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CONTROLLING INTERNAL PARASITES WITHOUT ANTHELMINTICS
(A review)

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CONTROLLING INTERNAL PARASITES WITHOUT ANTHELMINTICS
(A review)

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Review: Controlling internal parasites without anthelmintics

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1.0 Executive summary

1. Internal parasites are a major source of economic loss in grazing ruminants. To a greater or lesser degree, most farms in the UK rely on anthelmintics for control. In most situations these products continue to be highly effective, but anthelmintic resistance is increasing to the limited range of products available, raising serious concerns over the future of worm control.

2. Internal parasites are also of concern on organic farms, where the prophylactic use of anthelmintic is prohibited by the standards for organic production. Organic farms generally rely on grazing management, with restricted use of anthelmintic if required. However, also within the regulations is the absolute requirement to treat individual animals if this is necessary to avoid suffering. Organic systems should aim to eliminate the need for anthelmintic drenching, but the number of farms where this has been achieved is few.

3. This report reviews current methods of parasite control, and evaluates the potential of alternatives to the use of anthelmintic, with particular reference to organic systems.

Epidemiology

4. The biology and epidemiology of the major internal parasites of sheep and cattle are well known. These form the basis of management and biological control, including strategies for clean grazing. However, less is known specifically about the complex interactions between parasite, host, climate, management and pasture factors which give rise to the occurrence of disease.

5. Useful computer simulation models have been developed, usually related to specific locations, species of parasite or conditions of management. These are becoming increasingly complex as further variables such as host resistance, sward type and grazing behaviour are included in the model. As knowledge and computing power increase, the opportunity is there for models to become more comprehensive, and more accurate.

6. Trends in the occurrence of disease can broadly be predicted, on a national or regional basis, from climatic and management data. At the present time however, there is no single comprehensive model which can be used to adequately quantify and predict the development of disease at a farm or system level. Research work is continuing on this topic.

Maximising the host's ability to fight disease

7. Host factors affecting the incidence and severity of parasitic attack include the development of acquired immunity, the effect of nutritional status and the presence of concurrent disease.

8. Under-nutrition has a general debilitating effect on an animal's ability to fight infection. In terms of roundworms, the development of the immune response and the host's ability to restore damaged tissue has been shown to be related to energy, and particularly protein, intake. A shortfall of specific minerals and trace elements e.g. cobalt or selenium will affect the host response to infection. Parasitic infection in it's own right can increase the requirement for specific nutrients, due to increased loss or less efficient use.

9. The underlying approach to disease control on organic farms is to promote the natural immune system and livestock health. Optimising management conditions to minimise stress, provide high quality, balanced diets and avoid concurrent disease is entirely consistent with an organic approach to animal husbandry, and a good basis for any disease control programme.

Clean grazing systems

10. Management strategies which optimise health, and reduce the exposure of animals to parasitic infection are a prerequisite on organic farms. Clear benefits have been demonstrated under conventional, as well as organic systems. Clean grazing systems are the favoured and most direct method of controlling internal parasites on organic farms, and wherever possible should underpin all other methods of parasite control.

11. However, the managerial discipline and farm infrastructure are not always present to operate an effective clean grazing system. On conventional farms, the perceived conflict between efficient and flexible grassland utilisation, and the availability of effective anthelmintic products, has discriminated against greater uptake of clean grazing. On organic farms the motivation is greater, but the optimum balance of livestock and arable enterprises is not always present, making management more difficult or reducing the effectiveness of a clean grazing approach. Implementation of clean grazing systems is particularly difficult on hill farms, on single enterprise units with permanent pasture, or where the ratio of cattle to sheep livestock units is wider than 35:65.

12. It is also difficult to operate current clean grazing systems without using some anthelmintic, particularly when animals are first put onto clean pasture. This is particularly critical for freshly lambed ewes, which temporarily lose their immunity and produce a high output of worm eggs during early lactation. In this case anthelmintic drenching is often required to reduce contamination of clean grazing, and to avoid the system breaking down later in the season. Systems of alternate or mixed grazing have value, but on their own are unlikely to achieve an acceptable degree of parasite control.

13. Where clean grazing cannot be set up, for example on hill farms, there is greater reliance on the extensive nature of the grazing to reduce parasitic burden, and on the sale of lambs at weaning. By means of a carefully timed move from lambing pastures to open hill, an extensively managed hill farm could theoretically avoid the need to drench lambs at least until weaning.

14.However, for organic farms in the hills/uplands trying to finish lambs after weaning, parasitic gastro-enteritis will remain a hazard, and the limited use of anthelmintic is almost inevitable for individuals, or whole groups, depending on the season. Even where lambs are sold at weaning, all or a proportion of lambs may require drenching on arrival at their new destination, particularly if going onto clean pasture.

15.On lowland organic farms supporting 'commercial' stocking rates, current practice is to support clean grazing by the strategic use of anthelmintic, often a single drench to ewes around lambing time, before entry to clean pastures, or as a 'salvage drench' should parasitic burden become too great.

Genetically resistant animals

16.Trials have shown that 10% of lambs in a given flock may contribute 50% to total faecal egg output.Ironically, one method of reducing total anthelmintic use is to target those individual lambs within the flock which, in terms of faecal egg output, appear to be the worst offenders. At a practical level this is done by drenching scouring lambs. However, scouring in not necessarily indicative of a high faecal egg output.

17.Eliminating the most contaminating individuals from a flock, can have a very significant impact on the overall level of parasitic challenge. The existence of genetically linked resistance to roundworms is well recognised in the UK and abroad. Several experimental flocks have been established in Australia and New Zealand, with high and low responder lines differing in faecal egg output for a particular parasite, usually *Haemonchus contortus* or *Ostertagia circumcinta.*

18.These traits are low to moderately heritable, and therefore can be used to increase the frequency of resistant genes in a particular flock or population. Neither does selection for increased parasite resistance necessarily reduce performance in economically traits, especially in a heavily parasitised environment.

19.Genetically resistant animals have traditionally been selected on the basis of nematode egg output in the faeces, after dosing with a known challenge of infective larvae, or from naturally acquired worm burdens. This the most direct and cheapest form of selection. Indirect methods have been sought on the basis of host physiology and blood biochemistry. So far the results have not been conclusive.

20.Some progress has been made in the identification of genes associated with the sheep Major Histocompatibility Complex (MHC) which may be involved in conferring increased resistance to internal parasites. However, there are other non-MHC genes also involved in the regulation of host responses.

21.A recent development by Glasgow University Veterinary School has been the identification of a genetic marker for increased resistance to *O. circumcinta* in Scottish Blackface sheep. This test is currently being validated on commercial farms where single sire mating is practised in pure-bred flocks. With continuing improvement in genetic mapping and biotechnology techniques, this type of test is likely to be used increasingly in genetic selection.

22.One of the difficulties in extrapolating from an experimental flock of genetically resistant animals, is in determining how representative this sub-group is of the sheep population as a whole. Nevertheless, commercial breed improvement programmes are now in operation in Australia and New Zealand which incorporate resistance to worms in the selection index.

23.On an individual organic farm which breeds its own replacements, selection for parasite resistance is possible. Selecting future breeding stock by the extent of dagginess (as currently practised on some organic farms) may in fact be selecting for *resilience* against parasite attack, rather than for resistance. Fortuitously, *resilience* and *resistance* traits are positively correlated. The accuracy of selection for resistance could be greatly improved by carrying out egg counts in samples of faeces taken over a period. Just as importantly, this strategy could be used to eliminate from the breeding flock animals inclined to have persistently high faecal egg output, thereby reducing pasture contamination and parasitic challenge to the flock as a whole.

Manipulating sward structure and composition

24.Sward structure has been shown to affect the concentration of infective larvae on the upper horizon of the sward, through effects on the micro-climate within the sward or due to the morphology of the plants themselves. These effects have been shown to modify parasite burden in the grazing animal; Yorkshire Fog for example, has been shown to result in lower rates of infection than Ryegrass swards.

25.Most of the data derives from studies in Australia and New Zealand, often with *H. contortus*. Significant effects remain to be demonstrated at a strategic or applied level under UK conditions. Conclusive relationships have yet to be established, which would allow this factor to be used in a management system.

26.New Zealand studies have shown that the species of plant present in the sward can also affect the worm burden acquired by grazing stock. Some of the most interesting work relates to certain plants, in particular, *Lotus corniculatus* and sulla (*Hedysarium coronarium*) which contain condensed tannins (CT's). Several experiments have shown that CT's can reduce the parasite load and improve the performance of parasitised lambs due, at least in part, to their protective effect on dietary protein which increases protein supply at the duodenum.

Control by vaccination

27.The host parasite relationship is very complex. A lack of detailed knowledge of the immune response is the main factor which currently limits the ability of molecular biologists to develop suitable vaccines. Initial successes against blood sucking and mucosal parasites provide some optimism for effective vaccination against gastrointestinal nematodes in the future.

28.Commercial vaccines are not yet available, but considerable progress has been made in isolating various parasite enzymes and proteins which may be used as antigens. As knowledge of the immune response increases, so too does the ability to select appropriate antigens to stimulate an immune response in the host. Improvements in adjuvants will ensure the right type of response is induced.

29.Much of the work has been undertaken with *H. contortus* - it's blood sucking feeding habit providing a good means of delivering antibody to the digestive system of the parasite. However, this species is of limited importance in the UK. For practical use, control of *Ostertagia* in particular, will need to be incorporated in any commercial vaccine.

30.While a vaccine for the control of parasitic gastro-enteritis may be available in the future, its adoption within organic systems will depend on how its acceptance by the Organic Sector Bodies. Draft EU Standards would allow vaccination in circumstances where disease had been identified and treatment recommended.

Role of homeopathy

31.There is little evidence to confirm any direct effect of homeopathy in the treatment of parasitic gastro-enteritis. However, homeopathic preparations may have a useful role in aiding the recovery of tissues damaged by parasitic attack. An effective nosode is available to provide protection against lungworm infection.

Herbal treatments

32.Many plants and their extracts have been shown to act as mild verimfuges. However, little comparative information is available on their potential for worm control in farm animals. A herbal approach may have better longterm prospects for nematode control than homeopathy, but further screening and evaluation is necessary.

33.With both homeopathy and herbal treatment, a practical method of delivery under field conditions can be difficult. One option could be to establish monocultures of certain plants (vermifuges, or CT's) to be grazed strategically by organic stock, for example immediately after weaning.

Biological control

34.Fungi are only one type of organism with potential for controlling the free living stages of gastrointestinal worms, but these have been the most studied. Other biological control agents are theoretically possible, particularly bacteria.

35.Initial screening work carried out in Australia identified approximately 100 species of fungi with nematophagous activity. Progress has been made under laboratory conditions in selecting fungal species which meet this criteria, and which can survive passage through the ruminant gastrointestinal tract. Some field testing has been carried out under Australian conditions with selected fungal species. Significant reductions in the number of infective larvae present on the pasture were reported, and a level of control comparable to the use of anthelmintic was claimed.

36.Research is ongoing to determine threshold dose levels and to investigate systems of sustained delivery of the fungi. Genetic typing and manipulation, while less acceptable for organic systems, could be another option to increase efficacy. The ultimate aim might be to develop a biological control system through a feed supplement, feed block or an intraruminal controlled release device.

37.New Zealand research has concentrated on understanding the role, and factors which affect the activity, of fungi already present on the pasture, rather than artificially deploy fungi onto faeces. There is little or no information on either aspect available from the UK. With a better understanding of fungal distribution on pasture, it may be possible to encourage sward conditions to maximise the impact of nematophagous fungi which are already present on the sward

Controlling internal parasites without anthelmintics - Conclusions

38.Effective systems of clean grazing have been developed in the UK. With current knowledge, these must be rigidly applied to be fully effective, often reducing their chances of being taken up on farms whose infrastructure and enterprise mix are not ideal. Furthermore, current systems of clean grazing generally depend on strategically timed anthelmintic treatment. To retain effective parasite control, while simultaneously reducing anthelmintic input and relaxing some of the more rigid features of conventional clean grazing systems, poses a considerable challenge.

39.An increasing number of factors are recognised as affecting parasitic burden. The need is to understand how collectively to harness some, or all of these, to bring practical benefits to parasite control. The best prospect is to combine several approaches in an integrated control programme, which could vary depending on individual farm circumstances. Some research has been carried out in New Zealand, but this work has been curtailed because of lack of funding. More information is required on parasite epidemiology, the effect of pasture species, grazing management and factors affecting larval movement and survival, which can be incorporated into a predictive model. Some of this basic modelling work is already taking place. However, practical evaluation under commercial conditions is still some time away.

40. Breeding for host resistance to parasites is a relatively new subject in the UK. Carried out on a flock basis, there is the advantage that selection is specific to farm conditions. However, if selection is based solely on the incidence of scouring the accuracy of selection and rate of progress will be low. Accuracy of selection may be improved by the use of faecal egg counts, replicated over time. The use of genetic markers, although promising, requires further investigation and validation in the field. Ultimately selection should be based on a multi-component selection index. The weighting of this index for disease resistance may need to be greater for organic systems, simply because the costs (economic or ideological) are higher, and the response to improvement in disease control greater in a parasitised environment, where the aim is to avoid anthelmintic treatment. Serious consideration should be given to developing a protocol for selecting more resistant animals on a within-flock basis, perhaps using existing Sire Reference Schemes as a model framework.

41. Experience of biological control outside of controlled glasshouse situations is often unconvincing. In terms of biological control of roundworms, there are reasonable prospects of developing a delivery system through the grazing animal to target the parasite in the faecal environment. Alternatively, a better understanding of how to optimise pasture conditions in favour of the control agent, probably a fungus, could significantly reduce the viability of free living stages. Further research needs to be undertaken in the UK.

42. The approach which might give the best return, could be the strategic use of specific forages. These are likely to be those containing condensed tannins, or perhaps plants with specific vermifuge qualities. Typically, these could be used for freshly lambed ewes before being moved on to clean pasture, so that periparturient worm burdens are reduced, or for lambs after weaning. Alternatively, weaned lambs from organic hill farms could be put onto such forages, before being released onto finishing pastures. There is a need to evaluate the role of these forages on organic farms, their effectiveness, agronomy, and short/longterm effects on the grazing animal.

Recommendations for further research

The current response of the farming industry to the development of anthelmintic resistance has been to devise strategies which prolong the usable life of existing products. The immediate prospects of developing new anthelmintics are low. Any impetus from the conventional farming or supply industries to seek alternatives to anthelmintic treatment is only likely to result from an intolerable level of parasite resistance, or complete breakdown in efficacy of existing drugs. For organic producers the need is greater, if the aim is to combine commercial stocking rates, acceptable standards of animal welfare and minimal or nil use of chemical inputs.

A comprehensive, multi-faceted programme of research is likely to be very expensive, which would be difficult to justify solely on the basis of the needs of organic farmers. However, any research on this subject would be immediately transferable to the wider farming industry. Set out below is an attempt to prioritise research objectives taking account of relevance to organic producers, overall cost and turn-around time of usable results.

Research priorities

	Desirability	Relative cost	Turn-around time to usable results	Overall priority
Specialised forages	***	***	***	High
Breeding for resistance	***	**	**	High
Epidemiological components/modelling	***	**	*	Medium
Biological control	**	**	*	Medium
Homeopathy/Herbal	*	*	*	Low

* least favourable   *** most favourable

2.0 Introduction

One of the success stories in livestock farming in the past 40 years has been the development of efficient and cost effective anthelmintic drenches, capable of achieving a 95% mortality rate, or greater, in the target parasite. Combining a knowledge of epidemiology with modern anthelmintics has allowed great increases in disease control, and in stock carrying capacity. However in recent years, control of gastro-intestinal-intestinal nematodes has been seriously threatened by the development of resistance by the parasite to the commonly used anthelmintic drenches (Jackson and Coop, 1994).

Control of internal parasites is of particular concern on organic farms (Kintail, 1991), where routine medications are restricted. While organic farms tend to have lower stocking rates and a better integration of arable and livestock enterprises, considerable practical difficulties remain in controlling internal parasites through management alone. This is recognised within the standards set out by UKROFS (United Kingdom Register of Organic Food Standards) for organic production. Depending on farm circumstances, an additional period may be allowed after grassland conversion, so that a disease control programme for organic stock can be progressively implemented.

Organic systems greatly reduce the requirement for anthelmintic, but organic livestock farms which use *no* anthelmintic are few and far between. The ideal is to develop a system of farming which completely eliminates the need for drenching. In practice, this goal is rarely achieved. Anthelmintic treatment is permitted where disease occurs and is threatening the health and welfare of the animals concerned. The use of anthelmintic in this 'fire brigade' manner does not address the fundamental problem of parasitic challenge, and leaves organic farming vulnerable to criticism on the grounds of animal welfare. Restricted, strategic use of anthelmintic is currently allowed (Lampkin, 1990; Anon, 1996a), for example, a single drench to ewes at lambing, or before entry to clean grazing. In these circumstances its use is on the basis of no viable alternative, rather than satisfying the principles of organic production.

As an alternative to anthelmintic, several approaches are possible. These include greater use of clean grazing, genetically resistant livestock, manipulating sward composition, use of homeopathy, specific plants and herbs with anti-parasitic properties, and biological control of free-living stages of the parasite. This review summarises the current performance and future potential of various control strategies in the context of UK organic farming systems, and the current standards for organic production.

3.0 Important internal parasites of cattle and sheep

Economic losses due to helminths (roundworms and tapeworms) in the UK, have been estimated to be £228 million per annum for farmed species. Worm infestation in lambs alone has been calculated to cost £30-£40 million each year (Anon, 1993).

Parasitic worms of domestic ruminants can be grouped into three categories on the basis of their morphology and lifecycles. These are **nematodes** or roundworms, **trematodes** or flukes, and **cestodes** or tapeworms.

3.1 Nematodes (Roundworms)

The gastrointestinal nematodes that affect grazing livestock are the cause of parasitic gastro-enteritis (PGE). The disease is commonly seen in young stock during their first grazing season and is characterised by diarrhoea, loss of appetite, poor growth, dehydration and death (Radostits, et al 1994). Gastrointestinal nematodes are economically important even when the infestations are clinically inapparant (Leland, 1980; Malczewski, et al 1972). Research in both cattle and sheep has demonstrated improved weight gain and food conversion efficiency in sub-clinically infested animals after anthelmintic treatment (Leland, 1980; Malczewski, et al 1972; Reid and Armour, 1978). Similar studies have shown that strategic treatment against trematodes and nematodes in sheep leads to improved weight gains and wool and milk yields (Petkov, et al 1986).

3.1.1 Species and target host

The species of nematodes found in the gastrointestinal tract of cattle and sheep are listed below (Taylor, 1987). A few species are common to both cattle and sheep but these are usually of low importance.

Table 1 (a) Gastrointestinal nematodes of sheep

Abomasum	**Small Intestine**	**Large Intestine**
Haemonchus contortus	*Cooperia onchophora**	*Oesophagostomum venulosum*
Ostertagia circumcincta	*Cooperia mcmasteri*	*Trichuris ovis*
Ostertagia trifurcata	*Cooperia curticei*	*Chabertia ovina*
*Teladorsagia davtiani**	*Nematodirus filicollis*	
Ostertagia leptospicularis	*Nematodirus battus* *	
Skrjabinagia kolchida	*Nematodirus spathiger*	
Trichostrongylus axei	*Trichostrongylus colubriformis*	
	Bunostomum trigonocephalum	
	Strongyloides papillosus	
	Capillaria spp	

* these species may also infect cattle

Table 1 (b) Gastrointestinal nematodes of cattle

Abomasum	**Small Intestine**	**Large Intestine**
Haemonchus contortus	_Cooperia oncophora_*	_Oesophagostomum radiatum_
Ostertagia ostertagi	_Cooperia mcmasteri_	_Trichuris spp._
Ostertagia lyrata	_Cooperia curticei_	
Ostertagia leptospicularis	_Nematodirus helvetianus_*	
Skrjabinagia kolchida	_Trichostrongylus longispicularis_	
Trichostrongylus axei	_Bunostomum phlebotomum_	
	Strongyloides papillosus	
	Capillaria spp.	

* these species may also infect sheep

Few species cause serious economic loss in the UK. These are _Ostertagia_, _Trichostrongylus_ and _Nematodirus spp._ However, the relative importance of each parasite varies geographically. _Haemonchus_, for example, which can be of local importance in the UK, is a very serious problem under Australian conditions.

3.1.2 General epidemiology

To devise suitable control strategies for roundworms, it is important to understand the epidemiology of the parasite, how pasture becomes contaminated and what strategies are employed in order to come into contact with the host, in this case the grazing ruminant.

In the typical lifecycle, eggs are passed onto the pasture in the faeces of the host (Dunn, 1978). The egg develops on the pasture to form the L1 larva which hatches and immediately begins to feed and grow. The larva moults to form the L2 and then the L3 phase. The L1 and L2 larvae are free-living, but the L3 larva is parasitic and must survive on its own food reserves until it enters a host. The L3 larvae move to the top of the pasture herbage in a film of moisture where they may be ingested by the host. Within the host, the larvae shed their protective sheath in the rumen or abomasum. The exsheathed larvae contact the mucosa and penetrate deeply into the spaces between the villi or into the glands. Subsequent development occurs within the mucosa until the fifth stage larvae or young adults emerge into the lumen of the gut. The worms mature and copulate, and the females begin to lay eggs. The period from ingestion of the parasite with the grass to the appearance of eggs in the faeces is known as the prepatent period. The development of the parasite within the host may be delayed by host factors, and the larval development can be inhibited for long periods (see Section 6).

The development from the egg through to the infective L3 on the pasture is influenced by a number of environmental conditions especially temperature and moisture (Dunn, 1978). The stages with the greatest resistance to climatic extremes are the egg and the L3 larva. The eggs can resist dry conditions.

Both egg and L3 larvae can survive moderate freezing so that pasture may never be presumed free of infection at the end of the winter even if it has been left unstocked. Eggs deposited onto the pasture in early spring can take several weeks to complete their development. Eggs passed later in the grazing system develop faster because of the higher ambient temperature, with the result that all the eggs passed on the pasture through spring and early summer tend to complete their development around the same time.

Summer rainfall favours the emergence of the larvae from the dung and can result in a rapid increase in numbers of infective larvae on the herbage. In the case of sheep nematodes, this increase can occur from late June onwards. For cattle, the increase is usually from mid-July onwards. Herbage levels can fluctuate throughout the late summer and autumn months and can persist at a high level until the following spring, often reaching their peak during the winter months. By late spring, herbage levels decline rapidly reaching low levels by May.

The larvae are very susceptible to desiccation, and in very hot, dry summers the pasture larval population may be decreased to zero. This was seen following the very dry summer of 1976, when a return of autumn rains precipitated hatching of eggs and a sudden rise in pasture larval numbers, resulting in the development of clinical PGE.

3.1.3 Specific parasites of cattle - Ostertagia

PGE in cattle most commonly results from ostertagiasis (Dunn, 1978). The majority of gastrointestinal nematodes of cattle follow the epidemiological pattern described above. However, with *Ostertagia spp* there are a number of important differences.

Ostertagia ostertagi is the primary pathogen, and *Skrjabinagia lyrata* is almost invariably present, but as less than 10% of the parasite population (Dunn, 1978). Ostertagiasis is mainly, but not exclusively, a problem of young stock. Adult cattle which have been moved from areas of low ostertagiasis incidence to areas where the disease is heavily endemic are particularly at risk.

The epidemiology of ostertagiasis is characterised by two peaks, one in the late summer, and the other in the winter and early spring. The autumn peak is usually referred to as Type I and the winter peak as Type II ostertagiasis. In an ordinary Type I infection, the ingested larvae enter an abomasal gland within 6 hours of ingestion. The larvae begin to grow causing enlargement of the gland, but the opening of the gland remains patent. The larvae leave the glands after approximately 3 weeks, and the mucosa recovers rapidly over the next couple of months. By contrast, in the winter form of the disease (Type II), the larvae remain in the abomasal glands in a hypobiotic state. Hypobiosis allows the majority of the *Ostertagia* population to survive the climatic extremes of winter in a protected environment. This phenomenon is less prevalent but does occur in sheep. In northern temperate zones, hypobiosis is induced by falling environmental temperature. Inhibition is greater in heavily infested animals, and is influenced by the immune response of the host. Some strains of a parasite have a greater tendency to inhibit than others (Stear et al, 1996a), implying some genetic variation in the predisposition to inhibit amongst the parasite population.

Climatic conditions during the grazing season can affect the relative incidence of Type I and Type II disease in the succeeding winter/spring. In dry conditions, a dung pat containing nematode eggs can remain intact for months with eggs and larvae trapped under its crust. Animals will not graze within 15 cm of the dung pat for a considerable period of time, and this distance can only be traversed by the L3 larvae in a film of moisture. In a wet summer there is a ready emergence of L3 larvae from the pat resulting in a high incidence of Type I disease. In a dry summer, the larvae are not released until the autumn when they are exposed to temperatures that will induce hypobiosis. This results in severe Type II disease in the following spring (Dunn, 1978). Furthermore, with a mass release of larvae in the autumn, many more are available for overwintering and this can lead to an early onset of Type I disease the following year.

In general, calves turned out onto a pasture carrying an overwintering infection begin to pass worm eggs 3 weeks later. If the calves remain on the pasture they are exposed to increasing levels of infection during the second half of the grazing season resulting in Type I disease. Young cattle grazing the same pasture during the autumn or early winter will acquire large burdens of larvae which will enter a hypobiotic state until spring, when they will complete their development and cause Type II disease (Taylor, 1987).

By contrast, pastures grazed by beef suckler cows and their calves rarely develop dangerous levels of infective larvae because of the dilution effect of the resistant dam. Spring-born, single-suckled calves which remain with their dams are therefore not usually at risk of ostertagiasis (Taylor, 1987).

Symptoms of Type I ostertagiasis are those of typical PGE with weight loss, poor condition and diarrhoea. The mortality is usually low. By contrast, Type II ostertagiasis is associated with damage to the parietal glands of the abomasum and the clinical symptoms include severe weight loss, profuse watery diarrhoea, oedema particularly of the limbs and jaw, and anaemia. Mortality is often high.

3.1.4 Specific parasites of sheep

Trichostrongyles

As with cattle, the majority of the gastrointestinal nematodes of sheep follow the general epidemiological pattern described above with a few exceptions. However, there is one very important difference.

Around lambing time and in early lactation, resistance to nematodes is reduced in ewes, resulting in an increase in the worm egg output onto the pasture (see Section 6). This is known as the "spring rise" or "periparturient rise" (Dunn, 1978 ;Taylor, 1987). Worm burden increases due to larvae newly acquired from the pasture, and/or development of hypobiotic worms. The adult worms also lay more eggs at this time.

During the suckling period, the ewes contribute significantly to pasture contamination. Where ewes and lambs are turned out onto pasture contaminated with overwintering larvae, lambs will become infested before the overwintered larvae die off, and will themselves contribute to the pasture contamination (Taylor, 1987; Dunn, 1978). The net result is a new generation of infective larvae on the pasture from the end of June onwards, which can cause clinical PGE or poor weight gains in the lambs. In the south of England, the larval peak due to the new generation of larvae may occur earlier, and there may be a second peak in September and October in some years.

Nematodirus spp.

Nematodiriasis is confined to lambs (Dunn, 1978). The ewes contribute significant numbers of eggs to the pasture, but do not usually develop clinical disease. The disease therefore is mainly transmitted from one lamb crop to the next. Typically infection progressively increases on contaminated pasture grazed by ewes and lambs every year.

The most important factor of the pre-parasitic stage is the tremendous capacity of all *Nematodirus spp.* to survive freezing. Development of the larvae from L1 to L3 takes place entirely within the egg-shell. Eggs deposited on the pasture in spring can remain viable through the following winter. In addition, they are capable of surviving for up to two years, even if fields are ploughed and reseeded (Mitchell, 1987a). The eggs hatch in response to specific conditions, resulting in the abrupt release of many infective larvae onto the pasture (Taylor, 1987; Dunn, 1978). The timing of this hatch is dependent on a period of chill followed by warmer conditions, and varies from year to year. The hatched L3 has only a short, active life. In southern England, there is a second hatching period in the Autumn for eggs deposited during the Spring and Summer. Hatching in this case is triggered by moisture after a period of dry weather, and is not dependent on chill. Autumn nematodiasis has also been observed on some hill and upland farms (Henderson, 1990), and it is possible that autumn to autumn transmission may be established in these flocks.

If the hatch occurs early in the spring, susceptible lambs may not be grazing sufficient quantities of herbage to acquire a pathogenic infection. If the hatch occurs in late April or early May, there is a high risk to young lambs (Taylor, 1987). When the hatch occurs late, the lambs may be sufficiently resistant to withstand challenge. From weather patterns over the winter and early spring it is possible to forecast the likely incidence of disease each year, and to provide practical recommendations.

Nematodiasis typically results in rapid weight loss and dehydration. Death can occur within 2 - 3 days. Because of the simultaneous availability of large numbers of L3 to all the lambs in a field, it is usual to find all the lambs affected to varying degrees within 6 to 10 days of the first case occurring (Dunn, 1978).

3.2 Lungworm

3.2.1 Species and target host

Parasitic bronchitis can occur in cattle and sheep. The disease is of particular importance in cattle where it is caused by the nematode *Dictyocaulus viviparous.* Losses due to lungworm in cattle have been put at £30 million per annum (Anon, 1993). Like PGE it is primarily a disease of young stock at first turnout. Recently the disease has been increasingly reported in adult cattle (Anon, 1996b).

3.2.2 Epidemiology

The mature worms live in the bronchi and are prolific egg producers. Their eggs are coughed up and swallowed by the host. The eggs hatch in the airways or gut, and only larvae are passed in the faeces. Provided conditions are suitable, the first stage larvae (L1) develop in the external environment to L2 and L3 stages. The L3 are protected by the cuticles of both L1 and L2 which have been retained. Moisture is essential for survival and development. Larvae survive best in cool, damp surroundings especially in the presence of long herbage or free standing water. Under optimum conditions larvae can survive on the pasture for over a year (Radostits et al, 1994).

The infective third stage larvae are relatively inactive, and few migrate from the faecal pat. Factors that predispose to dispersion of the larvae include diarrhoea, mechanical spreading, rain, earthworms and stocking density. A fungus *Pilobolus spp.* also acts as an important spreading agent. Up to 50 larvae may be found on each sporangium and its explosive discharge may propel the larvae up to 3 metres (Radostits et al, 1994). The presence of *Pilobolus spp.* in dung pats can result in a 19 fold increase in larvae on the surrounding herbage.

The third stage larvae are ingested by the host and migrate through the wall of the intestine to the mesenteric lymph nodes where they develop to fourth stage larvae. They then enter the venous blood flow via the lymphatics, and travel through the heart to the lungs. The larvae enter the alveoli where they remain for 3-6 weeks before migrating to the bronchi.

Several factors are involved in the continuation of infection from season to season (Dunn, 1978). The L3 larvae are highly susceptible to desiccation, but are capable of overwintering through freezing conditions and will infect cattle at turnout. Furthermore, the adult worms can live for up to 6 months and their presence within the host at turnout will also contribute to pasture contamination. This reservoir is most important in yearling cattle which typically carry the heaviest burdens. The manure from houses in which carrier animals have been overwintered may spread infection onto pasture. A winter inhibition phase has also been identified.

The characteristic symptoms of lungworm infestation is the development of a cough, dyspnoea, pyrexia, weight loss and death. The progress of the disease is rapid, and in the acute form 75 - 80% of animals may die during the pre-patent phase (Dunn, 1978; Radostits et al, 1994).

In sheep, infestations with *Dictyocaulus filaria* follow the same pattern as that seen with *D.viviparus* in calves. The life-cycle is direct and the L3 larvae are long-lived in damp, cool conditions. The prevalence of infection tends to be lowest in spring and summer, but rises rapidly in the autumn and winter when most clinical cases are seen. In contrast to *D.viviparus, Pilobolus* fungi do not contribute to distribution of the larvae (Dunn, 1978).

The other lungworm species of sheep, *Muellerius capillaris* and *Protostrongylus rufescens*, have an indirect lifecycle, with a landsnail or slug as an intermediate host.

3.3 Trematodes (Flukes)

3.3.1 Species and target host

The liver fluke, *Fasciola hepatica*, is the cause of fascioliasis in cattle and sheep. In Florida, the cost of liver fluke infestations in cattle in terms of liver condemnations at the abattoir exceeded $500,000 dollars annually (Simpson, et al, 1985) and the introduction of control measures was highly cost effective. In the UK, the annual economic losses attributable to infestation of sheep and cattle with *Fasciola hepatica* was estimated at £5 million and £46 million respectively (Froyd and Mc William, 1975). These estimates did not take into account revenue lost from condemned livers (£2 million), the mortality resulting from sporadic outbreaks of acute fascioliasis in sheep, the role of fascioliasis in general debilitation of livestock, the reduction in fertility, the higher incidence of metabolic disorders, or the calf mortality in fluke affected herds due to the increased prevalence of *Salmonella* carriers.

The disease can occur in animals of all ages. In sheep, it may be the cause of sudden death or may be responsible for a sub-acute, or chronic condition characterised by weight loss, anaemia and oedema, particularly of the jaw. In cattle, the disease is chronic and affected animals lose weight, develop anaemia, and oedema. In dairy cows, milk production falls. An acute condition can occur in calves (Radostits et al, 1994).

Like *Fasciola hepatica, D. dendriticum* affects both cattle and sheep, but is of limited importance economically.

3.3.2 Epidemiology

Fasciola hepatica

Cattle appear to have a high natural resistance to liver fluke, and the clinical syndrome is usually seen in the chronic form. In contrast, clinical signs in sheep can be divided into acute, sub-acute and chronic forms depending on the number and age of flukes present.

The parasites mature in the bile ducts of the host. The eggs pass down the bile ducts and are excreted with the faeces. The eggs hatch to release miracidia which actively invade the intermediate host, the snail *Lymnaea truncatula.* These form sporocysts in the digestive tract of the snail, producing a number of rediae which migrate to the hepatopancreas where they develop into cercaria. The cercaria leaves the hepatopancreas and passes to the hindgut from which it is expelled.

At optimal temperatures, the cercariae are shed within 5 weeks of infection of the intermediate host. The cercariae attach to plants where they form a resistant cyst wall and become metacercariae. After 2 - 3 days, encystment is complete and the metacercaria is infective to the definitive host when ingested with the herbage.

The epidemiological pattern is temperature dependent (Dunn, 1978). With the onset of winter and colder days, development of the eggs, and of the stages within the snails ceases. Some of the eggs, and some snails will not survive the winter, but the surviving infested snails form a reservoir known as "winter infection".

In spring as the temperature rises above 10°C, eggs that have survived from the autumn and those passed overwinter begin to develop. The winter infection in the snail is shed resulting in metacercariae available to infest grazing animals. The number of snails at this time of the year is small, and the danger of acute disease resulting from winter infection is slight. However, once the snail begins to breed it is capable of multiplying many thousandfold during the summer. These snails are also available for infection by miracidia. The presence of developmental stages of the parasite from June until September is referred to as "summer infection". It is from this summer infection, that the number of cercariae released reaches a maximum and acute disease occurs. Tissue damage caused by migrating flukes can also provide suitable opportunities for the development of clostridial disease e.g. Black's Disease (Henderson, 1990).

Development of the disease depends on temperatures above 10°C. A damp environment is also essential as both the snail intermediate host, and the miracidia and cercariae stages require moisture. The metacercariae cannot survive strong sunlight for more than a few weeks. They die quickly in silage.

The likelihood of fascioliasis can be predicted from climatic conditions. In Britain, the critical temperature for fluke and snail development only occurs between May and October, while the optimal moisture levels are seen in autumn, winter and early spring. However, in wet summers and wet paddocks, ideal conditions can occur.

Dicrocoelium dendriticum

D.dendriticum has an indirect life-cycle involving passage in two intermediate hosts, a land snail and an ant. It is a parasite of dry land (Radostits et al, 1994); a specific habitat associated with *D.dendriticum* has not been defined (Dunn, 1978).

The definitive host is infected by ingestion of metacercariae in an ant. The young flukes enter the common bile duct directly from the gut and mature to egg laying adults within the bile ducts. The eggs are passed in the faeces of the definitive host, and only hatch after ingestion by the land snail. The egg of the parasite is very resistant to freezing, and will survive many years on the ground. The miracidium penetrates the gut wall and reaches the hepatopancreas where two generations of sporocysts develop. There is no rediae stage. The daughter sporocysts produce cercariae which are expelled in batches covered with slime from the respiratory pore of the snail. These "slime balls" may contain up to 400 cercariae, and a single snail may produce 5 slime balls.

The expulsion of the slime balls is stimulated by a fall in temperature, or change in day-night temperature gradient. When conditions are very humid the slime balls liquefy and the cercariae die. Desiccation makes the slime balls more dense and compact, and the embedded parasites survive well. The snail borne phase lasts around 5 months.

The second intermediate host, the brown ant, carries the slime balls to its nest where it will eat them either immediately or after storage. Whole ant communities may be infected, and in endemic areas the infection rate of ants is generally 35%. A few of the metacercariae in the ant migrate to its "hind brain" where they cause a lesion that affects the ant's behaviour and causes it to climb and remain at the top of herbage overnight, before descending again during the day.

D.dendriticum infection is associated with fibrous and cirrhotic changes in the liver and with black disease in sheep (Dunn, 1978; Radostits et al, 1994).

3.4 Cestodes (Tapeworms)

Despite their size, and the fact that segments can easily be seen in the faeces of infected animals, in practice, there is little evidence than tapeworm infection affects animal performance. Heavy infestation of young animals, usually under 6 months of age, may be associated with a failure to thrive, poor coat and vague digestive disturbances such as constipation, mild diarrhoea or dysentery (Radostits et al, 1994). Infested animals may also be more susceptible to the effects of other internal parasites, other diseases or adverse environmental conditions.

Ruminants are also the intermediate hosts for the larval stages of a number of cestodes. These parasites generally inflict minimal damage on the ruminant but can pose a risk to man via the food chain. The exceptions to this rule are hydatid cysts (intermediate to *Echinococcus granulosus*) which can cause local organ damage, *and Coenurus cerebralis* (the larval stage of *Taenia multiceps*) in sheep which causes a neurological condition known as "gid" or "sturdy"(Dunn, 1978; Taylor, 1987).

Several anthelmintics are effective in removing tapeworms, but re-infection occurs quickly if the animal consumes the intermediate (pasture mite) host.

4.0 Limitations to anthelmintics

At the current time, worm control on most farms in the UK depends to a varying degree on anthelmintic treatment (Taylor and Hunt, 1989).

4.1 Treatment versus prevention

Despite the high efficacy of the modern anthelmintic products the period of protection against reinfection is limited. If a treated animal grazes heavily infected pasture its worm burden is quickly restored, and treatment will have little benefit (Henderson, 1990). Lambs grazing clean, as opposed to contaminated, grazing have shown a 50% increase in growth rate, even though both groups were drenched at frequent intervals (McAnulty et al, 1982). Current control recommendations generally aim to avoid exposing susceptible animals to high levels of infective larvae (Sykes, 1994).

4.2 Anthelmintic resistance

Anthelmintic resistance is the heritable change in the ability of individual parasites to survive the recommended therapeutic dose of an anthelmintic drug (Taylor and Hunt, 1989).

Some worms may survive by adopting strategies to reduce energy demand, switch to alternative energy pathways or reduce their uptake of the drug (Taylor and Hunt, 1989). Throughout the world resistance has been detected most commonly in gastrointestinal nematodes of sheep and goats, notably *H. contortus*, *O. circumcinta*, *Trichostrongyle*, *Cooperia* and *Nematodirus* species (Taylor and Hunt, 1989). The situation in Australia has been well documented, with reports of 90% resistance to anthelmintics of the benzimidazole group and a 60% resistance to those in the levamisole group (Anon, 1992). Resistance to both the benzimidazoles and levamisoles have also been reported from New Zealand. As yet no resistance to the Ivermectin group have been identified in sheep in Australia or New Zealand, but resistance has been found in goats, and these are able to infest sheep. There have been only a handful of reports of resistance in cattle, but this could also be expected to increase with greater use of bovine anthelmintic. In South Africa, strains of *H. contortus* have developed that are resistant to virtually all anthelmintic drenches. In Europe, resistance has been reported in France, Germany, Holland and Switzerland.

Anthelmintic resistance has been developing more slowly in the UK. Some of the earliest evidence is derived from the increased incidence of clinical haemonchosis in sheep in the South East of England from the mid-1980's. Coles (1992) reported approximately 70% of sheep farms in West Sussex had cases of benzimidazole - resistant nematodes .

In a random sample of sheep farms in the north east and south west of England Hong et al (1996) reported that 15% and 44% of farms in each area had benzimidazole resistant nematodes. Sixty five percent of non-dairy goat farms in England and Wales had resistant worms. *O. circumcinta* was the main species in sheep and *H. contortus* in goats. One case of levamisole resistance in sheep was confirmed among the 200 farms tested. Ivermectin resistance was not found in sheep.

In a study at the Moredun Research Institute, a strain of *Ostertagia* was found to remain highly resistant for more than 10 years, despite the total withdrawal of the selecting drug (Jackson and Coop, 1994). The practice of moving sheep from farm to farm will ensure that once established in the UK anthelmintic resistance will spread rapidly.

To slow the spread of resistance several anthelmintic strategies are generally recommended (Herd and Coles, 1995). These include choosing an effective drench, supplying the correct dose, annually rotating between the three main groups of anthelmintic, avoiding the introduction of resistant worms, and using the minimum number of treatments required. Reducing feed intake for 24 hours before and 3 hours after treatment increased efficacy against resistant strains by up to 40% (Anon, 1996c).

While conventional farmers are recommended to rotate the three main groups of anthelmintic, theoretically only two groups are available to an organic producer. Ivermectin products are excluded by Organic Production Standards, because of controversial claims of residual effects on dung fauna (Wratten et al, 1993).

The rate of development of resistance in a population of worms is also affected by the timing of anthelmintic treatment, the proportion of free living nematodes at the time of treatment and the biotic potential of the parasite (*H. contortus* is a more prolific producer of eggs than are *Trichostrongyle* species). Taylor and Hunt (1989) suggested that a 'dose and move' (evasive) strategy may well select heavily for resistance because all subsequent worms in the system are the progeny of survivors of the anthelmintic treatment. Drenching animals before moving onto clean grazing has the same theoretical risk.

A computer model by Barger (1989) predicted that resistant sheep given anthelmintic treatment at the same intensity as normal sheep will develop anthelmintic resistance more quickly. A similar observation was made in New Zealand by Leathwick et al (1995).

4.3 Relevance for organic systems

Reducing parasitic challenge improves animal performance even where anthelmintics are used routinely. The development of anthelmintic resistance in the parasite is also an increasing threat. All farmers, not just those farming organically, ought to be interested in reducing the exposure of livestock to internal parasites and their reliance on chemical control. A reduction in faecal soiling could have further welfare benefits, in terms of reduced fly strike and perhaps less need for tail docking (French and Morgan, 1996).

The likelihood of anthelmintic resistance developing on organic farms is very low. The amount of anthelmintic used is unlikely to exert the required selection pressure to induce resistance in the parasite.

However, organic producers that purchase breeding stock within the permitted guidelines would be advised to ensure they are fully aware of the history of those animals. The standard UK recommendation, for conventional producers to drench newly arrived animals with an ivermectin product, is clearly not an option for organic farmers.

Some features of 'dose and move' strategies of grazing management and the use of genetically resistant livestock may be conducive to the multiplication of resistant genotypes, if these are present in the worm population. These factors should be borne in mind in any integrated disease control programme, for example, should the use of genetically resistant hosts become more widespread in the future.

5.0 Conventional clean grazing systems

5.1 Roundworms

Clean grazing strategies aim to control the helminth parasites of grazing animals through pasture management and with minimal or no use of anthelmintics (Brunsdon, 1980). From a knowledge of parasite epidemiology it is possible to identify the periods when the animals are most at risk, and by moving them to fresh pasture it is possible to keep infection to a minimum.

5.1.1 Classification of pasture

The cleanliness of the pasture can be defined as follows (Michel, 1982):

"Clean"	- pastures which will not turn susceptible animals into a significant source of pasture contamination.
"Safe"	-pastures which do not carry infestations capable of impairing the production of susceptible animals, but do turn them into a significant source of contamination
"Acceptable"	- pastures which are safe in all but exceptional years or circumstances.
"Potentially dangerous"	-pasture which is liable to be carrying an infestation sufficient to impair the production of susceptible animals.

The status of a pasture depends on its grazing history (Michel, 1982). The grazing season may be divided in half with the mid-point considered to be 30th June for sheep and 15th July in cattle. In the first half of the grazing season, the levels of overwintering larvae on the herbage decline rapidly so that a pasture may be regarded as safe by the end of April, and clean by midsummer's day. If the pasture was grazed by lambs in the previous year it must be regarded as potentially dangerous until the middle of the season because of the hazard of nematodiriasis. In the second half of the grazing season, herbage infestations are due to new contamination. Calves, lambs and lactating ewes are the chief sources of contamination. Sheep and cattle in their second season are less likely to contaminate the pasture, while adult cattle and dry adult sheep will not do so.

5.1.2 Strategies to reduce parasitic infection

Practical systems of grazing management to control stomach worms have been published by Dickson 1978, MAFF (1982, 1983), Mitchell (1987b), and Henderson (1990). It is therefore not proposed to describe these in great detail in this review.

Three general grazing strategies are available (Michel, 1982).

Preventive procedures

This involves putting only animals which are not a source of contamination onto clean pastures. Clean pastures are likely to be new leys early in the season, and aftermath later in the year. Provided there is sufficient clean grazing available, preventative procedures allow considerable flexibility as dates of turnout and weaning are not critical.

Evasive

In these systems, no attempt is made to prevent pasture contamination early in the season. The animals are turned out onto safe pasture and become lightly infected. Before the pasture becomes dangerously contaminated, the animals are moved to clean or safe pastures. This strategy is limited in that turnout must be after the overwintered pasture contamination has fallen to safe levels; and weaning must be before the mid-season change of pasture.

Dilution

A diluting strategy is based on the premise that if susceptible animals which are a source of contamination graze with, and are sufficiently outnumbered by inert animals (i.e. not susceptible to that particular parasite), the pasture will be seeded by faeces of a low average worm count, and herbage infestations will remain low.

The weather is of prime importance in such systems (Michel, 1982). Annual variations in climate affect the epidemiology of the parasites, by affecting larval survival and egg hatching. The weather can also affect the availability of pasture. For example, drought conditions lead to scarce grazing and may necessitate moving animals back onto a potentially dangerous pasture

5.1.3 Cattle grazing systems

Prevention

Susceptible calves are grazed on new leys, or other clean pasture during the first half of the grazing season.

Evasive

Pasture contamination is not prevented but the calves are moved to clean pasture before there is a risk of disease (usually mid-July before the new season infective larvae build up on the pasture). The calves may be moved twice, in mid-July and again in August, or may just be moved in July and dosed with anthelmintic to reduce contamination of the new pasture. Where there are sufficient silage and hay aftermaths available, the animals can be moved frequently, reducing the need for anthelmintic treatment.

Dilution

Pasture contamination is controlled by dilution. This is generally achieved by grazing beef suckler calves with their immune dams, but can also be achieved through a forward grazing system with the calves grazing ahead of the adult stock.

It has been shown that the egg output of the single suckled calf is no less than that of the hand reared calf, but on pastures grazed by the calves and their dams, large herbage infestations did not arise because the egg output of the cows, which make up a very large part of the grazing force, was very low (Michel, et al 1972). However, if the calves graze together in the absence of the cows, as is normal after weaning, dangerous infestations can arise on the herbage. This hazard is restricted to autumn born calves which are weaned in the summer, and may be avoided by moving the calves every 3 - 4 weeks after weaning.

5.1.4 Sheep systems

Prevention

The epidemiology of helminth infections in sheep is such that clean grazing systems alone are rarely adequate for control so the strategic use of anthelmintics is required (Michel, 1976; Mitchell, 1984; Thomas, 1982; Whitelaw and Fawcett, 1982; Fawcett and Mc Donald, 1988). The timing of lambing is crucial to any control scheme (Michel, 1976). It has been shown that for April lambing flocks in NE England, the standard suckling period of 14 - 16 weeks is just long enough to allow transmission of the parasites from the ewe to the lamb before weaning (Boag and Thomas, 1973).

Where new leys are sown each year the only problem is pasture contamination by the ewe. When clean grazing is available at the start of the grazing season, the general recommendation is that ewes should be dosed with an anthelmintic before moving on to the new pasture (Mitchell, 1983; Taylor, 1995). To further minimise the risks of pasture contamination, an anthelmintic with high efficacy against the arrested stages should be used (Henderson, 1990). For ewes and lambs put onto clean pasture in the spring, the relative benefits of dosing ewes with anthelmintics at lambing, dosing lambs at weaning, or moving lambs to a clean pasture at weaning, were compared either singly or in combination (Boag and Thomas, 1973). If lambs were moved at weaning, there was no advantage in dosing the ewes, but if the lambs remained on the same pasture after weaning, dosing the ewes gave a much greater measure of control than dosing the lambs.

Permanent pasture can be used in a mixed grazing system without conservation (MAFF, 1982). In its simplest form the pasture is grazed in alternate years by cattle and sheep. This does not give a clean pasture for the lambs at weaning, and it is therefore preferable to change over the cattle and lambs in late July (Mitchell, 1987b). However, nematodirus may continue to be a problem. A 3 year study of annual alternate grazing of sheep and cattle demonstrated an increase both in the level of *N.battus* present on the sheep pasture, and in the number of clinically infected lambs (Coop et al, 1988).

Examination of the cattle faeces found that six-month calves passed moderate numbers of *N.battus* eggs in June and July, thus contaminating the next season's sheep grazing. The age of the calves was important as they appeared to rapidly develop an immunity to the parasite and faecal egg output decreased. Even where conservation was included under a three year system involving rotation of cattle, sheep and conservation, it has been shown that *Nematodirus* can persist at low levels for two years (Coop et al, 1988).

Henderson (1990) also suggests that under a system of alternate grazing one species of cattle worm (*Cooperia onchophora*), which can infest sheep sub-clinically, may pose a problem for calves in the succeeding year.

Evasive Strategies

Evasive strategies depend on the availability of clean grazing from mid-season. The effectiveness of this strategy in lambs depends on their weaning date, and the availability of the fresh pasture. The new generation of larvae begin to appear from June onwards in the South of England, and from the beginning of July in the north. Typically, lambs are dosed and moved to the aftermaths, but the timing is critical and should usually coincide with weaning (Taylor, 1995). If the aftermaths are not available until July and August, strategic anthelmintic dosing may be required. Where *Nematodirus* is likely to be a problem, lambs may require dosing in May.

Dilution

Data from the Organic Research Project at ADAS Redesdale and from SAC (Waterhouse et al, 1992) suggest that lambs grazing extensively on hill land carry a very low worm burden and are unlikely to suffer from PGE before weaning. However, Henderson (1990) warns that although sparsely grazed areas may be lightly infected, there may be pockets of better grazing where sheep congregate which can become relatively heavily contaminated. On this basis, it is recommended that all hill lambs should be drenched at weaning (Henderson, 1990)

Research work on mixed grazing systems, where cattle and sheep graze concurrently on the same pastures, has shown production benefits to both species within a 40:60/60:40 grazing mix (Nolan, pers. comm.). Whilst there may be some effect in diluting parasitic burden (Mitchell, 1996), the main reason for improved performance is the complementary grazing habit of both species, each avoiding areas around their own faecal deposits, but being less averse to grazing close to those of the other species. This results in an overall increase in the efficiency of herbage utilisation. For controlling parasitic gastro-enteritis in sheep, mixed grazing systems are not effective (Henderson, 1990). The complementary 'hoovering' effect of each species has insufficient impact on infection rate, particularly for the sheep component in the mix.

5.2 Lungworm

Grazing strategies alone are not totally effective in the control of lungworm because of the unpredictable nature of the disease (Taylor, 1995).

Routine use of anthelmintic is claimed to protect calves against lungworm during the grazing season. However, if there is no exposure to lungworm larvae, immunity will not develop and animals exposed to larvae at the end of the season, when the anthelmintic activity has waned, will not be protected. This is a topic still under investigation.

For the past 30 years, the main method of control of lungworm has been through vaccination. The vaccine contains irradiated third-stage infective larvae and is given to calves by mouth as two doses four weeks apart prior to turnout. Immunity is boosted by repeat exposure to infective larvae throughout the grazing season. The vaccine is adversely affected by anthelmintic dosing, and the interval between vaccination and worming is specified in the datasheets, and may be as long as 14 days with the avermectins (Veterinary Data Sheet Compendium, 1995). However Jacobs et al (1996) showed that calves did manage to develop immunity even when treated with a sustained release anthelmintic bolus containing febendazole.

There is increasing evidence (Anon, 1996b) that failure to vaccinate cattle against lungworm may be increasing the animal's susceptibility to this disease in the later stages of life. A report by a vaccine manufacturer (Intervet) showed that there was a decline in usage from over a million doses a decade ago to 330,000 in 1990 and 250,000 doses in 1993. Reports by the VIDA (Veterinary Investigation Diagnosis Agency) indicate a rise of 93% in reported outbreaks during 1993 compared to 1992 - 75% of these outbreaks were in adult cattle (Anon, 1996b). It was suggested that the susceptibility of adult animals is increasing because farmers are relying solely on the latest range of anthelmintics without realising that this is reducing the general level of lungworm immunity in their herds.

5.3 Liver fluke

The presence of liver fluke tends to be associated with specific geographical areas, particularly the wetter areas of the north and west. Where liver fluke is present on the farm, a measure of control can be achieved by drainage or by excluding grazing livestock from areas infested by the snail (Dunn, 1978). Between 1975 and 1985 the removal of intermediate host sites by drainage and restricting stock access was claimed to have reduced liver condemnations by 42% and 50% in GB and Ireland respectively (Sykes, 1984). However, it can be difficult to identify all such habitats, and would be impractical on many upland farms due to the large areas affected (Fawcett, 1990). The incidence of liver fluke disease is highest in autumn and winter, and by keeping the stock off the wettest fields at this time of year, the disease incidence can be reduced (Taylor, 1987).

The incidence of liver fluke is affected by the climatic conditions, and a wet spring and early summer predisposes to a rapid increase in the snail population and a good hatch of fluke eggs, leading to large numbers of infected snails. Dry weather over this critical period will prevent the snails breeding and will kill many fluke eggs (Dunn, 1978).

MAFF used to provide a fluke forecast annually, so that anthelmintic treatment could be varied according to the predicted threat of disease. Unfortunately, this service has been discontinued.

Control of acute fluke disease without the use of flukicides would be very difficult (Eales, 1990). While anthelmintics may be used to treat both acute and chronic fascioliasis, they can also be used strategically in the spring to prevent the summer infestation of the snail (Taylor, 1995). Two treatments are given, in March and May, to prevent significant pasture contamination with fluke eggs. Triclabendazole is the drug of choice because of its high efficacy against immature fluke stages.

5.4 Clean grazing without using anthelmintics

From the evidence presented above, the prospects for further reducing or eliminating the use of anthelmintics is greater for cattle systems, particularly for single suckled beef herds, than for sheep. This is primarily because of the potential contaminating effect of the ewe in early lactation. In the UK, several experiments have looked at eliminating anthelmintics for organic sheep production.

Within an extensive hill system, Waterhouse et al (1992) tried to make use of differential stocking densities between the native hill and improved grazings in an attempt to control stomach worms in lambs. Two grazing strategies were investigated;

- *E* : Ewes and lambs were transferred from lambing parks to hill grazing on 20 June thus reducing stocking rate to less than one ewe per hectare.
- *L* : Ewes and lambs were retained on improved land until 29 July when they also went to the hill. The sheep stocking rate during the period 20 June till 29 July was reduced by half by the removal of the E group of ewes and lambs.

Lamb liveweight and blood pepsinogen level at weaning were very similar for both groups, indicating that single lambs on the hill carried very low worm burdens and did not suffer from parasitic gastro-enteritis. However, the lambs were sold at weaning before parasitic challenge increased significantly.

Under more intensive hill conditions, Keatinge and Merrell (1994) showed that drenching ewes around lambing significantly reduced worm burden in lambs, which were not drenched during the grazing season, despite being retained for further finishing. In one year, a large proportion of lambs were finished without any anthelmintic input to ewes or lambs. However, significant worm burdens built up in tail-end lambs and in replacement hoggs. Both groups required drenching. These results suggest that even in a hill system, eliminating the use of anthelmintic drenching is difficult unless some sort of clean grazing is practised and/or the lambs are sold off the farm at weaning.

Mitchell et al (1992) adopted an evasive strategy to control stomach worms in a late (May/June) lambing crossbred flock. No anthelmintic was used. Ewes were put onto clean pasture for lambing and for the first 7 weeks of lactation. One group of ewes and lambs were transferred on 19 July to clean aftermath grazing. The second group of ewes and lambs remained on contaminated pasture. The trial ceased at the end of August. Although lambs transferred to aftermath grazing had significantly higher growth rates, by August there was no difference in parasite burden between both groups.

From New Zealand, Niezen et al (1996) reported two systems studies where alternate grazing of sheep and cattle was used in an attempt eliminate the need for drenching organic stock. The first of these, looking at worm control within a mixed farming system was undertaken at Flock House Experimental Station. Parasite control was achieved solely by alternating sheep and cattle grazing. The grazing area was divided into two blocks. From weaning until lambing the ewes were set stocked in one block, and lambs/cattle grazed the other. At lambing the ewes were moved to the block grazed by cattle, and visa versa. Ewes and lambs were moved monthly between paddocks from lambing until weaning, when the lambs entered a grazing rotation with finishing cattle or yearlings. Weaned lambs were moved every 7-14 days, and did not re-graze paddocks for at least 60 days. During this interval, the paddocks were grazed by cattle. Ewes were bred to either nematode resistant, or non-resistant rams.

Over two grazing seasons, larval contamination on the pasture remained low (> 100 larvae per kg fresh herbage). During one period where larval challenge exceeded this level, progeny of parasite resistant rams recovered more quickly. The role of the cattle was mainly to support parasite control in the lambs. In the second year, all (yearling) cattle were drenched.

A second study was conducted on a hill country farm at Ballintrae on pastures dominated by Agrostis tenuis. Two 25 ha farmlets were used to compare conventional and organic management. For the organic stock, similar strategies were used as at Flock House. Cattle to sheep ratio was 42:58, and grazing management was the only method of parasite control in organic animals. The conventional stock were drenched 5 times during the course of the year. All lambs were sold at weaning, therefore a low proportion of susceptible lambs were on the unit during the main period of larval contamination.

Acceptable levels of sheep production were achieved using little or no anthelmintic. However, this again was at the expense of cattle performance, possibly because of the longer retention time of nematode larvae in the cattle dung pat. Live weight gains of replacement ewe lambs from the organic flock tended to be lower, faecal egg counts were higher and the lambs were lighter at 12 months than conventionally managed stock. In the first year 24% of these lambs required salvage drenching, but this had fallen to 6% by the third year. Organic hoggs grew better during the following season, and were heavier at 24 months than conventional sheep. This is consistent with findings from the organic project at ADAS Redesdale (Keatinge and Elliott, 1994, 1995).

5.5 Commercial exploitation of clean grazing systems

Although the benefits of clean grazing have been well documented and promoted by research and extension bodies such as ADAS, SAC, Agricultural Colleges, Universities etc., only a minority of livestock farmers practise a clean grazing system.

The difficulty associated with promoting greater uptake of clean grazing was exemplified by the results of an ADAS- run 'Clean grazing advisory project' for beef and sheep in Nottinghamshire, Derbyshire and Leicestershire (Emmerson, 1983). Following a three year campaign to create awareness and provide information, including the monitoring of 6 commercial farms, a disappointing 66% of the farmers surveyed did not practice clean grazing (Table 2).

Table 2 Farmer survey of clean grazing practices following an ADAS promotional programme in the East Midlands (1981-1983)

Percentage of farmers questioned (of 170 respondents)			
Usually practising clean grazing	First time in 1983	Planning to change	Not practising
20	9	5	66

Such was the estimated cost/benefit of adopting a clean grazing system, that the cost of running the project would have been recouped if only 0.5% of farms adopted the system. The inflexibility of clean grazing systems and a perceived conflict with efficient grassland utilisation were frequently cited as factors against establishing a system of clean grazing. Worm control by clean grazing systems alone is rarely practical on many units because of the limited flexibility of the pasture available (Anon, 1993).

More recently, Davies et al (1996) reviewed the effectiveness of technology transfer and the degree of commercial uptake of grassland R&D. Clean grazing was again cited as a failure in terms of uptake by farmers. Factors such as the layout of the farm, rotational practices, and the location and availability of cutting fields were implicated in reducing the appeal of clean grazing systems.

It also seems reasonable to suggest that the availability of effective anthelmintic drenches simplifies management and makes livestock producers reluctant to change their whole system in favour of one enterprise. Where the arable rotation provides some clean grazing, farmers are happy to use this to advantage, particularly for more vulnerable classes stock such as ewes rearing twin lambs. With greater awareness of the potential for anthelmintic resistance, conventional farmers may become more receptive to methods of reducing their reliance on anthelmintic treatment.

Organic producers on the other hand might be expected to be acutely aware of the need to avoid the use of anthelmintics, and to seek suitable alternatives. However, a survey by Kintail (1991) of Scottish Organic Producers found a surprisingly limited use of clean grazing - 59% of sheep flocks, 63% of suckler herds and 92% of dairy herds usually grazed the same fields as the previous year.

5.6 Role of clean grazing systems on organic farms

There is a significant, but limited, amount that can be done to control liver fluke through drainage, fencing and grazing management. Where lungworm is a problem it is difficult to control through management alone, however an effective vaccine is available which is permissible within the standards for organic production.

For roundworms, a well planned and conscientiously implemented clean grazing system offers by far the best method of reducing the risk of parasitic gastro-enteritis on organic farms. The current ground rules have been clearly established, and are available to organic producers through the various advisory services. However, there are considerable limitations, particularly on all sheep farms.

Parasite control through clean grazing requires diligent husbandry and attention to detail (Daw, 1990; Niezen et al, 1996; Rhodes, et al 1996). The lower stocking rates and more mixed farming systems generally found on organic farms suggest that implementing a clean grazing will be easier than on many conventional farms. However, the ideal infrastructure is rarely found even on organic farms, and almost never on extensive hill farms. Taking account of these limitations there is evidence for the use of 'partial' clean grazing systems on at least some organic farms.

Mixed organic farms are most likely to have the best opportunity to organise and maintain a clean grazing system. Most hill farms have either all sheep or very many more sheep livestock units than cattle, making clean grazing of permanent pasture virtually impossible (Henderson, 1990; Newton, 1993). Here the only options are to rely on a dilution effect at low stocking rates, the sale of lambs at weaning, or preferentially giving ewes rearing twin lambs priority for any cleaner grazing that might be available.

A system of alternate grazing of sheep and cattle was only moderately successful without the use of anthelmintics under New Zealand conditions. Under UK conditions there will be continuing risk from *Nematodirus*. Unless overall stocking rates are very low, mixed stocking of cattle and sheep on the same pasture alone will not achieve sufficient control of stomach worms, especially in sheep. In the tropics, a system of rapid paddock rotation has been shown to provide some parasite control (Le Jambre et al, 1995). However, both systems rely on complex and rigid grassland management which would be unacceptable to most practical farmers.

With clean grazing systems as currently practised, it is difficult to see under practical conditions how a system can easily be devised to eliminate all use of anthelmintics. For organic sheep systems, the use of anthelmintic before stock are put onto clean grazing can critically delay the gradual increase in parasite burden which inevitably tends to occur. Devising a system which eliminates the requirement for anthelmintic would almost certainly rely on combining a clean grazing approach with other factors in an integrated disease control programme. Some of these factors are considered in the following chapters.

6.0 Factors affecting the development of disease

A number of factors can have marked effects on the ability of an animal to deal with helminth infection. These include, hypersensivity (self-cure), age, specific immunity, infestation with other parasites, bacterial or viral infections, stress and nutrition. Such factors often act concurrently.

6.1 Immune response

In spite of intensive research, knowledge of how immune mechanisms act to cause parasite expulsion is still fragmentary (Rothwell, 1989; Windon, 1991). Resistance mechanisms responsible for protection against parasites may vary between individuals of an outbred population, in response to different stages of the parasite lifecycle, and for different parasite species (Rothwell, 1989).

Infection with gastro-intestinal nematodes and exposure to their numerous antigens generates a complex immune response by the host (Wakelin, 1985), both against ingested larvae and the resident adults. A great deal has been learned about the multiple humoral and cellular immune responses that are stimulated during infection (Rothwell, 1993). However, it is still not clear which of these responses are actually protective, and how they interact to achieve parasite expulsion from the digestive tract.

A non-specific inflammatory response follows primary exposure, but longterm regulation is achieved through acquired immune systems (Gruner, 1991). Stear et al (1995a) suggested that variation amongst mature sheep in faecal egg output was due at least in part to local IgA responses which retard parasite development and regulate worm fecundity, and to variation in local immediate hypersensitivity reactions which resist the establishment of incoming 4th stage larvae.

Resistance is acquired after a number of antigenic stimulations. The speed of acquisition and it's efficacy in terms of expulsion of worms present in the digestive tract and delayed development of new larvae, depend on the individual host. Development of immunity has both age and experience components. Naive lambs under 5 months of age mount a less effective local immune response than older lambs. Coop et al (1995) suggested that young lambs may partition available nutrients more towards growth and the repair of gastrointestinal tissue (as a result of parasite attack) at the expense of the immune response. The ability to mount an immune response has improved markedly by 12 months of age, although it may take 2 years for full resistance to be achieved.

The speed and efficacy of acquisition of resistance also depends on the species of parasite. Young lambs acquire a good resistance against *Nematodirus spp* after 2-3 months grazing on infected pasture. Lambs can develop good protection *against H. contortus* by the age of 4 months, whereas 8 months may be required against *T. circumcinta* and *T. colubriformis* (Gruner, 1991). Six month old lambs after 8 weeks of daily dosing with 1000 larvae of *T. vitrinus* showed almost total resistance to the establishment of incoming worms (Seeton et al, 1989). This does not suggest that older animals are entirely immune, particularly if underexposed to previous infection.

Development of immunity to lungworm can occur within weeks, but is very weak for liver fluke, especially in sheep (Sykes, 1984). Immunity to *Haemonchus*, is also weak and short-lived (Gray, 1991). Immunity may be lost after treatment with anthelmintic , and adult ewes and rams may suffer severe haemonchosis in the face of sufficient challenge (Henderson, 1990).

It is thought that pharmacologically active substances are released into the parasite microenvironment as a result of the immune response (Rothwell, 1993), and that these substances interfere with processes within the parasite which are crucial for their survival. The mode of regulation is not the same for every species of worm (Gruner, 1991). For *T. circumcinta*, as the number of fourth stage larvae increase there is a density dependent regulation of the number of eggs laid per female. Thus egg output becomes a poor reflection of infection. For *T. colubriformis*, *T. axei* and *T. vitrinus* higher numbers of worms mitigate against establishment of further infection. As a result, total worm burden plateaus, as 3rd stage larvae accumulate and older adults are expelled. Final expulsion of worms is preceded by reduced faecal egg output and a decline in the number of eggs in utero of female worms. In the case of *H. contortus*, there is a good correlation between egg output and worm burden. With a new infection there is a rapid expulsion of adult worms, a decrease in faecal egg output and a rapid development of the new population. For *O. circumcinta*, worm length is strongly correlated with the number of eggs in utero, and both are a measure of worm fecundity (Stear et al, 1996). Genetic variation among 3-6 month old sheep in faecal egg counts following natural infection is largely due to variation in average worm fecundity rather than to variation in worm burden (Stear et al, 1996). Due to these differential strategies, egg output is not always related to worm burden (Henderson, 1990; Stear and Murray, 1994) and the recognition of the level of resistance is not the same for each species (Gruner, 1991).

Immediate hypersensitivity responses appear to be the most important variables that regulate worm burdens in Ostertagia (Stear et al, 1996). Sheep may develop IgA responses that regulate worm fecundity, before they develop effective hypersensivity responses that regulate worm burdens (Stear et al, 1996).

The level of immunity acquired initially may also be subject to change. Increases in nematode faecal egg output are well known in ewes from the last month of pregnancy until 3-4 months of lactation (Gruner, 1991; Sykes, 1994). Intensity of lactation is the main influencing factor, but does not appear to be affected by the concentration of one particular hormone. The transfer of effector cells and antibodies from the gastrointestinal tract to the mammary gland may also be a factor (Stear et al, 1996). Higher egg counts are also found in stressed ewes, such as those rearing twins , which also have a higher intake of herbage and infective larvae. Stressed and undernourished hill ewes may be particularly susceptible to clinical parasitism (Henderson, 1990).

In *H. contortus* infection, protection is more effective against a challenge infection if a moderate worm burden remains (Gruner, 1991), and protection may be lost after anthelmintic treatment, or following treatment with immune-suppressing corticosteroids (Gray, 1991).

6.2 Protein and energy status

Worms in the small intestine cause enteritis which seriously reduces the efficiency of digestion and the absorption of nutrients. The presence of large numbers of developing worm larvae in the stomach lining causes a gastritis which destroys cells which produce gastric juices and enzymes which carry out the initial digestion. Hence the term parasitic gastro-enteritis (PGE), used to describe the clinical effects of helminth infection.

However, it is not the digestion of food which is considered to be the main impact of parasitic infection (Sykes, 1984), but the marked reduction in feed intake. This can be as great as 10-15% following moderate infection with roundworms (Henderson, 1990).

As a result of infection, considerable quantities of host protein may be lost into the digestive tract (Holmes 1993). Some resorption can occur, depending on the site of parasite infection, but in mixed infections affecting both the abomasum and small intestine, N losses are high. The repair of damaged gastrointestinal tissue and increased mucus and plasma protein secretion into the tract increases body protein synthesis, reduces the efficiency of metabolisable energy, and may result in an induced protein deficiency. Reduced feed intake is exacerbated by the reduction in feed conversion efficiency (Sykes, 1984), which is most severely affected by intestinal as opposed to abomasal infections.

Where lambs are unfed, particularly where protein levels are low, the effects of parasitism may be exaggerated (Henderson, 1990). Bown et al (1991) found that the debilitating effect of infection could be greatly reduced by increasing the protein supply to the duodenum. Holmes (1993) reported that lambs on a low protein diet were less able to withstand the pathophysiological consequences of infection with *H. contortus*, but that the diet had no apparent effect on parasite establishment. The performance of genetically resistant and genetically susceptible animals was also compared. While a high protein diet could overcome the disadvantages of reduced genetic resistance, at least under moderate levels of infection, genetic superiority was not compromised by a low protein diet. Protein rich clover pastures may reduce the severity of roundworm infection (Mitchell, 1996). However, for lambs grazing grass or grass/clover swards, Vipond et al (1994) observed that the development of immunity was dependent on the level of parasite challenge, but was not affected by the level of dietary protein.

Protein supplementation has been shown not only to reduce the pathological effects of haemonchosis, but also to improve the development of immunity in susceptible sheep (Sykes, 1984; Coop et al, 1995; Wallace et al, 1994, 1996). Lambs have been shown to respond to infection by *T. colubriformis* by selecting a higher protein diet (Kyriazakis et al, 1994). Stear et al (1996) suggested that immunosuppression could also result from a low protein diet.

General malnutrition has a debilitating effect which can predispose to heavy worm burdens. In the USA, introduction of measures to control liver fluke infestations was of greatest benefit on ranches where the cattle were subjected to substantial nutritional stress during the winter. Within the feral Soay sheep population in St. Kilda, which outgrows it's food supplies every 3-4 years, mortality is most severe amongst the heavily parasitised sheep (Stear et al, 1995).

Optimal nutrition however, does not offer protection against overwhelming numbers of some worms, and haemonchosis may cause heavy losses when nutrition is excellent but environmental conditions favour massive infestations.

6.3 Mineral status

Worms seriously interfere with water regulation and mineral balance, resulting in diarrhoea, weight loss and a characteristic 'wet' carcass in heavily parasitized animals (Henderson, 1990). The skeleton may be improperly mineralised, further stunting growth (Sykes, 1984). Changes in the intestinal tract have been shown to interfere with mineral absorption in the case of phosphorous, copper, and possibly calcium, (Sykes et al, 1988). Suttle (1992) suggested that normally efficient recycling of sodium could be impaired by worm infestations, especially if the infection resulted from a mixed population of abomasal and intestinal nematodes.

Evidence for an effect of trace element status on the establishment and severity of parasite infections is ambiguous (Sykes, 1994). A dietary deficiency of a specific nutrient such as cobalt, copper, or phosphorous can lead to a reduction in the animal's resistance. Ferguson, et al (1989) concluded that cobalt-deficient lambs exhibited a non-specific immune unresponsiveness in the face of challenge from *Ostertagia.* Similar problems occurred in the cobalt-depleted lambs after a lag period during which, presumably, the cobalt reserves were exhausted. However, it has been shown that *H. contortus* may develop better in sheep fed a cobalt supplement than in those on a cobalt deficient diet, suggesting that there may be differences between parasite species in their reaction to specific levels of minerals.

6.4 Other infections

Catchpole and Harris (1989) infected 3 - 5 week lambs with single infections of either 5,000 oocysts of each two species of coccidia, *Eimeria crandallis* and *E. ovinoidalis*, or with 30,000 infective larvae of *N. battus*. These lambs developed only a transient diarrhoea with no effect on growth. By contrast, lambs infected first with coccidia and then two weeks later with *N. battus*, suffered from severe diarrhoea and weight loss, and some of these lambs died. Other lambs challenged by simultaneous administration of coccidia and nematodes showed increased clinical severity of the syndrome and increased numbers of nematode eggs produced.

6.5 Implications for organic systems

Promoting health and development of the natural immune system, through the use diets balanced for energy, protein, minerals and trace elements, the avoidance of stress and concurrent disease, are inherent requirements of organic management.

The evidence presented above, particularly in the case of protein, is further validation of the practical value of this approach to maximise an animal's ability to fight parasitic infection. While conclusive proof has not been provided, the use of high clover swards could be expected to confer some benefits to organic stock, particularly for lambs after weaning.

7.0 The use of genetically resistant animals

The consequences and severity of parasitic infection depend on an animal's innate resistance, resilience or acquired resistance to that particular infection (Emery and Wagland, 1991).

Innate resistance occurs because of biochemical or physiological properties of the host which are unsuitable for the parasite (Gruner 1991), but this is not thought to be a factor in governing nematode infection in sheep (Windon, 1991). **Resilience**, is described as the ability of a host to mitigate the deleterious effects of parasitism, and still maintain reasonable levels of production. **Resistance** is defined as the ability of an animal to suppress establishment and/or subsequent development of worm infection (Gruner, 1991). Resistance, or acquired immunity, develops in response to infection or vaccination.

Resistance (generally measured by faecal egg count) is more highly heritable than resilience (measured by the loss in production during infection) and the two traits are favourably correlated (Bisset and Morris, 1995; Woolaston and Piper, 1996). Most research has therefore concentrated on genetic resistance.

7.1 Variation in genetic resistance

The existence of genetically controlled host resistance in sheep to nematode parasites has been known for many years (Stewart et al, 1937). There is substantial evidence for variation **between breeds** in resistance to *H. contortus* and *O. circumcinta*, and to a lesser extent *Trichostrongylus spp.* (Gray, 1991). Scottish Blackface sheep have been shown to be less susceptible to reinfection with *H. contortus* compared to the Dorset Horn (Taylor, 1987). However, for *T. axei* the situation is reversed, and Dorset Horns show more resistance than do Scottish Blackface sheep. Florida native ewes have been shown not to undergo a periparturient rise in faecal egg output when compared to Rambouillet crosses (Courtney et al, 1984).

Variation **between strains** of single breeds, is less easy to prove (Gray, 1991) due to the difficulty in establishing flocks in which proper genetic comparisons can be made.

Notable variation in resistance also exists **within breeds**. Between sire differences can be as great as the largest between-breed differences in resistance (Gray, 1991). Groups of animals exist which are classified as "high" and "low-responders" as shown by the considerable variation which is evident in faecal egg output from individual animals within a group. Estimates of the heritability of resistance to *H. contortus*, *T. colubriformis*, *O. circumcinta* and *Nematodirus spp.* range from 0.2 - 0.5 (Barger, 1989; Windon, 1990; Gray, 1991; Stear and Murray, 1994). With the diverse gene pool and sheep breeds that exist within the UK there is scope to develop work on breeding for genetic resistance to helminths (Hughes et al, 1994).

7.1.1 Measuring genetic resistance

Differences in worm burden could result from differences in grazing behaviour, as well as the efficiency of host responses to infection. In order to exploit the existence of genetic resistance within a population, an accurate method of identifying more resistant individuals is required. Several methods have been used;

Direct methods

For a given species of parasite, pathological effects depend on the number of worms present. No estimation of immature worm burden is possible without slaughtering the animal. While Hughes et al, (1994) suggested that plasma pepsinogen may be a better indicator of resistance than faecal egg count, pepsinogen level in the blood only gives estimation of the worm burden in the abomasum. Following deliberate infection with *O. circumcinta*, Stear et al (1995b) reported that faecal egg count was the most strongly correlated with worm burden compared to peripheral eosinophil counts and plasma pepsinogen concentrations. The three variables together accounted for half the variation in worm burden. It was concluded using the three variables concurrently could improve the identification of resistant and susceptible lambs.

Egg and larval outputs are the easiest parameters that can be measured. In different situations, these counts represent the mature worm burdens. Within a flock of sheep, nematode worm burdens exhibit a negative binomial distribution i.e. a relatively small proportion of the host population harbours a relatively large proportion of the parasite population. Manipulation of this within breed variability by selection aims to reduce the numbers of susceptible animals such that the overall resistance of a flock can be increased. Resistant dams also have a far less contaminating effect on the pasture through their own faecal output, which in turn reduces the parasitic challenge in the lambs (Grey, 1991). A mere 10% of lambs may be responsible for 50% of eggs produced (Stear and Murray, 1994).

Currently the most effective method of assessing the likely resistance of an animal to nematode infection is to allow the animals to become naturally infected (or to artificially infect them) and then to measure the response in terms of faecal egg output. (Gray 1991). There is some evidence that lambs need to be primed by an initial infection before genetic resistance can be adequately detected (Gray, 1991; Windon, 1991) and that greatest weight should be given to estimates from naturally occurring infections if the aim is to increase on farm resistance.

Stear et al (1996) reported that genetic effects accounted for only 20% of the total variation in faecal egg counts in a flock of Scottish Blackface sheep. Other factors were: environmental effects, 14%; measurement error , 28%; unexplained, 29%; egg count at 2 months, 4%; sex, 2% and date of birth, 1%. In this work, the heritability of single egg counts increased from 0.12 at 3 months to 0.22 at 6 months of age. Measurements based on a single egg count are very variable, and heritabilities can be significantly improved by taking the average of several faecal egg counts across time (Bishop et al, 1996).

Egg output is also important as it measures contamination of the pasture which in turn determines the level of infection to which the flock is exposed. However, the process is labour intensive and only enables rankings within each flock or management group.

When selecting their own flock replacements, some UK organic farmers have adopted a selection strategy based on avoiding animals that have scoured. The assumption is that these animals are more susceptible to roundworm infection. However, the association between faecal egg count and dag score ('dirtiness') is not always favourable, suggesting that some forms of host response may result in immunopathology (Suttle, 1994; Bisset and Morris, 1995). Selecting on the basis of minimal symptoms may in fact be selecting for resilience.

Hohenhaus and Outteridge (1995), used a specific antibody assay to identify lambs which were more resistant to *T. colubriformis* and *H. contortus*, and this technique is being used routinely in New Zealand. The heritability of antibody titres was high (0.37-0.56), and may be more accurate than faecal egg counts in predicting levels of resistance.

Indirect methods

Numerous parameters have been measured in an attempt measure the potential for host resistance to internal parasite (Windon, 1990). These have included haemoglobin type, anaemia, lymphocyte blastogenic responses, overall productivity, presence of dags, blood eosinophilia, skin sensitivity and blood lymphocyte stimulation by parasite antigens. However, the results to date are inconclusive.

A wide range of immunological functions are under genetic control (Windon, 1991). Relatively little is known about the mechanism by which resistant hosts are able to express or inherit their resistance (Barger, 1989). It may be that resistant hosts are able to mount an earlier or faster response to the parasite than susceptible animals. Given the moderate heritabilities of resistance, and the complexities of the immune system through which resistance operates, it is reasonable to assume that the trait is under polygenic control (Barger, 1989).

Considerable attention has been directed at the involvement of genes linked to the Major Histocompatibility Complex (MHC) in controlling responses to infection (Hohenhaus and Outteridge, 1995). This interest arises from the well established role of MHC-gene products in the regulation of T-cell function, and the predominantly T-dependent nature of antihelminth immunity (Wakelin, 1985). Some studies have shown a combination of the ovine lymphocyte antigen (OLA) to be associated with resistance to *T. colubriformis* (Outteridge et al, 1985, 1988) but this was not extended to *H. contortus* (Hohenhaus and Outteridge, 1995).

While some of the variation in response to infection appears to be attributable to genes at or near the sheep MHC, genes outside the MHC also appear to play an important part in expelling parasites from the intestine (Cooper et al, 1989; Hohenhaus and Outteridge, 1995). In one example of highly resistant stock, the progeny of a single sire, a single major resistance gene could not be identified (Gray, 1991).

Simple genetic markers have so far been as elusive as physiological traits that predict resistance (Woolaston and Baker, 1995). A role for the MHC in selecting for increased production or disease resistance may be premature (Stear and Murray, 1994). However, Stear et al (1996) reported an allele within the DRB1 locus of the ovine MHC which had a major effect on faecal egg count for *O. circumcinta* in Scottish Blackface sheep. This test is currently being validated in other flocks. More work is needed to identify other genes to allow marker assisted selection. Restriction fragment length polymorphisms i.e. genetic probing, is likely to play an increasing role in this process.

7.1.2 Correlations with productive traits

It has been suggested that selective breeding for disease resistance would result in reduced productivity. However, there is substantial evidence to counter this argument (Windon, 1990).

Cattle bred for high fertility and high growth rates in tropical Australia have been shown to be less resistant to worm infections (Gray, 1991), but more resistant to tick infection. The effect was greater in *Bos indicus*, which had higher levels of resistance to both parasites, than in *Bos taurus*. It was concluded that in heavily parasitized environments susceptible breeds have more to gain by reducing the pathogenic effects of disease, which in turn may improve growth rate and fertility. However, as selection progressed towards resistance, the gains from having fewer parasites are less and the true genetic relationship, for example, with fertility is revealed.

In sheep, correlations between parasite resistance and reproduction are few and variable (Gray, 1991). Bishop et al (1996) noted considerable inconsistency amongst reports of genetic correlations between faecal egg counts and production traits. Stear et al (1996) showed a large negative correlation (-0.85) between growth rate and faecal egg count, indicating that selective breeding for resistance to *Ostertagia* could be desirable to improve performance. Bishop et al (1996) recommended that faecal egg count and liveweight should be monitored in any selective breeding scheme, especially if the level of parasite exposure varied between years.

In the UK, a successful breeding strategy would need to be based on a weighted selection index incorporating other desirable traits in addition to parasite resistance.

7.1.3 Resistance to other diseases

In sheep, there is little hard information on the effect of increasing resistance to one disease on susceptibility to another. It is reasonable to assume that stock selected for resistance to one disease, will not necessarily be resistant to another. From the cattle study mentioned earlier, there was a negative correlation between resistance to ticks and resistance to worms (Gray, 1991).

The importance of particular associations between resistance to nematodes and susceptibility to other diseases will not be relevant in all environments depending on the occurrence and significance of each disease (Windon, 1991). The overall lack of positive correlations among immune traits, and the possibility of some negative correlations, may mean that conventional selection methods are not appropriate. Theoretically, selection for resistance to one organism could focus on particularly limiting mechanisms and upset overall immunological equilibrium.

7.1.4 Specificity of resistance

Selection for improved responsiveness against one species can lead to greater responsiveness against other nematodes (Windon 1990). However, the degree of cross protection may depend on the nature of the parasite as well as the physiological mechanisms invoked for immunological control.

7.1.5 Potential of the parasite to adapt

Nematodes have demonstrated their ability to rapidly adapt to the single mode action of anthelmintics, resulting in resistant strains of nematode. It might not be unreasonable to expect that parasites could respond to other selection pressures, including protective host responses. Potential mechanisms of adaptation could involve a convergence in antigenicity between host and parasite, immunological tolerance of a particular parasite antigen, or the masking of parasite antigens by host proteins (Windon, 1991).

For a given population of worms within the gastrointestinal tract, some individuals are rejected earlier than others (Windon, 1991). This suggests that within the parasite population, individuals are capable of surviving and reproducing in the face of severe host responses. If host resistance operates through a variety of mechanisms and is under polygenic control, selection pressure would be less intense. On the other hand, if resistance were based on a major gene, parasite adaptation could occur more rapidly.

Albers and Burgess (1988) serially passaged a specific strain of *H. contortus* through resistant and susceptible sheep for 6 and 9 generations respectively. No significant difference was found between the infectivity of passaged strains. This suggests that parasite adaptation to improved host resistance is not a major risk.

7.2 Breeding programmes for genetically resistant sheep

The usefulness of resistant genes present in different breeds depends very much on the breed being used and the nature of the product (Gray, 1991). Therefore, substituting one breed for another more resistant breed will be viable only where the economic loss due to parasitism is high relative to any penalty in terms of output potential. There is anecdotal evidence , for example, that lambs sired by Texel rams scour less that other breeds. Similar observations have been made in New Zealand. However, even if such effects are proven, changing terminal sire to a more resistant/resilient breed does not reduce faecal egg output by the dam.

For an individual sheep, the outcome of exposure to infected larvae is to acquire a burden of worms, and it should be possible to rank sheep according to their worm burden from the most susceptible to the most resistant. In contrast to other diseases of sheep such as footrot or blowfly strike, resistance to worms is not an all or nothing trait. The objective in a breeding programme may be to progressively reduce worm burdens to a level at which the cost of treatment, control and lost production is acceptable.

Several long-term breeding programmes for resistance to nematodes have been established in Australia and New Zealand. In all cases selection has been on the basis of faecal egg count. Broadly these have similar objectives (Windon, 1990). Most of these experiments had the dual aims of creating a resource for studying physiological mechanisms of resistance and of assessing feasibility of including resistance in a commercial breeding goal.

In Australia, several Merino lines have been successfully established (Windon, 1990) with increased resistance to *H. contortus*, *T. colubriformis* and *O. circumcinta.* Experiments have also been carried out on selection against mixed infections in Merinos, and in other breeds of sheep.

Reductions of 85-90% in infection rate by *T. colubriformis* were reported by Windon (1991) in resistant lines of sheep. Under Australian conditions, Piper and Barger (1988) developed an economic threshold for each parasite, defined by the minimum number of worms likely to cause economic loss. The relative importance of each of these species changed according to climatic zone, each of which for the purposes of breeding for parasite resistance would have a different breeding objective. These authors also estimated the gains which could be made by including resistance in sheep breeding programmes. In a typical Merino flock the net gain was estimated to be 10%. In the absence of parasites the gain was very small increasing as parasitic burden increased. In a computer simulation, genetically resistant lambs required treatment with anthelmintics less frequently and resulted in a lower level of pasture contamination (Windon, 1990). Larval populations developing on pastures grazed by resistant sheep may be less than one third of those when grazed by non-resistant sheep (Barger, 1989). Under Australian conditions, the greatest pressure for breeding programmes which include resistance may not come from marginal economic gains but from potentially catastrophic losses which might occur if anthelmintic were to fail completely.

Lines of Romney sheep selected for low faecal count have also been established in New Zealand (Steifel, et al 1991). However, the inclusion of resistant genes has not shown conclusive advantages (Niezen et al, 1996). However, this may be related to the prevailing parasitic challenge (Steifel, et al 1991). Interest has recently been renewed in selecting Romney sheep for resilience (Bisset and Morris, 1995).

It should be feasible to include resistance to internal parasites in a multi-trait breeding programme (Woolaston and Piper, 1996). Commercial breeding programmes for sheep which include resistance to gastro-intestinal roundworms are now operating in Australia and New Zealand (Woolaston and Baker, 1995). Apparently farmer interest has been high, despite the new technology and the unanswered questions which remain.

7.3 Relevance for organic systems

Genetically resistant animals are the ideal mechanism for improving the ability of organic stock to withstand challenge from internal parasites. Even in the absence of major genes for resistance, the observed heritabilities of resistance and the effects of parasitism on production are sufficiently large that selection for resistance could still be commercially attractive. The most susceptible or resistant individuals keep their status all their lives. Neither should overall productivity be reduced under a properly constructed selection programme. Parasite resistance is now incorporated into selection indices in commercial breeding programmes in Australia and New Zealand.

More rapid progress can be made by concentrating on selecting for resistance within the male line. This could be done on crossing sires such as Bluefaced Leicester, or on terminal sires e.g. Texel and Suffolk. Ideally, a selection index is required which would weight economically important traits, as well as disease resistance. Most sheep farms in the UK do not record individual performance. However, there are several sire referencing schemes in operation, predominantly for terminal sire breeds, into which selection for resistance to roundworms could be incorporated.

Many organic flocks are closed, i.e. they breed their own flock replacements. This could provide the opportunity to choose more resistant individuals, under selection pressure from parasites specific to that farm. Just as important is increasing the genetic resistance of the flock, is the removal of the most contaminating individuals that perpetuate parasitism through their faecal egg output.

Some, but less effective, selection may already be carried out on some organic farms by avoiding breeding from 'dirty' sheep. However, there is scope to undertake this selection on a more structured basis, making use professional expertise, measured faecal egg counts, and at some time in the future perhaps, a marker-based genetic blood test.

8.0 Manipulating sward composition

In terms of the grazing animal, the sward is an important intermediate component in the host parasite relationship. Factors such as the foraging behaviour of the animal, the physical structure of the sward, its botanical and chemical composition could potentially influence the incidence and severity of nematode infection. Some of these factors are considered below.

8.1 Animal factors

8.1.1 Foraging behaviour

It is widely assumed that maximising net energy or protein intake is the primary objective of foragers (Stephens & Krebs 1986; Sih 1980, 1993). However, maximising nutrient intake is only an optimal strategy if feeding behaviour does not conflict with other demands, and parasitic infection might have such an effect (Lozano, 1991).

Ideally, an animal would behave in such a way that maximises nutrient uptake whilst minimising its risk of parasitism. This could be achieved by avoiding food items or areas of ground contaminated by parasites, or it could incorporate elements into its diet with prophylactic or anti-parasitic properties (Lozano, 1991). Only a limited amount of observational work has considered that foragers avoid foods that harbour parasites or that they prefer foods that have anti-parasitic properties. There has been no experimental work in this field and there is no foraging theory that addresses these constraints on foraging behaviour (Sih, 1993).

Nematode larvae are capable only of limited lateral migration away from the faecal deposit. Most infective larvae are found on herbage close to the faecal pat (Durie, 1961; Rose, 1961; Goldberg, 1970; Williams & Bilkovich, 1973). Ruminants tend to avoid grazing in areas which are contaminated with faeces (Taylor, 1954; Crofton, 1958; Marten & Donker, 1964a, 1964b, 1966; Frame, 1970; Marsh & Campling, 1970; Pain *et al.*, 1974; Gruner & Sauve 1982). Crofton (1958) observed that sheep will selectively defecate at night away from areas that they will graze during the day.

Taylor (1954) proposed that grazing animals might avoid faeces to avoid contact with helminth parasites. Despite wide recognition that cattle and sheep avoid their own faeces, little research has been done to support this assumption. Michel (1955) observed that cattle grazed in a way which should result in the consumption of fewer *Dictyocaulus viviparus* larvae than if grazing was random. Gruner & Sauve (1982) noted that calves tend to avoid grazing near faecal pats, but did not conclude that faeces avoidance was a parasite control strategy.

Recent work at the Macaulay Land Use Research Institute has shown that sheep avoid areas of ryegrass pasture which have been experimentally contaminated with infected faeces. This discrimination behaviour was more apparent in animals which already carried a parasite load than in uninfected animals (Cooper et al, 1994).

Further work determined that infected sheep avoided areas which carried faeces irrespective of whether these faeces were infected with larvae or not. They did not avoid areas which had a similar density of infective larvae, but were uncontaminated by faeces (Cooper, 1996).

8.1.2 Diet selection

According to the theory of nutritional wisdom, animals are able to select foods which optimise their nutrition (Kyriazakis and Emmans, 1991), and to reject foods which are poisonous or low in nutritional value (Zahorik & Houpt, 1977). There is evidence to suggest that ruminants can select foods that meet nutritional needs and avoid toxic foods. Kyriazakis *et al* (1994) demonstrated that sheep infected with the intestinal parasite *Trichostrongylus colubriformis* were able to modify their diet so as to meet the increased protein demands resulting from the infection.

Work on plant toxins shows that animals are able to associate the post-ingestive reaction to consuming a food containing toxins with the ingestion of that food (Provenza & Balph, 1990), and sheep discriminate against foods with known toxic properties. Ruminants acquire aversions to foods that contain toxins by associating the flavour of the foods with aversive post-ingestive feedback, which appears to be caused by stimulation of the emetic system (Provenza *et al.*, 1994). Animals may be capable of forming associations not only between flavours and toxins, but also with flavours and parasites. It has been shown that rats are able to form taste aversions to a feed that has been paired to a subcutaneous inoculation of the nematode parasite *Nappostrongylus brasiliensis* (Keymer *et al.*, 1983).

As animals can form aversions to foods associated with internal malaise, they might be expected to be able to assess the relief available from the incorporation of certain medicinal food items into the diet. Support for this idea comes from the way that lambs can learn to rectify acidosis by drinking a solution containing sodium bicarbonate.

Secondary compounds (e.g. cyanide, glucosides, alkaloids, coumarins, lectins, toxic lipids, terpenoids, saponins, flavenoids, tannins etc.) are chemicals produced by plants which are not necessary for plant growth. These substances have a wide range of ecological functions, and some are implicated in chemical defence against parasites of herbivores. Little is known about the behavioural control of parasite infection through selection of beneficial food items. In theory, animals could use plant secondary compounds for their pharmacological properties. The subject has been reviewed and discussed by several authors (Janzen, 1978; Sears, 1990; Newton, 1991; Newton & Wolfe, 1992; Clayton & Wolfe, 1993; Grizanzio, 1993).

Support for the idea that animals use could use secondary compounds to control disease comes mainly from observations made in chimpanzees and baboons. Sage brush (*Artemisia tridentata)* whose essential oils have antibacterial properties (Carlson *et al.*, 1946) is eaten by mule deer (Dietz *et al.*, 1962) but if the plant is consumed in large quantities it could cause extreme illness (Nagy *et al.*, 1964). The fact that mule deer can avoid toxic foods suggests that toxic plants like sage brush are 'knowingly' ingested. However, there is no hard evidence to suggest that grazing herbivores can utilise plant secondary compounds as a parasite defence mechanism.

8.2 Sward factors

8.2.1 Sward structure

When infective larvae first emerge they are concentrated at the bottom of the sward, migrating towards the top of the sward (Williams & Bilkovich, 1973). The concentration of larvae in the sward surface will depend upon the rate of emergence of the larvae, their rate of migration and the rate of mortality of the larvae at various stages of their journey. It is widely known that the rate of development of eggs and emergence of larvae is determined by moisture and temperature at the soil surface (Michel, 1976). The rate of migration is governed by temperature, moisture and light (Rogers, 1940). Under favourable conditions of moisture and temperature there can be higher densities of larvae at the top than the bottom of the sward, facilitating uptake by the grazing animal. Little is known about the survival of larvae once they are on the laminae.

These relationships have been modelled for ryegrass dominated swards by Beecham *et al.* (in prep.) based on data from Rogers (1940), Rees (1948) and Callinan & Westcott (1986). This model concludes that there are relatively low levels of larvae in the top layer of the sward. However, more recent work suggests that methodological problems with the earlier papers underestimated the proportion of larvae in different sward strata, and that there are in fact higher proportions in the upper layers of the sward than estimated from the model (Moss & Vlassoff, 1993; Niezen pers. comm.).

Sward factors can determine the amount of light, moisture and heat at various levels of the sward strata. Taller swards will have more moisture and remain cooler than short swards of the same density, whilst dense swards will be cooler and moister than sparse swards. These sward factors also affect the herbage intake rate and bite depth of the grazing animal, determining both the nutritional value of the sward and the rate of ingestion of infective larvae.

Unfortunately, no conclusive relationships have yet been established between sward structure, and the distribution and ingestion rate of infective larvae. At this stage, any management prescriptions for reducing the effects of parasitism by manipulating sward structure could only be done on theoretical grounds.

8.2.2 Effect of plant species (also see Section 8.2.3)

There is clear descriptive evidence that plants species vary in the concentration of nematode larvae on their laminae. This might be due to variation in the distribution of biomass, differences in the microclimate associated with the sward structure, or due to the morphology of the laminae themselves. For example, *Holcus* has hairy leaves which might limit the ability of larvae to move up to the sward surface.

Moss & Vlassoff (1993) showed that prairie grass and ryegrass had significantly higher densities of *Haemonchus* larvae than did chicory or lucerne. Niezen et al (1993) found that lambs grazing browntop (Agrostis tenuis) and tall fescue (*Festuca arundinacae*) had higher faecal egg counts than those on Yorkshire fog or ryegrass, and despite periodic drenching clinical parasitism occurred particularly in animals grazing browntop. This might be associated with greater accumulation of fungal toxins, lower nutritive value, or a better micro-climate for larval survival in *Agrotis* swards (Neizen, pers. Comm.). The results suggest that in addition to nutritional effects of different grass species, there could be effects on the levels of parasitism acquired by lambs, even where similar sward heights are maintained.

In a study of the concentrations of *H. contortus* larvae in different strata of swards made up of ryegrass (*Lolium perenne*) + clover (*Trifolium repens*), prairie grass (*Bromus unioloides*) + clover, chicory (*Cichorium intydus*) + clover, or lucerne (*Medicago sativa*), Moss & Vlassoff (1993) found that swards containing chicory had the lowest concentrations per unit of herbage mass. Lucerne combined the lowest larval populations with high nutritive value and herbage mass. In this study, it was concluded that lucerne offered the opportunity to minimize the rate of natural infection while offering highest lamb growth potential. The extent to which these findings can be extrapolated to parasite species other than *H. contortus* is unknown at this stage.

Under New Zealand conditions, Niezen et al (1994) assessed the effects of species composition of the sward on lamb growth rates. Liveweight gains (g/day) were higher where infected lambs (*Trichostrongylus* and *Ostertagia spp*) grazed *Lotus* dominated swards, and lowest where they grazed ryegrass/white clover. Other species examined (Niezen *et al.*, 1994) were chicory, red clover, lucerne and sulla (*Hedysarium coronarium*). In a separate study using similar species, but with the inclusion of plantain (*Plantago lancelota*) Robertson *et al.* (1995) found that undrenched lambs had highest growth rates on sulla (175 g/day), and lowest on plantago (-2 g/day). In both studies the infected lambs had lower growth rates than drenched lambs grazing the same swards (243 v 175 g/day on sulla; 51.2 v -2 g/day grazing *Plantago*).

8.2.3 Condensed tannins

A wide variety of plants contain condensed tannins (CT's) including Lotus species (*Lotus pedunculatus* and *Lotus corniculatus*), dock (*Rumex obtusifolius*), sainfoin, sulla (*Hedysarium coronarium*) and Mulga (*Acacia aneura*). Condensed tannins are phenolic compounds comprising between 2 and 12% of the dry matter in these species (Waghorn et al, 1995). When fed to ruminants they can be either beneficial or detrimental to nutritive value through their ability to form hydrogen bonds with plant proteins. This bonding reduces the extent to which rumen microbes can degrade plant proteins to ammonia, and can increase protein flow to the intestine by 20-30% (Waghorn et al, 1995).

In digestibility studies with sulla, Stienezen et al (1996) reported a dry matter digestibility of 70% and a reduction in N digestibility of 14% due to the presence of CT's. While sulla was highly palatable to young sheep, there was a tendency towards a reduction in voluntary intake. This effect has been noted elsewhere when sulla was fed as the sole diet for a period of 2-3 weeks, possibly due to a delay in rumen clearance resulting from inhibition of microbial activity. Stienezen et al (1996) urge caution in feeding sulla as a sole diet, and recommend feeding in conjunction with other pasture or another forage without CT's.

Niezen *et al.* (1995) hypothesised that the increase in productivity in lambs grazing sulla and Lotus was a consequence not only of their high N levels, but also the high levels of condensed tannins in their tissues. Infected lambs grazing sulla (containing over 12% DM as CT's) had higher growth rates (206 g/day v 50 g/day) than those grazing lucerne (0.2% DM as CT's) Both herbage species had similar N levels (3.13 v 3.03 %N respectively), but sulla had a substantially lower in vitro digestibility (0.540 v 0.767 respectively).

Niezen et al (1994) found that faecal egg counts were significantly lower in sulla grazed lambs compared to those grazing ryegrass/white clover swards. Abomasal worm counts were also significantly lower. This effect could be due to an inhibition of larval development, or the persistence of adult nematodes (Robertson et al, 1995). The effect may be restricted to abomasal roundworms such as *Ostertagia*, rather than those that inhabit the small intestine e.g. *Nematodirus* (Mitchell, 1996).

In a further study, Niezen et al (1995) compared the performance of drenched or undrenched lambs grazing either lucerne or sulla. Undrenched lambs grazing sulla had lower faecal egg counts, less perineal faecal contamination, and a higher daily liveweight gain (129g Vs -39g) than those grazing lucerne. Parasite-induced anorexia was evident in the lambs grazing lucerne but not those grazing sulla.

More recent trials have shown that *Lotus pedunculatus* given to lambs was able to reduce numbers of *O. circumcinta* relative to ryegrass and that CT's appeared to affect the ratio of male:female worms (Waghorn et al 1995). It has also been shown that the condensed tannin in *Lotus pedunculatus* may be better able to overcome the effect of nematodes than that in *Lotus corniculatus*. Leathwick and Atkinson (1995) demonstrated that grazing lambs on *Lotus corniculatus* had significantly reduced dagginess and flystrike.

When Robertson et al (1995) observed higher levels of dags than expected from stock grazing sulla, the effect was attributed to frost damage which could have altered the chemical composition of the herbage.

Grazing forage crops containing condensed tannins may even have ecological benefits (Stienezen et al. 1996). Condensed tannins cause an increase in faecal N content and a decease in urea output in the urine, reducing the likelihood of N leaching into ground water.

8.3 Relevance for organic systems

There is no evidence that grazing animals can knowingly modify their grazing behaviour or intake of specific plant species to mitigate the effect of nematode infection.

The level of infection present in the sward is influenced by sward structure, and plant species composition. Growth rates of parasitised lambs have been shown to vary according to the composition of the sward being grazed. This may be due singly or in combination, to structural characteristics which reduce survival and migration of larvae up the plant, inherent productivity and digestibility of the plant material, or the presence of specific compounds (notably condensed tannins) which reduce the presence or impact of worm infection.

Most of the evidence thus far is derived from studies in New Zealand and Australia under environmental conditions very different from those in the UK. The work has also tended to concentrate on *Haemonchus* spp. a parasite species of limited relevance in this country.

Further research is required to provide basic data on the interraction of sward type and composition, climate and management factors which might ultimately be used to guide parasite control. In addition, any agronomic losses in production (output or nutritive value) in replacing, for example, one grass species with another would have to be offset by improvements in parasite control.

There appears to be considerable potential in the strategic use of forage crops containing condensed tannins to reduce parasite burdens. The role, effectiveness and implications of this approach on organic farms should be investigated.

9.0 Vaccination against gastro-intestinal nematodes

Vaccines against gastrointestinal parasites have been significantly more difficult to develop than vaccines for other infectious agents. Helminth parasites have a much more complex molecular make-up than viruses or bacteria (Meeusen, 1995), often changing antigenic structures between the different life-cycle stages. In addition the lack of understanding of the basic immunological mechanisms and antigens involved in the natural rejection response has hampered research in vaccine development. A purified parasite antigen can induce an immune response that can lead to either protection or exacerbation of the challenge infection, depending on the way the antigen is delivered to the immune system of the host (Meeusen, 1995). The risk of parasite resistance, is another factor to take into account in vaccine design (Le Jambre et al, 1995).

9.1 Progress in vaccine development

The only successful nematode vaccine commercially available at the moment is the lungworm vaccine for cattle (Huskvac ® - Mallinckrodt Veterinary) used to protect calves during their first season at grass. Vaccines similar to the attenuated lungworm vaccine have been used to protect lambs older than 6 months against *T. colubriformis* and *H. contortus* (Emery and Wagland, 1991). Homologous protection was greater than 80%, and cross protection was 30-40%. However, a minimum of 2x10^{4} irradiated larvae were required for each sheep, making this approach impractical for field use.

Another approach is to use specific antigens derived from the parasite to provoke an immune response in the host. These antigens may be either conventional or covert (Emery and Wagland, 1991). **Conventional** antigens are recognised by the host during a normal infection, and would have evolved with the host parasite relationship. Vaccines based on these antigens would augment naturally acquired immunity. Several conventional antigens have been shown to protect sheep against *T. colubriformis* and *O. circumcinta* (Emery and Wagland, 1991), and against *Oestophagostomum radiatum* in cattle. Meeusen (1995), described a more targeted technique where locally produced antibody secreting cells present at the site and time of infection could be used to identify antigens associated with the host's immune rejection response. This could significantly reduce the complexity of antigen candidates for potential vaccine development, and eliminate some of the 'hit and miss' involved in their identification. Because conventional antigens are recognised during natural infections, if mutation should occur in the parasite, resistance could spread more rapidly (Emery and Wagland, 1991).

Covert antigens are not presented to the host during a normal infection and therefore are not normally recognised by the host. For this reason, immunity is not boosted by a challenge infection and repeat vaccination might be required to provide sustained protection. However, immunity could be induced in young animals where naturally acquired immunity is slow to develop.

The most spectacular successes have been obtained using covert vaccines against blood sucking parasites like *Haemonchus* (Munn, et al 1987; Smith, 1993). Sheep were immunised with proteins taken from the intestinal cells of the parasite, so that when they are subsequently challenged, the worms ingest antibodies to these proteins in their blood meal. The antibodies attach to the worm intestine, interrupting the parasites digestive processes leading to starvation and death.

Smith (1993), used this approach very successfully to confer immunity against *H. contortus*. In this study, he did not stimulate any cross protection against *O. circumcinta* or *N. battus*. This may reflect antigenic differences between parasite species, or that *O. circumcinta* and *N. battus* do not ingest sufficient quantities of host immunoglobulin to be effective. However, a similar approach does have potential for *O. circumcinta* (Smith et al, 1994). Significant progress has been made in isolating and cloning further enzymes and antigens from *H. contortus*, *T. colubriformis* and *O. circumcinta*, in the pursuit of an effective vaccine. In the UK work is currently being undertaken by the Moredun Foundation, mainly concentrating on *Haemonchus* with some studies on *Ostertagia*. Using an adjuvant, a 90 - 95% reduction in egg counts and a 70 - 75% reduction in worm burdens have been achieved.

Because the method is so inefficient, it would be uneconomic to produce a commercial vaccine using native protein antigens collected in vivo. The solution is to purify the protective antigen and to reproduce it on a large scale by protein synthesis or recombinant DNA techniques. Under commercial UK conditions, it would be desirable to produce an effective vaccine, combining antigens from several parasite species of major economic importance (*Ostertagia, Haemonchus, Trichostrongylus spp.*). The aim might be to produce polyvalent vaccines containing at least two antigens from different stages of the parasite (Emery and Wagland, 1991). However, the same authors observed that antibody response to individual proteins in a multicomponent vaccine may be reduced by comparison with a single protein.

Commercial production of either type of antigen (covert or conventional) is technically complex, and involves a certain degree of trial and error to produce recombinant antigens identical to the natural molecule (Munn, 1995). Further work is required to identify prospective antigens (Smith, 1993), and to refine suitable adjuvants that would induce the right type of immune response (Meeusen, 1995). It is still likely to be several years before a product is available for on farm use (Smith et al. 1994).

9.2 Implications for organic systems

It may be only a matter of time before commercial vaccines are available against the most important species of roundworm. Uptake by the farming industry will depend on their efficacy against the important species of parasite and cost relative to anthelmintic treatment.

For organic producers the main impediment to the use of vaccines may be from an ideological perspective. There is a consensus within those responsible for organic standards that routine use of vaccinations should be discouraged. This arises from a belief that extensive use of vaccines could compromise animal immune mechanisms (Lampkin, 1990). Within current organic standards, vaccination (for example against clostridial disease, lungworm etc.) is permitted in cases of known disease risk, or to protect human health, for example, against leptospirosis in cattle (Measures, 1990). The proposed EU Standards for organic production continue this approach. Vaccination may not be allowed as a routine prophylactic treatment. However, in the survey by Kintail (1991), 39% of respondents used vaccines for disease control.

However, control of parasitic gastro-enteritis by novel vaccination techniques might be viewed differently. Vaccination might be considered merely as an alternative to clean grazing or genetically resistant stock. Less emphasis on husbandry and management for disease control might follow the development of new vaccines. In addition, commercial vaccines may only be available through recombinant DNA technology, techniques which may be unacceptable to the Organic Sector Bodies. In either case, once commercial vaccines do become available, they are likely to provoke considerable debate before being accepted within organic production standards.

10.0 Homeopathy

There is considerable anecdotal evidence for the successful use of homeopathy in cases of mastitis, skin disorders, calf scour, difficult calving etc. However, its potential for controlling parasitic gastro-enteritis is less convincing. Liver fluke is particularly difficult to deal with homeopathically (MacLeod, 1987), and the requirement for frequent administration of the remedy weighs against the use of homeopathy for PGE. The practical difficulties of treating on a flock basis, particularly sheep at pasture, are considerable.

10.1 Prevention

Halliday (1990) used a combination of grazing management and a homeopathic nosode to control parasitic gastro-enteritis in organic cattle. Two groups of nine animals were treated from three weeks before turnout to grass with one of two homeopathic nosodes - Santoninum or Teucrium marum. The results were inconclusive, particularly as there was no group of untreated animals to act as a control. Calves acquired a very significant worm burden in spite of the remedies used; however no clinical symptoms of worm infestation were apparent.

MacLeod (1981), recommends a nosode prepared from a suspension of contaminated material containing D. viviparous, as an effective method of preventing lungworm infection.

10.2 Treatment

In order to safeguard animal welfare, the use of conventional anthelmintics is universally recommended for an acute outbreak of PGE, although various homeopathic preparations may be useful in promoting recovery subsequently.

Depending on the symptoms, Elliott and Pinkus (1993) recommend treating lambs with either ARSENICUM ALB 1M, or PULSATILLA 200 given daily until a response is obtained or for a maximum of five days.

For treatment of clinical cases of lungworm MacLeod (1981) recommends, conventional anthelmintics in the first instance, but a range of homeopathic remedies are also suggested to aid the recovery of damaged lung tissue.

10.3 Relevance for organic systems

A homeopathic approach to disease control is fully compatible with the organic philosophy of naturalness and minimum residue. There are undoubtedly conditions which respond well to homeopathic treatment. However, parasitic gastro-enteritis does not appear to be one of these. In the acute phase of the disease, treatment with conventional anthelmintic is required to safeguard animal welfare and promote a speedy recovery to health in the stock affected. However, homeopathy may have a supportive role in aiding the recovery of damaged tissues. The use of a nosode may be particularly suitable for lungworm control. However, it's performance would need to be judged against that of an effective commercially-available vaccine (Huskvac®).

11.0 Herbal treatment

The preparation of a herbal remedy drench is another possibility for worm control in organic stock (Steifel, et al 1991), more as a short-term solution than a programmed drenching system. Furthermore if such plants/herbs were palatable, they could be established in a field where animals could graze periodically as an anthelmintic treatment.

11.1 Herbal anthelmintics

Man has used herbal medicines throughout history. The first study of herbal medicine was made around 2700 BC (Mann, 1994) and it is still practised by many indigenous people. Clinical and laboratory studies have shown that certain plants species are effective anthelmintics against a range of human nematode parasites (Kaleysa Raj, 1975; Singh *et al.*, 1981). The anthelmintic properties of certain plants against free-living nematodes has also been demonstrated (Ibrahim, 1992).

Antiparasitic properties of plants have also been shown against infections in animals. Akhtar & Ahmad (1992) have shown that the fruit of *Mallotus philippinensis* is as effective as a conventional levamisole based anthelmintic in the treatment of gastrointestinal cestodes in goats. *Artemisia herba-alba* has anthelmintic properties against *Haemonchus contortus* in goats (Idris *et al.*, 1982) and *Hedera helix* is effective against liver fluke in sheep (Julien *et al.*, 1985).

Under commercial conditions, herbal remedies such as garlic, and wormwood, acting as mild vermifuges, have generally not provided a convincing cure for the economically important species of roundworms (Newton, 1995). Lampkin (1990) suggested a preparation made from the seed hairs of Kamella philipensis as a useful vermifuge. Elliott and Pinkus (1993) recommend KAMALA 3x as a vermifuge for lambs, given daily for seven days and thereafter once fortnightly during the grazing season.

Despite the anecdotal evidence of the anthelmintic properties of a number of species of British flora, there has been no large scale screening of these species to assess their true efficacy as vermifuges. In a preliminary trial using a gerbil/*Trichostrongylus* model Cooper & Gordon (1996) measured the anthelmintic activity of the extracts of the aerial parts of wormwood (*Artemisia absinthium*), tansy (*Tanacetum vulgare*), greater birdsfoot trefoil (*Lotus pedunculatus*) and the bark of Scot's pine (*Pinus sylvestris*). High doses of wormwood and tansy, and medium doses of pine resulted in lower numbers of worms than in control animals, although these differences were not statistically significant. The number of worms recovered was highest from animals treated with a low dose of wormwood. It was suggested that low doses of wormwood inhibited expulsion of worms by the host, but at higher doses it was effective in suppressing worm burden.

11.2 Relevance for organic systems

Day (1995) suggests that ultimately a herbal approach may have more potential for PGE control than homeopathy, but more information is required. Many herbal candidates with potential to control internal parasites remain to be evaluated.

Herbal vermifuges may have some benefits in sub-clinical infestations, particularly for the treatment of individual cases. In acute cases of PGE in ruminant livestock, they are unlikely to be sufficiently potent to bring about a speedy expulsion of the parasite and safeguard animal welfare. As with homeopathy, the method and duration of treatment may make practical application on a flock/herd basis difficult, particularly for sheep at pasture.

However, one approach might be to include plants with natural vermifuge qualities e.g. wormwood (Artemisia absinthium) into grazing swards, or to be made available to the grazing animal as and when required.

12.0 Biological control of nematodes.

The greatest proportion of parasite biomass does not reside within the host animal but in the external environment, where free living stages may be subject to a range of abiotic factors (temperature and desiccation) or biotic factors (macro and micro organisms) that can decimate their numbers. Waller (1992) reviewed the prospects for biological control of free-living nematodes by a range of cohabiting micro-organisms including bacteria, protozoa, viruses and fungi. Bacteria, which have been used successfully as control agents in arthropods, may offer good prospects for future research (Waller and Faedo, 1995). However, it is the possibility of fungal control that has been the most intensively studied to date.

12.1 Nematophagous fungi

Fungi with nematicidal properties may operate through a number of mechanisms (Waller, 1992). The most important act as nematode-trapping (predacious) fungi, or as endoparasites. There are also fungi that parasitise nematode eggs, and others that produce metabolites toxic to nematodes.

Waller and Faedo (1992), studied the potential of 94 species of fungi with known nematophagous activity to reduce the number of infective *H. contortus* larvae in faecal cultures, and to produce nematode-attractant and nematicidal substances against free living stages of the parasite.

For the genera *Arthrobotrys, Geniculifera and Monacrosporium*, reductions exceeding 80% in the number of infective larvae were consistently obtained from 100 - 250 fungal conidia per gram of faeces. The most active were 6 species of *Arthrobotrys*, two species of *Geniculifera* and two species of *Monacrosporium* all of which showed a similar level of activity to *A. oligospora*. These studies also demonstrated that whilst many fungal species exhibit nematophagous activity against a variety of free-living nematodes, few showed efficient activity against free-living stages in the sheep faecal environment.

In a further study, Waller et al (1994) tested the ability of fungal spores or conidia from these species to survive passage through the gastrointestinal tract of sheep. This could provide a practical delivery method, which could reduce parasite survival in the dungpat. Fungal survival was tested *in vitro* in simulated rumen conditions, and also *in vivo*. Unlike some previous studies, large amounts of fungal material or a means of protection from the gut environment were not provided. Total mean gut transit time of orally administered conidia was found to be around 24 hours, sufficient to allow some innoculum to survive. *A. oligospora* was the only species found in faeces following oral dosing, however there was evidence to suggest that both *A. oviformis* and *G. eudermata* were also capable of surviving passage through the gut.

Field work has begun with several species of the genus *Arthrobotrys* and *Duddlingtonia flagrans* (Waller and Faedo, 1995). These studies confirm the nematophagous capabilities of these fungi in reducing the number of infective larvae on pasture. It is claimed that levels of control can be achieved comparable to the use of anthelmintics.

In New Zealand, research has concentrated more on the basic biology of the fungal species that already colonise the pastures, rather than on trying to develop a suitable feed ingredient (Niezen et al 1996). Nematophagous fungi can be cultured from faeces within three days of deposition on the sward. Pasture species also appears to affect the species and type of fungi that colonise the faecal pellet, presumably through effects on microclimate beneath the sward canopy, or affecting the numbers of plant parasite and microbial feeding nematodes in the soil.

12.2 Relevance for organic systems

Biological control does not aim to be an effective replacement for chemotherapy, but to prevent clinical disease and production loss by reducing the exposure of susceptible animals to pathogenic levels of infection.

A biological control agent, capable of reducing the number of free living larvae available for ingestion by the grazing animal, could be an attractive proposition for use in organic systems. Combined with other control measures such as genetically resistant stock, they may reduce further the need to use anthelmintic and increase flexibility in grazing management.

To date no system of biological control has been developed which could be used commercially. While some studies have been carried out in Denmark with nematophagous fungi (Gronvold et al, 1988, 1989), little or no research work has been done in the UK. Before there could be any commercial application, initial screening, efficacy and pasture ecology work would have to be carried out under UK conditions.

13.0 Modelling parasitic infection

The occurrence and severity of fluke and roundworm (including lungworm and nematodirus) infection can broadly be predicted from meteorological data. However, the development of models which can be used to direct specific disease control programmes at individual farm level is potentially very complex. Epidemiology is complicated by interactions between the effects of weather on the development, migration and survival of free-living stages, the variety of mechanisms of host resistance, numerous grazing management practices used on farms, and the number of nematode species involved (Leathwick, et al, 1995). Topography, animal behaviour and pasture species may also affect the availability of infective larvae (Niezen et al, 1996).

Assessing the effect of any major epidemiological factor in a disease as complex as PGE can only be done by experimental observation over several years, or by computer simulation (Barger, 1989). The more information that becomes available through research, the more factors can be introduced to an increasingly complex predictive model. However, it is a goal worth pursuing to promote a better understanding of infection and disease, to test current theories about the occurrence of disease, evaluate options to improve disease control and reduce the spread of anthelmintic resistance.

Mathematical modelling of nematode populations is not a recent innovation (Rogers, 1940, Rees, 1948), however recent improvements in computing power and statistical techniques facilitate greater speed and complexity. Several models exist for natural, predominantly *O. circumcinta* infections in sheep (Paton et al, 1984; Gettinby et al, 1989). Strategic models have been developed for *H. contortus* (Coyne and Smith, 1994) and for *O. circumcinta* and *O. ostertagia* (Smith and Galligan, 1988).

In recent years models of nematode infection have developed beyond simple considerations of climatic and population dynamics. Grenfell et al (1995) incorporated the acquisition of host resistance into a model for cattle and sheep. A model by Roberts and Heesterbeck (1995) attempted to quantify the dynamics of mixed parasite species in one host, the effects of breeding for resistance and the development of resistant strains of roundworm. Leathwick et al (1992) modelled mixed infections under New Zealand conditions and predicted both parasite epidemiology and lamb performance. This model was most sensitive to variation in parameters affecting survival and migration of free living stages and host resistance to infection, suggesting that these factors are most influential in regulating parasite populations. Beecham et al (1994), developed a model to predict the dynamics of intake and parasitic burden of *O. circumcinta* in lambs, based on weather, pasture conditions and sheep immune status. This included measurements of microclimate within grass swards to predict the vertical migration of infective larvae and their distribution within the sward.

These models are generally site specific and rely on local weather conditions to predict populations of infective larvae. They complement each other, but basic data is still inadequate (Sykes, 1994). Further research work is required in most subject areas, before a single robust model can be constructed.

14.0 Integrated control without using anthelmintics

There has been little or no work on developing an integrated programme for controlling parasitic gastro-enteritis on organic farms (Niezen et al, 1996). Developing a programme which can eliminate the requirement for anthelmintic will be a challenging objective.

To some extent this is already being practised in principle, through the operation of clean grazing systems and the integration of both livestock and arable enterprises on organic farms. However, there is the potential to go much further, in terms of combining all or several of the potential control methods described in previous chapters. An aggregation of control strategies is essential if anthelmintic is to be dispensed with in all but the most extensive of production systems.

The development of immunity requires exposure to parasites (Sykes, 1994). The intention could not be to eliminate the parasite, but to provide the host with sufficient advantage to withstand parasitic challenge without undue production loss, whilst still developing longer term immunity to the disease. Several promising avenues have been reported above. All may not be applicable in a given situation. However, combining one or several, could be sufficient to improve the degree of protection provided and reduce the need for very inflexible systems of grazing management. Any moderation of parasitic challenge through selective breeding, targeted culling, crop rotation, grazing management, etc. will reduce the overall risk for the most susceptible classes of stock, which in turn will contribute less to the build up of disease.

Before an integrated control programme can be formulated to give predictable results, more basic data is required under UK conditions, to take account of parasite epidemiology, climate, management system, pasture composition, host resistance, etc. Ultimately a model may be constructed to relate these variables one to another for a given set of farm circumstances.

In the interim, significant benefits in parasite control on organic farms might be obtained by developing a protocol for selecting more resistant animals, and exploring the strategic role of specialised crops (notably those containing condensed tannins) within organic systems.

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