actual weight gains of lambs and their expected performance based on a calculation of their relative efficiency of nutrient use (Greer *et al.*, 2007). This incorporated

estimates of the individual intake of metabolizable energy, moderated by environmental factors such as herbage availability, and their estimated deposition of energy in the carcass, measured at short intervals during the grazing season. Field experiments indicated the growth rates of targeted treated lambs to be at least as good as strategically-treated lambs, with lower worm egg and pasture larval counts, for some reduction in total drench treatments. Compared to a worm-suppressive treatment, weight gains in the targeted groups were reduced by a maximum of 10% while providing a consistent reduction of 50% in anthelmintic use (Kenyon, Greer, Jackson, unpublished data). The results suggest that the index accurately identified individuals that would benefit from an anthelmintic treatment, and that the strategy has potential for a significant reduction in the exposure to anthelmintic with only a small effect on lamb production.

## **CONCLUSIONS AND QUESTIONS**

Adoption of the FAMACHA approach to sustainable *H. contortus* management continues to increase, and with modifications where appropriate for specific circumstances, is likely to have a significant impact on the anthelmintic resistance problem. For non- *H. contortus* genera, targeted treatment systems still require validation, and in some cases basic research, before advisers can be confident they can be recommended to livestock owners as effective and safe.

A number of specific issues which must be addressed before the targeted treatment concept can be efficiently translated to a field reality are discussed below.

#### **Efficient indicators of parasitism in individual animals**

Although a visual indication of anaemia has proved to be appropriate for the diagnosis of the risk of haemonchosis, no single index has emerged for the major non-haematophagous genera. Body weight change, which is easily measured and is relatively sensitive to short term-changes, appears a better indicator than body condition score, which is scored on a

relatively coarse scale and is difficult to assess in young growing animals. Where intensive and frequent measures of production are routinely taken, such as in dairy production, short-term trends will be easily seen. Yet to be investigated is the proposed subjective index based on visual indications of poor performance. As a potential complication, co-infection with *H. contortus* and production-limiting genera must be considered, as the latter may be easily over-looked.

All treatment indices based on animal production must be related to the prevailing nutritional situation, which is often a far more important cause of reduced performance than parasitism. This may be addressed through the Moredun approach, which relates weight change to nutritional availability, individual animal weight and environmental factors, or using other prediction models of expected animal production in different pasture situations. Whether genetic variation between individuals in the efficiency of feed conversion complicates measures of comparative worm resilience is not clear.

### Practical systems

The effort needed to identify individual animals requiring drenching must be simplified as much as possible if wide adoption is to be achieved. Both the mode of assessment and the frequency have consequences for the practicality of a targeted treatment system. These may not be a restriction with intensively managed animals, but in very large flocks the effort of restraining each animal has proved a limitation to the adoption of FAMACHA. For instance, it is difficult at present to see that targeted treatment of individual sheep for *H. contortus* is feasible in many situations in Australia.

However, some labour-saving is possible using weight-based systems, where electronic animal identification is linked to a weighing and drafting unit so treatment decisions can be made while an animal is restrained (van Wyk *et al.*, 2006). In very extensive systems, where even an automated approach requires more time for assessment than is usually feasible, the subjective visual index may have application, although at a cost of rigour in the assessment process. Regardless of the basis of assessment,

it will be important to identify annual risk periods and the optimal inspection frequency to minimise individual animal handling.

### Risk of disease or production loss

Targeted treatment research must define the appropriate proportion of a group which requires treatment to maintain acceptable animal production, and to manage pasture contamination with worm larvae, not to simply maximise the benefits in combating anthelmintic resistance. However, while the risk of greater production loss than with traditional control programs is inherent in all refugia-based resistance management programs, an effective monitoring routine will ensure that excessive parasitism does not develop.

An overlooked benefit of targeted treatment approaches is the identification of poor-performing animals when the group is not obviously affected, or parasite counts are relatively low. The gain from treating animals which would not normally be revealed as performing sub-optimally may help offset any loss due to withholding treatment from some at times when the entire group is treated.

### Relationship between worm burden and pathogenic effects

Drenching the most worm-affected (least resilient) animals where *Teladorsagia* and *Trichostrongylus* are dominant may not necessarily have a major impact on flock worm egg excretion. In contrast to *H. contortus*, where the degree of anaemia closely parallels the size of worm burden and faecal egg count (Albers *et al.*, 1996), some studies have indicated that for these genera higher-producing sheep (Bisset *et al.*, 2001) or goats (Hoste *et al.*, 2002a) do not generally have lower worm egg counts. Although this may not hold in every situation (Bishop *et al.*, 1996), it appears that in some cases drenching the poorest-performing animals will not provide a disproportionately greater reduction in pasture contamination with worm eggs, and hence no added benefit in terms of future infection rates. This also raises queries over the effects on production of targeting treatment to animals identified as having the largest parasite burdens (although in practice frequent

measurements in individuals would rarely be economic in commercial operations).

Conversely, a resilience-based index may result in the continued excretion of considerable numbers of *Trichostrongylus* and *Teladorsagia* eggs by non-treated animals, and hence a larger proportion of those populations in refugia from anthelmintics than would occur with *H. contortus*. The epidemiological consequences of targeted treatment strategies must obviously be considered.

### Assessment of effects on anthelmintic resistance

Evaluating the success of a new program in reducing the rate of development of anthelmintic resistance over a short period (one or two years) is difficult unless large changes are expected. Although there are sensitive *in vitro* tests to detect shifts in the level of benzimidazole anthelmintics, *in vitro* tests are at present less universally accepted for the macrocyclic lactone anthelmintics, especially for *T. circumcincta*, and the widely used faecal egg reduction test is not sufficiently sensitive over a short period. One alternative has to been to use computer simulation studies, which have the benefit of allowing comparisons between a range of potential scenarios (Barnes *et al.*, 1995; Leathwick, 1995). Where the model is shown to simulate the real-life worm ecology and population changes due to immunological effects with fair accuracy, reasonable confidence can be placed in the model outputs regarding anthelmintic resistance. This approach has relevance to targeted treatment investigations, where it is otherwise difficult to demonstrate progress towards the core aim of the strategy.

### Communication to livestock owners

As a new concept, the proposal to limit anthelmintic treatments to only part of a group will require some communication effort to achieve adoption. Although at present most animal managers take pains to ensure that every animal receives a treatment, experience with refugia-based strategies in Western Australia shows that new approaches can be palatable if new recommendations involve little additional work and there is minimal risk

of disease or significant production loss. An advantage of targeted treatment systems may be that they are easier to comprehend and implement than other sustainable approaches. The benefit of avoiding expensive whole-flock treatment is likely to have additional appeal, especially to resource-poor farmers.

As with all new approaches to anthelmintic resistance management, a goal of current research will be to translate the targeted treatment concept into practical and effective recommendations before new anthelmintics arrive to tempt livestock owners back to chemical-based solutions.

*Acknowledgements.* The generous assistance of Drs Frank Jackson and Andy Greer at the Moredun Research Institute with discussions and research data, and comments on the manuscript by Fiona Kenyon, is gratefully acknowledged. Computer modelling support from Dr Robert Dobson (Murdoch University), and funding from the Australian Sheep Industry Cooperative Research Centre, for the Western Australian research is greatly appreciated.

### REFERENCES

- Albers, G.A.A., Gray, D.G., Piper, L.R., Barker, J.S.F., le Jambre, L.F. & Barger, I.A. (1996). The genetics of resistance and resilience to *Haemonchus contortus* infection in young Merino sheep. *International Journal of Parasitology* **17**: 1355-1363.
- Barnes, E.H., Dobson, R.J. & Barger, I.A. (1995). Worm control and anthelmintic resistance: adventures with a model. *Parasitology Today* **11**: 56-63.
- Besier, R.B. (2001). Re-thinking the summer drenching program. *Western Australian Journal of Agriculture* **42**: 6-9.
- Besier, R.B. & Love, S.C.J. (2003). Anthelmintic resistance in sheep nematodes in Australia: the need for new approaches. *Australian Journal of Experimental Agriculture* **43**: 1383-1391.
- Besier, R.B. (2007a). New anthelmintics for livestock: the time is right. *Trends in Parasitology* **23**: 21-24.

- Besier, R.B. (2007b). Targeted anthelmintic treatment of sheep for resistance management: early experience in Australia and future directions. *21st International Conference of the World Association of the Advancement in Veterinary Parasitology*, 19-23 August 2007, Ghent, Belgium. Abstract No 192, p 225.
- Bishop, S.C., Bairden, K., McKellar, Q.A., Park, M. & Stear, M.J. (1996). Genetic parameters for faecal egg counts following mixed, natural, predominately *Ostertagia circumcincta* infection and relationships with live weight in young lambs. *Animal Science* **63**: 423-428.
- Bisset, S.A., Morris, A.C., McEwan, J.C. & Vlassoff, A. (2001). Breeding sheep in New Zealand that are less reliant on anthelmintics to maintain health and productivity. *New Zealand Veterinary Journal* **49**: 236-246.
- Burke, J.M., Kaplan, R.M., Miller, J.E., Terrill, T.H., Getz, W.R., Mobini, S., Valencia, E., Williams, M.J., Williamson, L.H. & Vatta, A.H. (2007). Accuracy of the FAMACHA system for on-farm use by sheep and goat producers in the southeastern United States. *Veterinary Parasitology* **147**: 89-95.
- Chandrawathani, P., Adnan, M. & Waller, P.J. (1999). Anthelmintic resistance in sheep and goat farms on Peninsular Malaysia. *Veterinary Parasitology* **82**: 305-310.
- Chartier, C. & Hoste, H. (1997). Response to challenge infection with *Haemonchus contortus* and *Trichostrongylus colubriformis* in dairy goats: differences between high and low producers. *Veterinary Parasitology* **73**: 267-276.
- Coop, R.L. & Kyriazakis, I. (1999). Nutrition-parasite interaction. *International Journal for Parasitology* **84**: 87-204.
- Dobson, R.J., Besier, R.B., Barnes, E.H., Love, S.C.J., Vizard, A., Bell, K. & Le Jambre, L.F. (2001). Principles for the use of macrocyclic lactones to minimise selection for resistance. *Australian Veterinary Journal* **79**: 756-761.
- Geary, T.G., Conder, G.A. & Bishop, B. (2004). The changing landscape of anti-parasitic drug discovery for veterinary medicine. *Trends in Parasitology* **20**: 449-455.
- Greer, A.W., Kenyon, F., Bartley, D.J., Jackson, E.B., Gordon, Y., Donnan, A.A., McBean, D.W., Jackson, F. (2007). Development and evaluation of a decision support model for the identification of lambs that would benefit from anthelmintic treatment. *21st International Conference of the World Association of the Advancement in Veterinary Parasitology*, 19-23 August 2007, Ghent, Belgium. Abstract No 266, p265.
- Höglund, J. (2006). Targeted selective treatment of lungworm infection in an organic dairy herd in Sweden. *Veterinary Parasitology* **138**: 318-327.
- Hoste, H. & Chartier, C. (1998). Response to challenge infection with *Haemonchus contortus* and *Trichostrongylus colubriformis* in dairy goats: consequences on milk production. *Veterinary Parasitology* **74**: 43-54.
- Hoste, H., Le Frileux, Y., Goudeau, C., Chartier, C., Broqua, C. & Bergeaud, J.P. (2002a). Distribution and repeatability of nematode faecal egg counts in dairy goats: results from a farm survey and implications for worm control. *Research in Veterinary Science* **72**: 211-215.
- Hoste, H., Le Frileux, Y. & Pommaret, A. (2002b). Comparison of selective and systematic treatments to control nematode infection of the digestive tract in dairy goats. *Veterinary Parasitology* **106**: 345-355.
- Hoste, H., Chartier, C., Lefrileux, Y., Goudeau, C., Broqua, C., Pors, I., Bergeaud, J.P. & Dorchies, P. (2002c). Targeted application of anthelmintics to control trichostrongylosis in dairy goats: result from a 2-year survey in farms. *Veterinary Parasitology* **110**: 101-108.
- Kahn, L. (2006). Findings from the IPMS Project: drench decision aid. *Proceedings of the Australian Sheep Veterinarians 2006 conferences* (Waga Wagga and Hobart). (Ed. C.Trengove) **16**: 48-52.
- Kaplan, R.M. (2004). Drug resistance in nematodes of veterinary importance: a status report. *Trends in Parasitology* **20**: 477-481.

- Krecek, R.C. & Guthrie, A.J. (1999). Alternative approaches to control of cyathostomes: an African perspective. *Veterinary Parasitology* **85**: 151-162.
- Krecek, R.C. & Waller, P.J. (2006). Towards the implementation of the "basket of options" approach to helminth parasite control of livestock: emphasis on the tropics/subtropics. *Veterinary Parasitology* **139**: 270-282.
- Jackson, F. & Miller, J.M. (2006). Alternative approaches to control – quo vadit? *Veterinary Parasitology* **139**:371-384.
- Leathwick, D.M., Vlassoff, A. & Barlow, N.D. (1995). A model for nematodiasis in New Zealand lambs: the effect of drenching regime and grazing management on the development of anthelmintic resistance. *International Journal of Parasitology* **25**: 1479-1490.
- Maingi, N., Krecek, R.C. & van Biljon, N. (2006). Control of gastrointestinal nematodes in goats on pastures in South Africa using nematophagous fungi *Duddingtonia flagrans* and selective anthelmintic treatments. *Veterinary Parasitology* **138**: 328-336.
- Malan, F.S., Van Wyk, J.A. & Wessels, C.D. (2001). Clinical evaluation of anaemia in sheep: early trials. *Onderstepoort Journal of Veterinary Research* **61**: 165-174.
- Martin, P.J., Le Jambre, L.F. & Claxton, J.H. (1981). The impact of refugia on the development of thiabendazole resistance in *Haemonchus contortus*. *International Journal for Parasitology* **11**:35-41.
- Molento, M.B., Van Wyk, J.A. & Coles, G.C. (2004). Sustainable worm management. *Veterinary Record* **155**: 95-96.
- Prichard, R.K., Hall, C.A., Kelly, J.D., Martin, I.C.A. & Donald, A.D. (1980). The problem of anthelmintic resistance in nematodes. *Australian Veterinary Journal* **56**: 239-251.
- Sangster, N.C. & Dobson, R.J. (2002). Anthelmintic resistance. In: *The Biology of Nematodes*, Lee, D.L. (editor). London: Taylor and Francis, pp. 531-567.
- Van Wyk, J.A. (2001). Refugia – overlooked as possibly the most potent factor concerning the development of anthelmintic resistance. *Onderstepoort Journal of Veterinary Research* **68**: 55-67.
- Van Wyk, J.A. & Bath, G.F. (2002). The FAMACHA system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. *Veterinary Research* **33**: 509-529.
- Van Wyk, J.A., Hoste, H., Kaplan, R.M. & Besier, R.B. (2006). Targeted selective treatment for worm management – how do we sell rational programs to farmers? *Veterinary Parasitology* **139**: 336-346.
- Vatta, A.F. & Lindberg, A.L.E. (2006). Managing anthelmintic resistance in small ruminants of resource-poor farmers in South Africa. *Journal of the South African Veterinary Association* **77**: 2-8.
- Waller, P.J. (1997). Sustainable helminth control of ruminants in developing countries. *Veterinary Parasitology* **71**: 195-207.
- Waller, P.J. (2006). From discovery to development: Current industry perspectives for the development of novel methods of helminth control in livestock. *Veterinary Parasitology* **139**: 1-14.
- Woolaston, R.R. & Baker, R.L. (1996). Prospects for breeding small ruminants for resistance to internal parasites. *International Journal Parasitology* **26**: 845-855.