DOCTOR OF PHILOSOPHY

The control of gastro-intestinal nematodes of sheep using a computer-based advisory system

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Award date:
1995

Awarding institution:
University College of North Wales, Bangor

UNIVERSITY OF WALES, BANGOR

THE CONTROL OF GASTRO-INTESTINAL NEMATODES OF SHEEP USING A COMPUTER-BASED ADVISORY SYSTEM

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SCHOOL OF BIOLOGICAL SCIENCES

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DECEMBER 1995

Acknowledgements

I would like to thank the three sponsoring pharmaceutical companies: Syntex Animal Health, Hoechst Animal Health and SmithKline Beecham Animal Health for their support throughout the three years of this study. I would especially like to thank Mr Steve Dean from Syntex Animal Health, without whom this project would not have been possible. I would also like to thank my project supervisor Dr Allan J. Probert and project consultant Dr Dewi ap T. Rowlands for their advice and support over the last five years, and Dr G.Gettinby for his help and advice at the beginning of this project. I would also like to thank Intelligent Environments who manufacture the expert system shell Crystal4 used to develop the WORMS application for their technical advice and support.

I would also like to thank my family - my mother and father for their encouragement and support, especially during the difficult times and also to my husband Mark for being there and believing in me. Finally, I would like to thank Gilles Choquet who helped me with the more technical aspects of expert system technology.

Summary

The main aim of this study was to produce a computer advisory program which could help the farmer choose the most suitable control method against parasitic gastro-intestinal nematodes in sheep. Chapter 2 discusses the biology and epidemiological patterns of the nematode species responsible for causing parasitic gastroenteritis in sheep. Chapter 3 then goes on to describe the anthelmintic drugs currently marketed in the UK for worm control in sheep. Chapter 4 introduces the concept of an expert system, an area of artificial intelligence which has come to the fore over recent years. In Chapter 5, the sheep farm survey carried out in 1992 of sheep farmers in the Gwynedd area of North Wales is discussed. It was shown that the basic trends found in other similar surveys over recent years were also found here. The survey highlighted the need for a new approach to educating the farmer on effective worm control. The development cycle of the expert system application WORMS is then described in Chapters 6 and 7. WORMS was developed using the expert system shell Crystal4. This ultimately led to the production of a user guide and the documentation of four case histories to demonstrate the methods used by WORMS to reach a conclusion. Two auxiliary programs are also included into the WORMS application as educational tools to enhance the farmer's understanding of worm control. These include a database of all products currently marketed in the UK for sheep and how to use these products effectively.

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Chapter 1 - Introduction

Agriculture is one of the few remaining industries in which many producers sell within competitive markets in which pricing is often determined by supply and demand. On the other hand, the farmer's costs are set according to the current rate of inflation. This situation has resulted in a price/cost squeeze, in which the price achieved by the product has not risen as rapidly as the costs incurred to produce the end product. Thus, in order to survive, agriculture as a business must make every effort to become more efficient. One way of achieving this ultimate aim is by the adoption of new technology.

In order to remain in business, today's farmer must have as much information as possible available to him/her on growing crops, rearing livestock, controlling disease, applying fertilizer, pesticides and herbicides, the nutritional requirements of his stock and so forth. In order to make profitable management decisions, the farmer must also have records of all areas of the farming operation to be undertaken. This includes performance records on crops and livestock, costs likely to be incurred such as treatment costs, cost in man hours to perform the task, together with market prices likely to be achieved from the end product. In order to best apply that information which is available, and which of this is relevant to his farm situation, the use of a computer and suitable software is becoming increasingly desirable.

Research and development in pest management does not always lead to practical improvements. Where this is the case, the problem generally falls within two categories:

1. Research and development is sometimes aimed at the wrong questions or at developing inappropriate practices. In other words, there is a fault with the design.

2. Despite research and development being well targeted, the results are not getting through to be implemented by pest managers and their advisors; i.e. there is a problem with communication.

What is required in the short and medium term, is for more emphasis to be placed on matching applied science to the real problem. Computerised decision tools can do this by providing an explicit and rigorous means of analysing the decision problems faced by the various players involved in pest management, and facilitating interactions between them.

If a new control practice is to be adopted, it must be technically possible, practically feasible, environmentally acceptable, politically advantageous and economically desirable. In order to improve pest management, the following issues should be addressed:

1. The target area of feasibility, acceptability and desirability has to be identified and then research and development can be directed towards this target. Decision tools can help to define the pest management problem(s), to identify key questions and provide a way of disseminating research findings to the target user.

2. Implementation of better pest management can be enhanced by better communication, such as training programmes and improved information dissemination. Decision tools can perform as both a training tool and as a method of disseminating knowledge about a certain area to a wider audience.

The aim of this project is to produce a computerised advisory parasite control program and demonstrate how a decision tool can help disseminate knowledge between the researcher and the end user i.e. the farmer. The application should help the farmer develop a more efficient control strategy for the coming season and also educate the farmer in terms of what drugs are available and how to use them effectively. The area of pest control to be covered within the program is the group of parasitic nematodes which cause gastroenteritis in sheep. There a number of reasons why this area of parasitology is particularly suited to this approach:

1. A large proportion of the losses incurred by these parasites in terms of lamb production

occur before the animals show any signs of clinical disease. Subclinical disease can lead to a significant decrease in weight gain, poor carcass conformation and reduced appetite. This leads to the lambs requiring a longer period for finishing off which can lead to two consequences in financial terms: Firstly, increased cost is incurred due to the increase in feed requirements to finish off the lambs and secondly, market prices tend to fluctuate during the season which could lead to the value of the lamb crop being less through being held back from market for an extra two to three weeks.

2. A number of surveys have reported confusion by the farmer in terms of treatments used to control these roundworm parasites. In the majority of cases, the drugs available are not being utilised in the most efficient manner. For example, the dose rate is not being administered correctly, the dosing equipment is not being maintained properly and there is confusion regarding the optimum periods in the season to dose the flock. Therefore, a large number of inefficiencies exist within the control process.

3. In recent years, a large number of articles have appeared regarding anthelmintic resistance. In the UK, this has not yet become the major problem that has been reported in the southern hemisphere. However, it has been recognised that unless the drugs currently available are used efficiently and intelligently, the prospect exists for the resistance problem to increase within the UK in years to come. There are only four possible groups of broad spectrum wormers available, therefore there is a need to increase the longevity of these wormers by educating the farming community to use less wormer more effectively.

4. A large wealth of information has been documented in both the lay press and research journals over a number of years. However, this information has never been accumulated in one place, making it more accessible to the farmer, farm adviser or student.

This thesis is divided into seven independent chapters followed by a conclusion chapter which discusses how successful the project has been in fulfilling the original aims and objectives. In Chapter 2, the worm parasites which cause parasitic gastroenteritis in sheep are introduced. In this chapter the basic lifecycle of these parasites is described; this is then followed by an account of the individual parasite species. There then follows a discussion about the characteristic epidemiological patterns which may occur if no control treatment is given to the flock. Chapter 3 provides information concerning the drugs which are available for the control of worm parasitism in sheep. A discussion then follows on a subject which has come to the fore over the last ten to fifteen years - that is anthelmintic resistance. This section of Chapter 3 provides the basis for a review article which has since been published (Hazelby *et al*, 1994). A copy of this article can be found at the back of this thesis. In Chapter 4, expert system technology is introduced and important terminology defined. A history of this expanding area of Artificial Intelligence is discussed which is then followed by a description of the various stages that occur within the development cycle of a new application. The combination of the information presented in these three chapters provide information required for building the advisory system, together with a methodology of how to develop an expert system application.

A survey of sheep farmers in the Gwynedd area was carried out in order to appreciate how the farmers tackle worm parasitism in the field. This survey is discussed in Chapter five and provides the first insight into how the farmer views worm control, how much he understands the worm control strategy he may use and also how to develop the advisory system for optimal use by the end user - that is, the farmer. This information has since been discussed in two articles published by the lay press (copies can be found at the back of this thesis) and also presented at the Annual Conference of the Association of Veterinary Teachers and Research Workers held in Scarborough - 1993. In Chapters 6 and 7, the methodology for the development of the application is presented, based on the development cycle previously discussed in Chapter 4. Chapter 8 then provides a users guide describing the different sections built into the overall advisory system package, which is then followed by four case histories to demonstrate how the system reaches a conclusion.

Because the information in each chapter is generally so diverse from that of other chapters, it was decided to treat each chapter as an independent unit within the thesis. For this reason, each chapter includes its own contents page and reference list.

Contents - Chapter 2

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Chapter 2 - Epidemiology of Gastro-intestinal Nematodes of Sheep

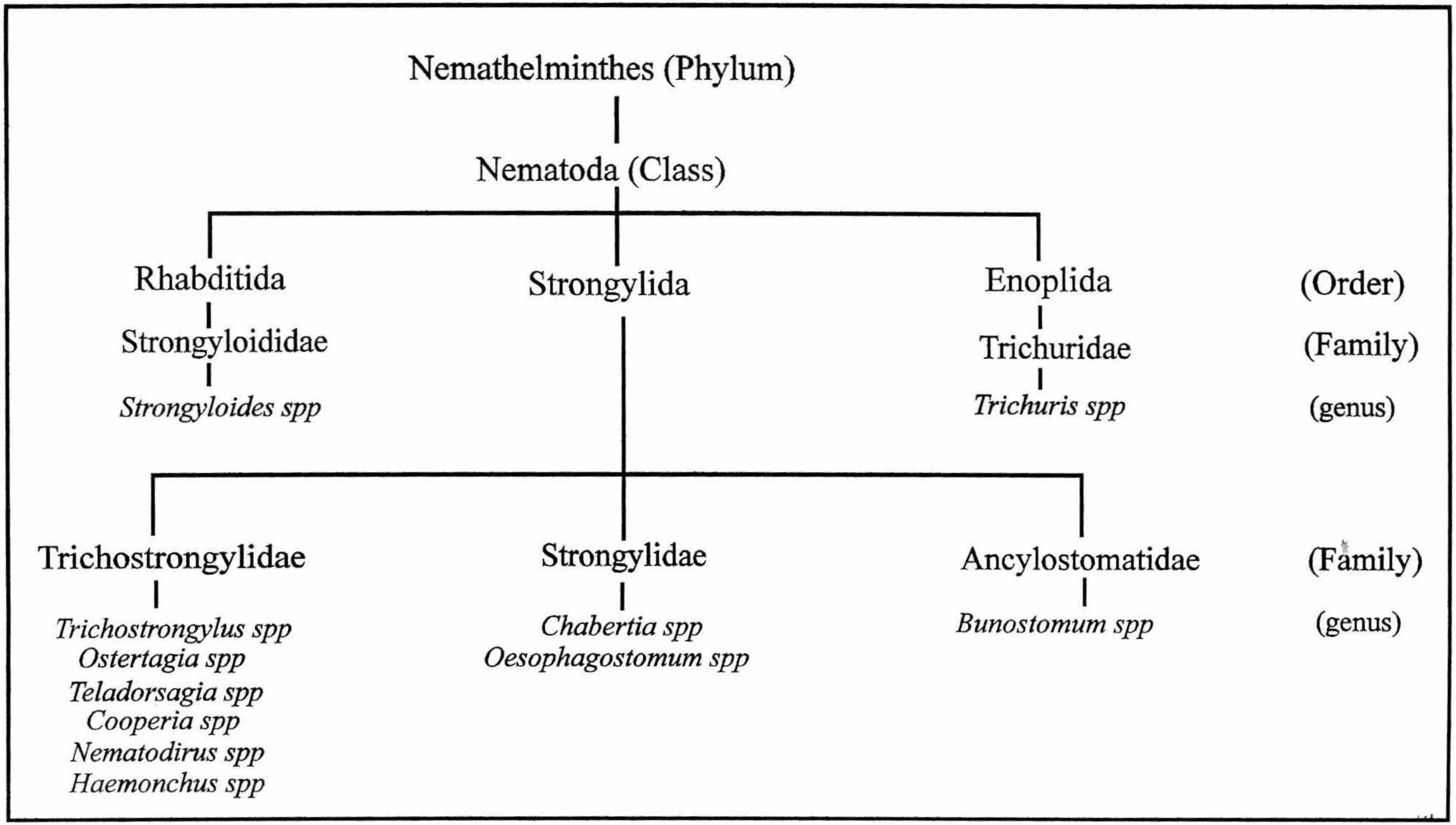
2.1 Introduction

Nematode parasitism has become more important in recent years due to the increase in stocking and twinning rates. This leads to lambs grazing earlier and harder than single lambs (Thomas and Boag, 1970). Consequently there is an increased need to understand the biology of the nematode parasites responsible and how the infection patterns of the field nematode population change throughout the season.

Parasitic gastro-intestinal worms of sheep are cylindrical, unsegmented elongate worms which include free-living and parasitic phases within their lifecycle. All the species of significant economic importance are included within three orders of the Class Nematoda (see Figure 2.1 for classification details). In all cases, the sexes are separate.

The free-living phase (egg to 3rd larval stage) occurs on pasture and the parasitic phase (3rd larval stage to mature adult) occurs within the host i.e. the sheep. A significant factor with the lifecycle of these parasites is that it cannot be completed without the presence of the host animal. This fact has implications both in epidemiological terms and also when considering strategies to control these parasites. Both of these factors will be discussed in more detail later in this chapter. Because the lifecycle consists of two distinct phases, the larval stages occurring within each phase must develop different characteristics in order to survive within a particular situation. Those free-living stages developing on pasture must be able to withstand the variations in climatic conditions, sustain a reasonable longevity and move to a position which increases the chance of contact with a suitable host (i.e. the top of a blade of grass). There are two possible routes of entry into the host used by these nematodes. The one most commonly used is by ingestion while grazing. However, some species (eg. *Bunostomum* spp) can gain entry by skin penetration - usually through the foot.

Figure 2.1



Classification of PGE Nematodes of Sheep (Soulsby, 1986)

The latter method requires an adaptation to this route of entry either by the use of enzymes to digest skin tissues and/or a morphological structure to cut a hole through skin layers.

The parasitic stages must be able to cope with the immune system of the host, and to produce large numbers of progeny in order to spread infection and thereby increase the chance of survival of the species. However, while many species are pathogenic, natural selection tends to select those species which do not have a lethal effect on the host. It is not in the best interests of a parasite to kill its host - without the host animal nematode parasites cannot produce offspring and therefore the species would become extinct. Nonetheless gastrointestinal parasitism can sometimes overwhelm the young or immuno-deficient animal leading to death. Once within the host, the area of the gastrointestinal tract where a nematode is found is characteristic of that species (see Figure 2.2). The species of highest economic importance generally occur within the abomasum and the small intestine. However, some species do occur in the large intestine and thus contribute to the overall effects of nematode parasitism and are important therefore in terms of the overall worm burden within a single animal.

In this chapter the different species causing parasitic gastro-enteritis in sheep are introduced, together with a brief morphological description, their life history and clinical symptoms. There then follows a discussion of the epidemiological aspects of nematode parasitism, highlighting important considerations such as arrested development and relaxation in immunity status of the ewe during pregnancy and early lactation.

Figure 2.2

The Characteristic Location of Adult Nematode Parasites of Sheep within the Gastro-Intestinal Tract

Location	Species
Abomasum	*Haemonchus contortus*
	* *Ostertagia trifurcata*
	Teladorsagia circumcincta
	* *Trichostrongylus axei*
Small Intestine	*Trichostrongylus vitrinus* * *T.colubriformis*
	Cooperia curticei
	* *Nematodirus* spp
	Bunostomum trigonocephalum
	Strongyloides papillosus
Large Intestine	*Oesophagostomum* spp
	Chabertia ovina
	Trichuris ovis

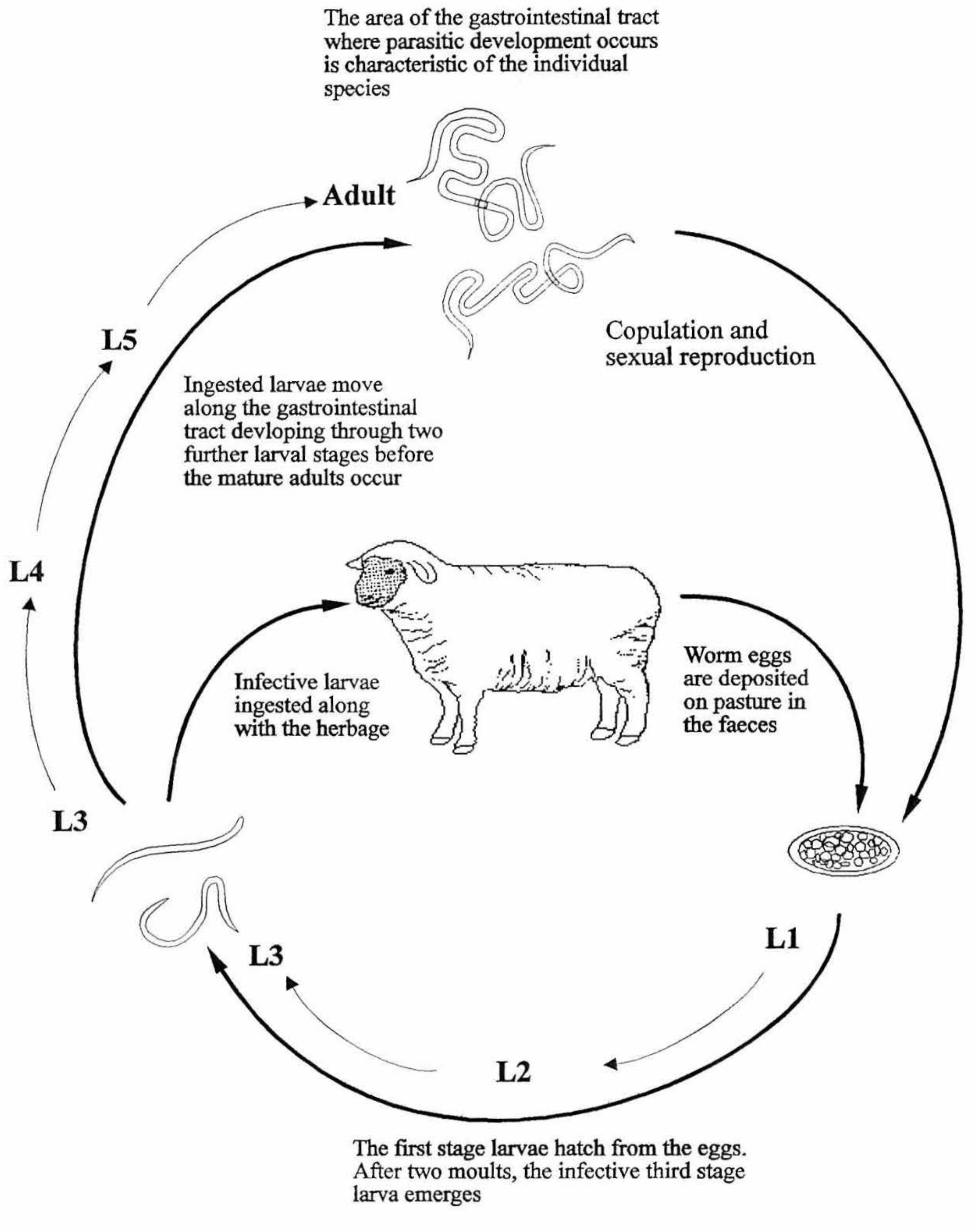
* species which also occur in cattle (Soulsby, 1986; Herbert and Probert, 1987)

2.2 Generalised Lifecycle

A diagrammatic representation of the generalised lifecycle of parasitic gastrointestinal nematodes of sheep can be seen in Figure 2.3. The nematode eggs are passed in the faeces of the host. Since they have a high oxygen requirement, if they are deposited in deep water or in the centre of a dense dung pat, development is inhibited (Dunn, 1978). The eggs hatch and develop through three free-living larval stages; the first two larval stages (L1 and L2) are relatively inactive, which feed on bacteria in the faeces (Levine, 1963). Food granules are deposited rapidly within the intestinal cells and the larvae almost double their length before the first moult. The third stage larva (L3 - also known as the infective stage) is an active, non-feeding form. Before each moult, the larvae stop eating and undergo a period of lethargus of varying duration, depending on the larval stage (Dunn, 1978). The second stage larva is dark coloured, due to the high density of food granules in the intestinal cells and continues to grow to the maximum pre-parasitic size. The infective third stage larvae cannot feed because the openings of their sheath (retained cuticle of the 2nd stage) have been sealed. Although this adaptation makes the infective larvae more resistant to adverse climatic conditions, their longevity is limited by the food reserves stored in their intestinal cells (Levine, 1963). The infective larvae migrate onto the herbage to be taken up by a grazing host (Levine, 1963; Thomas, 1974). Susceptibility of the free-living larval stages to temperature and low humidity is an important factor affecting the geographical distribution of each species.

Once inside the host, the third stage larva undergoes exsheathment. For exsheathment to occur, reducing conditions seem to be important, together with a low pH (Dunn, 1978). The parasite then continues through two further stages (the fourth stage larva or L4 and immature adult or L5), before the mature adult can be found. Each species is markedly site specific, a

Figure 2.3 Diagrammatic representation of the generalised lifecycle of parasitic gastrointestinal nematodes in sheep



factor which is discussed further below. While most nematode species of sheep are host specific, some species also occur in cattle (Soulsby, 1986; Herbert and Probert, 1987). This has important implications in the epidemiology of disease and is discussed further below.

2.3 Order: Strongylida

2.3.1 Family: Trichostrongylidae

2.3.1.1 *Ostertagia/Teladorsagia spp*

Two species of *Ostertagia* are found in sheep in the UK, namely *Ostertagia circumcincta* (recently renamed *Teladorsagia circumcincta*) and *O.trifurcata*. Both species occur in the abomasum (Urquhart *et al*, 1987), although *T.circumcincta* is often the dominant abomasal nematode (Reid, 1976). *O.trifurcata* also occurs in cattle.

2.3.1.1.1 Morphology

Adults are slender and reddish brown in colour (Dunn, 1978; Urquhart *et al*, 1987), with the males of *T.circumcincta* 7.5-8.5 mm and the females 9.8-12.2 mm long. The males of *O.trifurcata* tend to be slightly smaller i.e. 6.5-7 mm long (Soulsby, 1986). There is no apparent buccal capsule present, but both males and females do possess a pair of tiny cervical papillae.The spicules are characterised as consisting of three distinct branches (Dunn, 1978). They occur on the surface of the abomasal mucosa with the L4 and L5 stages occurring around the gastric glands (Urquhart et al, 1987). The eggs measure on average 80-100 μm by 40-50 μm (Soulsby, 1986).

2.3.1.1.2 Life History

Development from egg to third stage larvae on pasture, is dependent on climatic factors, requiring an air temperature in excess of 10°C for development to occur. Peak development occurs mid-summer and eggs passed in late summer do not reach the third larval stage until the following spring. Infective larvae are capable of surviving overwinter on pasture, however, they do show susceptibility to desiccation. As winter approaches, those infective larvae ingested at this time (i.e. September onwards) tend to become arrested in their development at the fourth larval stage and are referred to as arrested or hypobiotic larvae. The stimulus for this arrest in development appears to be an affect of environmental conditions on the free-living stages, `conditioning' the larvae to undergo arrested development after the fourth stage is reached. This subject which has important implications in control will be discussed in further detail in Section 2.6.1.4.

Herbage numbers of infective L3 increase from mid-summer onwards, leading to disease at this time of year. Such infective larvae are mainly derived from the faecal egg output of ewes during the peri-parturient period. Infective larvae can also develop from eggs shed by lambs which acquired their infection the previous autumn and in which the larvae have remained arrested over the winter period only to develop to maturity the following spring. Eggs deposited from April until June give rise to potentially dangerous populations of infective larvae from July until October. This is the most likely period for clinical symptoms to appear (Urquhart *et al*, 1987).

Host immunity is acquired slowly, with two seasons of exposure required before significant resistance develops. After this period, worm burdens remain low within the host throughout the year (Reid, 1976), apart from the peri-parturient period each year and other stressful occasions, when immunity wanes (Urquhart *et al*, 1987).

Once inside the host the infective larvae migrate into the abomasal mucosa where the worms undergo two further moults and emerge as young adults. The pre-patent period is usually 15-17 days (Dunn, 1978). In the adult ewe large burdens of *Teladorsagia/Ostertagia* spp can be found during late pregnancy/early lactation due to the relaxation in immune status during this time.

2.3.1.1.3 Pathology

In the lamb and young adult there are two forms of ostertagiasis which occur, similar to the Type I and Type II ostertagiasis conditions found in cattle. Type I occurs in August-October (Urquhart *et al*, 1987) with symptoms such as stained hindquarters, watery diarrhoea, reduction in weight gain followed by weight loss after which death may occur (Reid, 1976; Urquhart *et al*, 1987). Extensive abomasal damage occurs caused by 4th stage larvae burrowing in the abomasal mucosa. It has been found that the onset of symptoms coincides with a marked rise in the plasma pepsinogen level before abomasal damage occurs (Thomas and Waller, 1975). Anderson (1973) suggests that abomasal damage is preceded by a hypersensitive state due either to high larval intake or preconditioning by a previous infection.

Type II ostertagiasis occurs in late winter (January-March) in housed hoggs, gimmers and young ewes. Symptoms include progressive weight loss, softening of faeces followed by profuse diarrhoea. This is caused by maturation of previously arrested (inhibited) 4th stage larvae (Reid and Armour, 1973; Reid, 1976).

Subclinical infection is also seen causing a depression in appetite and loss of plasma proteins into the gastro-intestinal tract. In lambs even with moderate infestations, carcass evaluations show poor protein, fat and calcium deposition (Urquhart *et al*, 1987).

2.3.1.2 *Trichostrongylus spp*

The three major species found in the UK are *Trichostrongylus axei, T.vitrinus* and to a lesser extent *T.colubriformis* (*T.axei* and *T.colubriformis* are also species which occur in cattle) (Soulsby, 1986). However, other species found worldwide include *T.capricola, T.rugatus* and *T.falculatus* (Dunn, 1978). *T.axei* is different from the other *Trichostrongylus* spp in that the 4th stage larvae and adult worms are found in the abomasum. The remainder are intestinal species, predominantly found in the duodenum (Reid, 1976; Urquhart *et al*, 1987).

2.3.1.2.1 Morphology

The adults are small and hair-like, generally 5.5-8 mm long and difficult to see with the naked eye (Urquhart *et al*, 1987). There is no obvious buccal capsule, or cuticular ornaments other than the bursa found in the male worm. The simple bursa consists of a bifid dorsal ray, each branch of which may be further subdivided. A characteristic feature of the bursa is that the ventro-ventral ray is set well apart from the others. The spicules are brown in colour and easily visible (Dunn, 1978). In the female the tail is bluntly ended and there is no vulval flap (Urquhart *et al*, 1987). Because they are so small, their bodies can only contain up to a dozen eggs which lie end to end down the middle of the body (Dunn, 1978).

2.3.1.2.2 Life History

Under optimal conditions third stage infective larvae develop within 4-6 days (27°C, with high oxygen and humidity). Lower temperatures greatly increase development time, with no development occurring below 9°C (Soulsby, 1986). Because migration from the faeces to the top of blades of grass requires high humidity and reasonable light levels, the majority of larvae migrate in early morning or early evening. After ingestion, exsheathment occurs which involves shedding the sheath of the second stage larvae retained after the development to the third stage. The third stage larvae reaches the abomasum or small intestine (depending on species) within 2-5 days after ingestion. Development occurs to adult, with eggs being first observed 20 days after ingestion (Soulsby, 1986).

Embryonated eggs and infective larvae show high resistance to adverse conditions eg. extreme cold and desiccation, provided the relative humidity remains high (Wharton, 1982; Urquhart *et al*, 1987). The first and second stage larvae are highly susceptible to the effects of freezing, therefore in regions with long and severe winters, it is unlikely that many will survive until spring. In more temperate areas, significant numbers of these larvae do overwinter, although their survival capacity is generally lower than that of *T.circumcincta* (Dunn, 1978). Infective larvae survive well over winter, sometimes in large enough numbers to cause clinical problems in spring. More usually, larval numbers increase on pasture over summer and autumn with clinical problems occurring at these times (Urquhart *et al*, 1987). The difference in survival under adverse conditions between the susceptible 2nd stage and the more resistant infective 3rd stage larvae is generally considered to be caused by morphological differences between the two life stages. The retention of the 2nd stage cuticle is thought to be very important in controlling the rate of water loss in the third stage larvae (Ellenby, 1968). In temperate areas, evidence of hypobiosis (arrested larval development) is important in epidemiological terms, occurring at the infective larval stage. Its role in disease outbreaks has not yet been established (Urquhart *et al*, 1987).

Host immunity, as with *Ostertagia/Teladorsagia* spp is slow to develop and wanes during the peri-parturient period. One feature of the immunological resistance to infection has been found in the case of *T.colubriformis* to be related to an agent secreted by the host into the lumen of the gastrointestinal tract which paralyses larvae, preventing them from attaching to the surface of the mucosa and thus preventing them from developing to adulthood. This inhibitory factor was not found in those animals rested for six months from infection (MacRae, 1990).

2.3.1.2.3 Pathology

Infective larvae of intestinal dwelling species penetrate between the epithelial cells of the mucosa forming tunnels. When these tunnels rupture, releasing young worms 10-12 days after infection, considerable haemorrhage and oedema occurs causing plasma proteins to leak into the intestinal tract. Villi become distorted and flattened reducing the area available for absorption of nutrients and fluids. Damage is found predominantly in the duodenum (Urquhart *et al*, 1987).

In the case of heavy infestations diarrhoea occurs, which, with the loss of plasma proteins into the lumen, leads to weight loss. Reduced deposition of protein, calcium and phosphorus are also recorded (Urquhart *et al*, 1987).In the case of *T.axei*, changes in the gastric mucosa include alteration of pH and increased permeability of the mucosa.As is the case with *Teladorsagia/Ostertagia* spp, large worm burdens in the adult ewe only occur during pregnancy, parturition and lactation. The longevity of adult worms within fully susceptible hosts is over a year, however, more often previous experience of infection reduces the longevity to three to four months (Dunn, 1978).

During November and December, hoggs in particular suffer from a type of trichostrongylosis called "black scour". Symptoms include the onset of dark-coloured, foul smelling diarrhoea (hence the name) and the animals become dull and anorexic (Reid, 1973).

2.3.1.3 *Haemonchus contortus*

H.contortus occurs sporadically in the UK, mainly in the southern counties where the disease may be seen in lambs mid-summer (Reid, 1976). Although the species is at the northern limit of its range due to the severity of winter in the UK recent changes in climate suggest that it may well extend its northern range in Britain should global warming become a reality. Other species of *Haemonchus* which infect sheep include *H.bispinosus* which occurs and sheep and goats in South America and Indo-Pakistan, and *H.longistipes*, which is found in sheep, goats and camels in Asia and Africa (Dunn, 1978).

2.3.1.3.1 Morphology

H.contortus is often called the "barber's pole worm" as the blood filled intestine winds around the white ovaries giving the appearance of a barber's pole (Reid, 1976; Dunn, 1978;

Urquhart *et al*, 1987). The males are 10-20 mm and the females 18-30 mm long (Soulsby, 1986). The male has a large bursa, which is visible to the naked eye and which is characterised by the asymmetrically placed dorsal ray. Other characteristic features include the buccal capsule containing a tiny lancet for piercing blood vessels during feeding, a pair of wedge-shaped cervical papillae present in both males and females and the barbed spicules found in the male (Dunn, 1978).

2.3.1.3.2 Life History

Female nematodes tend to be prolific egg layers. The 1st stage larvae can develop to the infective third stage within five days under optimum climatic conditions, or delayed for weeks or months under cool conditions (Soulsby, 1986; Urquhart *et al*, 1987). No development can take place at temperatures below 9°C. Excess water has also been found to inhibit development because it interferes with aeration (Wharton, 1982). Although the eggs and infective larvae are susceptible to desiccation and low temperatures, those eggs which have reached the `pre-hatch' stage tend to be more resistant to adverse conditions (Silverman and Campbell, 1959; Soulsby, 1986). In temperate climates, such as the UK, *H.contortus* survives adverse conditions through arrested development within the host. This hypobiosis is similar to that experienced with *T.circumcincta*, but commences earlier in the season (Soulsby, 1986).

After ingestion and exsheathment in the rumen, the larvae moult twice in close apposition to the gastric glands. Before the final moult, they develop a piercing lancet which enables them to obtain blood from mucosal vessels as the adults move freely on the surface of the mucosa (Dunn, 1978; Soulsby, 1986). Fully developed adults usually feed for up to 12 minutes at a time and then move on to a fresh site. However, due to the anticoagulants secreted by the worms, blood continues to seep out of the old site for six to seven minutes

(Dunn, 1978) The pre-patent period is two to three weeks in sheep (Soulsby, 1986; Dunn, 1978; Urquhart *et al,* 1987).

It has been found that in NE England only a few of the ingested larvae proceed to adulthood, the remainder undergoing inhibition (Waller and Thomas, 1975; Urquhart *et al,* 1987). These arrested larvae mature the following spring to participate in the "spring rise" in egg output. This could be considered to be an adaptation to overcome unfavourable conditions. Therefore, Waller and Thomas (1975) suggested that a strain of *H.contortus* has evolved in which inhibition occurs without the necessity for stimulation by declining autumn temperatures. In the spring, maturation of these larvae occurs, leading to possible cases of acute haemonchosis at and around lambing time (Urquhart *et al*, 1987).

In some years, however, clinical haemonchosis may be seen in lambs during late summer. It is thought that a proportion of larvae fail to undergo hypobiosis in early summer thus giving rise to clinical symptoms at this time (Urquhart *et al*, 1987).

It has been observed that following a period of heavy rain, causing an increased intake of infective larvae, worm egg-counts drop sharply to around zero. This has been called the "self-cure phenomenon". It is thought that the expulsion of the adult worm burden is due to an intermediate-type hypersensitivity reaction stimulated by antigens derived from increased numbers of developing larvae in the gastrointestinal tract (Urquhart *et al*, 1987).

2.3.1.3.3 Pathology

In most of the UK, the temperature is not usually high enough for development of free-living stages, therefore it is more likely that sporadic outbreaks will arise following mild winters (Waller and Thomas, 1975).

There are three possible types of haemonchosis recognised:

1. Hyperacute haemonchosis: apparently healthy sheep drop dead from severe haemorrhagic

gastritis. Worm burdens are in the region of 30,000 worms (Urquhart *et al*, 1987). This form of haemonchosis is very rare in the UK, but may be seen if susceptible animals are suddenly exposed to a massive infection (Soulsby, 1986).

2. Acute haemonchosis: anaemia becomes apparent two weeks after infection. Other symptoms include loss of weight, hypoalbuminaemia (caused by the loss of blood protein into the gastrointestinal tract) and submandibular oedema (bottle jaw), where fluid retention causes a swelling under the jaw (Reid, 1976; Soulsby, 1986; Urquhart *et al*, 1987); death may occur (Soulsby, 1986). Infection is caused by worm burdens in the region of 2,000-20,000 worms (Urquhart *et al*, 1987). Acute haemonchosis only occurs sporadically in southern regions of the UK.

3. Chronic haemonchosis where continual blood loss from a worm burden of hundreds of worms causes loss of weight, weakness and inappetance (Soulsby, 1986; Urquhart *et al*, 1987). Severity of anaemia and hypoproteinaemia is dependent on the general wellbeing of the individual animal (Soulsby, 1986). Thus well-fed, well cared for animals may sustain high numbers without evidence of infection. This chronic form of the disease is the one most encountered in the UK, probably due to the nematode being at the northernmost limit of its climate range.

2.3.1.4 *Cooperia spp*

The main species in sheep is *Cooperia curticei* and the adult worms are characteristically found within the small intestine (Urquhart *et al*, 1987).

2.3.1.4.1 Morphology

The notable feature of *C.curticei* is the "watch spring-like" posture of the adult worm (Urquhart *et al*, 1987).They are small worms, generally reddish in colour. Males are 4.5-5.4 mm and females 5.8-6.2 mm long. The infective larva has a pointed tail (Soulsby, 1986) and the bursa of the male is unusually large due to large, fleshy supporting rays, which gives the male worm the appearance of a piece of thread with a large knot at one end. Other characteristic features include transverse cuticular striations, a small cephalic vesicle being present behind the oesophageal region and the spicules which bear transverse grooves in the middle section (Dunn, 1978).

2.3.1.4.2 Life History

C.curticei has a life history similar to that of *Ostertagia/Teladorsagia* spp (Urquhart *et al*, 1987). The pre-parasitic stages are very susceptible to freezing and desiccation which makes it unlikely that this species overwinters on pasture in the UK (Dunn, 1978). Therefore, hypobiosis takes place at the L4 stage and is a regular feature in late autumn/winter. Strong immunity develops after one year (Urquhart *et al*, 1987).

After ingestion and exsheathment, the infective larvae move into the crypts of the small intestinal mucosa where the first parasitic moult takes place. The 4th stage larvae return to the lumen and develop to adults within eight to ten days after infection. The pre-patent period is approximately 15 days and the longevity of adult worms is a few months in field infections (Dunn, 1978).

2.3.1.4.3 Pathology

C.curticei is a mild pathogen of lambs occasionally causing inappetance and poor weight gains.

2.3.1.5 *Nematodirus spp*

There are three species of *Nematodirus* in the UK namely *Nematodirus battus*, *N.filicollis* and *N.spathiger* (the latter only occurring in the Channel Islands) (Thomas, 1958_a). Other species occurring in other parts of the world include *N.helvetianus*, *N.abnormalis* (Asia, Southern Europe, America and Australia) and *N.oiratianus* (Europe and Asiatic Russia)

(Dunn, 1978). The adult worms of all three species are found in the small intestine (Urquhart *et al*, 1987).

2.3.1.5.1 Morphology

N.filicollis eggs are large (150 μm x 75μm), colourless and transparent. They are oval in shape, with one end more rounded than the other. *N.battus* eggs are large (164 μm x 72μm), brown , if recovered from faeces (Soulsby, 1986), and consist of seven to eight dark granular cells with the vitelline membrane visible at the poles. They are rounded at both ends with parallel sides and have a shell of uniform thickness (Thomas, 1958_b). The eggs of *N.spathiger* are also large measuring 152-182 μm by 67-77 μm and contain an embryo at the eight-cell stage when deposited onto pasture (Soulsby, 1986).

Adult worms are slender and approximately 2 cm long. The intertwining of the worms gives an appearance similar to that of cotton wool (Dunn, 1978; Urquhart *et al*, 1987). The posterior part of the female worm is thickened by the densely packed uterus, ending with a truncate tail with a small spine (except in *N.battus* which ends with a conical tail tapering to a point). In the male of all species, the two ventral rays are parallel, and in all but *N.battus*, the medio and postero-lateral rays are also parallel. The fused spicules are long and slender, with a small expansion on the end which is characteristic of individual species (Dunn, 1978).

2.3.1.5.2 Life History

N.spathiger eggs at 21°C develop to third stage larvae in 18-22 days. Larvae hatch readily between 21°C and 28°C, at the latter temperature all larvae hatch within a few days (Thomas, 1958_a).

N.filicollis eggs reach the first larval stage in 8-9 days at 21°C; this is an active, undifferentiated form. Within 12-16 days the larvae have moulted to the second inactive stage. During the next ten days, the body becomes transparent and the internal organs become visible. The third stage larvae become visible after 24-27 days. 4th stage larvae are recovered five days after ingestion and immature adults after 15 days (Thomas, 1958_a).

N.battus eggs develop to a recognisable 1st stage larva within 9-10 days under optimal conditions (21°C). The larvae are active, with long tails and no visible internal organisation. Moulting to the second stage takes place after 18 days. This stage is more sluggish than the first, with internal organs becoming visible between days 18 and 28. Moulting to the transparent third stage takes 28-30 days. When stimulated, the larvae move rapidly, rupture the egg membrane, but maintain the second stage sheath (Soulsby, 1986).

Unlike other species of gastrointestinal nematode in sheep, *Nematodirus* spp larvae develop slowly within the egg until the infective 3rd stage. This is an important feature within the lifecycle because the vulnerable 1st and 2nd stages are protected by the egg membrane from adverse climatic conditions. *N.filicollis* has been known to withstand -6.5°C for almost six months and *N.spathiger* -10°C for approximately two weeks. Infective larvae may even recover from temperatures as low as -60°C, if the temperature is reduced by stages. As well as resistance to freezing, the pre-parasitic stages are also highly resistant to desiccation for several months (Dunn, 1978).

After ingestion the infective larvae migrate to the intestinal mucosa (Soulsby, 1986). The fourth stage larvae appear four or five days after ingestion (Thomas, 1958_a; Soulsby, 1986). Many larvae leave the mucosa around days 4-6, but others remain within the mucosa until day ten (Dunn, 1978; Soulsby, 1986). Differentiation into the two sexes can be seen 8 days after ingestion, with the internal organs appearing more visible. Immature adults appear within 8-12 days after ingestion (Thomas, 1958_a) and egg production commences after 15 days (Soulsby, 1986).

At higher temperatures, development time is slightly increased, but an increasing number of eggs fail to hatch (1% development at 36°C). Mortality increases more slowly in *N.filicollis* with increased temperature than *N.battus* (2% survival at 36°C). At lower temperatures, development is slower, with the third stage of *N.battus* being reached in 50 days, and 40-45 days in the case of *N.filicollis* (Thomas, 1958_a).

2.3.1.5.3 Pathology

Most nematodiriasis is caused by *N.battus*, with *N.filicollis* contributing to the generalised symptoms of PGE found in lambs in late summer/early autumn (Boag and Thomas, 1975_a; Soulsby, 1986). *N.battus* was first seen in NE England and southern Scotland in 1951 (Reid, 1976). It occurs over a very restricted season (Thomas and Stevens, 1956), often resulting in a simultaneous large worm burden in a large proportion of the lamb flock, (Reid, 1976).

The low incidence of infection in ewes combined with the dramatic fall in burdens within the lamb crop indicate the development of strong resistance to re-infection (Thomas, 1958_b; Soulsby, 1986). This resistance occurs after initial infection, immediately inhibiting egg production and larval development, but does not cause immediate elimination of the adult worm burden (Thomas, 1958_b). Older lambs and adults may carry small burdens of *N.battus* which probably play a minor role in pasture contamination (Soulsby, 1986). It has also been shown that both *N.battus* and *N.filicollis* can cycle through calves without loss of infectivity (Herbert and Probert, 1987). This finding can have serious implications when considering pasture rotation as a method to control parasitic nematodes on mixed farming situations.

Infected lambs are unwilling to graze, with a high proportion suffering from profuse blackish-green and then yellowish diarrhoea (Thomas, 1958_a; Soulsby, 1986). They are reluctant to move, appear to have abdominal pain as they walk with a "tucked up" abdomen, have sunken eyes and rough wool. Rapid dehydration occurs, therefore congregation around drinking places is common. If no treatment is given deaths begin from 2 days from the start of the outbreak and continue for up to three weeks. In a bad year, mortality rates can be as high as 10-20%. When ingested, larvae migrate into the depths of the villi, returning to the lumen of the gut when mature (Thomas, 1958_a). The consequences of this migration are assumed to give rise to the symptoms (Thomas and Stevens, 1956; Thomas, 1958_a; Reid, 1976).

The age of lambs affected tends to vary from six weeks to five months with the majority between 6-12 weeks (Thomas and Stevens, 1956). Acquired immunity has been shown to develop within the first three months of life, depending on the size of antigenic stimulus encountered and the ability of the individual animal to respond (Taylor and Thomas, 1986). No disease is encountered in either pure hill flocks or adult sheep of any breed.

2.3.2 Family: Strongylidae

2.3.2.1 *Chabertia ovina*

This parasitic gastrointestinal nematode occurs in the colon of sheep and a number of other ruminants throughout the world (Dunn, 1978).

2.3.2.1.1 Morphology

The male worms are 13-14 mm and the females 17-20 mm long (Dunn, 1978; Soulsby, 1986). They are white in colour and have an enlarged, truncate appearance anteriorly due to the presence of a very large buccal capsule (Dunn, 1978). A distinguishing feature of this species is the leaf crown consisting of a double row of cuticular elements around the anterior aperture (Herd, 1971; Dunn, 1978; Soulsby, 1986). The eggs measure 90-105 μm by 50-55 μm (Soulsby, 1986).

2.3.2.1.2 Life History

After ingestion, the infective larvae move to the small intestine where they moult to the 4th stage larvae within the intestinal wall. These newly emerged 4th stage larvae move into the lumen of the small intestine and then to the caecum where development to the fifth stage occurs (Herd, 1971; Dunn, 1978). Immature adults develop which then move to the colon. It can take up to 26 days after ingestion before this stage reaches the colon (Herd, 1971; Dunn, 1978; Soulsby, 1986). These immature stages attach to the mucosa of the colon by means of the buccal capsule. Attachment occurs by pressing the buccal capsule against the mucous membrane and repeatedly expanding the oesophagus which results in a powerful sucking action. A plug of tissue is sucked in which is part digested by secretions produced by the dorsal oesophageal gland. The parasite remains firmly attached to the mucosal wall by a neck-like constriction (Herd, 1971). The pre-patent period tends to be around 49 days (Dunn, 1978; Soulsby, 1986). *C.ovina* has been shown to overwinter on pasture in the UK (Boag and Thomas, 1977)

2.3.2.1.3 Pathology

Clinical symptoms include marked diarrhoea containing large quantities of blood and mucus, and wool reduction. In extreme cases, severe anaemia may occur, followed by death (Soulsby, 1986). Host resistance has been observed where a single exposure of 2,000 larvae led to the expulsion of the adult worms (Herd, 1971).

2.3.2.2 *Oesophagostomum* spp

There are two species commonly found in sheep - *Oesophagostomum columbianum* and *O.venulosum*. *O.columbianum* has a worldwide distribution, but is more commonly found in tropical areas; it is rarely found in the UK. *O.asperum* can also be found in sheep and goats of South America and Asia (Dunn, 1978). These worms are generally referred to as nodular worms because several species cause nodule formation to the wall of the intestine. They are parasites of both the small and large intestine of sheep. Both species occur in the colon of sheep (Soulsby, 1986).

2.3.2.2.1 Morphology

These nematodes have narrow, cylindrical buccal capsules and a leaf crown may or may not be present (Dunn, 1978; Soulsby, 1986). Characteristic features include a cephalic vesicle which lies in front of a cervical groove. Behind these are cervical alae which are pierced by cervical papillae (Dunn, 1978). The male of *O.columbianum* is 12-16.5 mm and the female is 15-21.5 mm long. The tail of the female tapers to a fine point. *O.venulosum* is a slightly smaller worm with males 11-16 mm and females 13-24 mm long (Soulsby, 1986).

2.3.2.2.2 Life History

Eggs are passed in the host's faeces and the infective larval stage develops in 6-7 days under optimal conditions. After ingestion the third stage larvae move to the small intestine where they undergo exsheathment. They then penetrate the wall of the intestine and coil next to the *muscularis mucosa* where they cause cysts to be formed. The exception to this is *O.venulosum* which does not cause nodules to form. The larvae then moult to the 4th stage (Dunn, 1978). After five to seven days the larvae migrate back into the lumen and move to the colon where they develop to adults. The first eggs are passed within 41 days after infection (*O.columbianum*) or 28-31 days (*O.venulosum*) (Dunn, 1978; Soulsby, 1986). *O.venulosum* usually overwinters within the ewe in the UK (Boag and Thomas, 1977).

2.3.2.2.3 Pathology

O.columbianum is a serious pathogen of sheep, with worm burdens of 200-300 constituting a heavy infestation for young sheep. Nodule formation interferes with absorption, bowel movement and digestion. Nodules often suppurate and rupture causing peritonitis. In the case of acute disease, the first sign is usually a marked and persistent diarrhoea resulting in exhaustion and death. Faecal material is generally dark green and contains much mucus and occasionally blood. Chronic disease symptoms include progressive emaciation, weakness, dry skin and unthrifty wool. Death can occur within one to three days of the first signs of disease. On the other hand, *O.venulosum* is a relatively harmless parasite. Clinical symptoms are low, even with heavy infections (Soulsby, 1986).

2.3.3 Family: Ancylostomatidae

2.3.3.1 *Bunostomum* spp

Bunostomum trigonocephalum is a hookworm found in sheep and goats throughout the world. There have also been reports of the species occurring in Scottish red deer. It is a parasite of the small intestine (Soulsby, 1986).

2.3.3.1.1 Morphology

B.trigonocephalum are relatively large worms with the male 12-17 mm and the female 19-26 mm long (Dunn, 1978; Soulsby, 1986). At the ventral rim of the buccal capsule, there are two semi-lunar cutting plates and there may also be a pair of subventral teeth within the capsule. Another prominent feature is a very large dorsal cone projecting up from the base of the capsule (Dunn, 1978). The eggs, on average, are 92 μm by 50 μm, rounded at both ends and contain darkly granulated embryonic cells (Soulsby, 1986).

2.3.3.1.2 Life History

Infective larvae penetrate the host through the mouth or skin (Dunn, 1978) and pass to the lungs where they undergo one moult to the fourth stage larvae. These larvae then migrate to the small intestine (11 days after infection) and here develop into the mature adult stages. The adult worms attach themselves to the mucosa of the small intestine and suck blood. The first eggs are usually passed within 30-56 days after infection (Soulsby, 1986). *B.trigonocephalum* tends to be more important in warmer climates, requiring temperatures above 15°C to complete pre-parasitic development (Dunn, 1978), but nevertheless elsewhere usually contributes to the general effects of parasitism by gastrointestinal nematodes. The infective larvae have been found to be particularly susceptible to drying, therefore, control of infection can be achieved by keeping the flock off very wet pasture and treating the ground around water troughs with salt (Soulsby, 1986). *Bunostomum* spp have been shown to overwinter within the ewe and not on pasture in the UK (Thomas and Boag, 1977).

2.3.3.1.3 Pathology

Typical symptoms of *B.trigonocephalum* include progressive anaemia, hydraemia, submandibular oedema and diarrhoea. The faeces may be dark in colour due to altered blood pigments being present. Death occurs in extreme cases (Soulsby, 1986).

2.4 Order: Rhabditida

2.4.1 Family: Strongyloididae

2.4.1.1 Strongyloides

The main species of economic importance in sheep is *Strongyloides papillosus* which occurs in the mucous membrane of the small intestine (Beveridge, 1934) and has been found in a wide range of domesticated and wild ruminants (Soulsby, 1986).

2.4.1.1.1 Morphology

These are relatively small worms 3.5-6 mm long and 0.05-0.06 mm thick (Beveridge, 1934; Soulsby, 1986). The eggs are thin and blunt ended measuring 40-60 μm by 20-25 μm and contain fully developed embryos when deposited onto pasture (Soulsby, 1986).

2.4.1.1.2 Life History

Only females are found at the adult stage in the small intestine. Unlike all other nematode species described until now, *Strongyloides* spp can undergo a parthenogenetic lifecycle. The parthenogenetic female can be found within the mucosa of the small intestine and produces eggs which are passed in the faeces. Once on pasture, one of two alternative life-cycle patterns may occur. The 1st stage larvae which emerge from the eggs may develop either to the infective third stage ready to infect another host (homogonic cycle) or may develop right through to adult free-living male and female forms which copulate and produce eggs which then hatch and develop to the third infective stage (heterogonic cycle) (Beveridge, 1934; Soulsby, 1986). Adult male worms are only found in the free-living state. Which cycle predominates depends on climate. If environmental conditions are favourable, the heterogonic cycle predominates, if adverse conditions are present, the homogonic cycle predominates (Soulsby, 1986).

The infective larvae tend to enter the host by skin penetration, although oral ingestion also occurs (Beveridge, 1934; Soulsby, 1986). The larvae then migrate through the tissue and enter a skin capillary or venule and are transported to the lungs. They migrate through the alveoli up the bronchioles, bronchi and trachea where they are swallowed, descending through the gastrointestinal tract to the small intestine where they mature. The prepatent period is five to seven days (Soulsby, 1986).

2.4.1.1.3 Pathology

Clinical symptoms include inappetance, weight loss, diarrhoea to varying degrees and anaemia (Soulsby, 1986). It has also been reported that there is a possible link between the skin penetration of *Strongyloides* spp and the foot-rot bacterium (Beveridge, 1934). Climatic conditions which tend to favour the development of foot-rot are also thought to be favourable for the development of free-living larvae of *Strongyloides* on pasture. These larvae tend to collect in the interdigital space as the sheep walks through pasture which means it is highly probable that larval penetration will occur at a point on the skin just where foot-rot commences. Although it has been shown experimentally that *Strongyloides* can pre-dispose towards foot-rot, it is not the only factor. However, as it is quite likely that faeces will contain both *Strongyloides* spp larvae and foot-rot bacteria, it is likely to be an important factor as both organisms will be deposited onto the foot at the same time (Beveridge, 1934).

2.5 Order: Enoplida

2.5.1 Family: Trichuridae

2.5.1.1 Whipworms

This is a generalised term for those nematodes belonging to the genus *Trichuris*. They are known as whipworms because the anterior end of the worm is long and thin, while the posterior portion is shorter and thicker, giving the whole worm the appearance of a whip. The main species of economic importance in sheep is *Trichuris ovis*, which inhabits the caecum of sheep and many other ruminants (Soulsby, 1986).

2.5.1.1.1 Morphology

These are very long worms, with the male 50-80 mm and the female 35-70 mm long. The anterior end in the male constitutes three quarters of the total length of the worm, whereas in the female it constitutes two thirds to four fifths of the total length (Soulsby, 1986). The posterior end is generally four or five times thicker than the anterior end. Males are characterised by tightly coiled tails and a single long, slender spicule which is enclosed within a sheath which may carry spines. The posterior end of the female is bent into a bow shape (Dunn, 1978). The anterior end of adult worms ends with a small, sharp point which is used to penetrate the mucosa (Dunn, 1978). The eggs measure 70-80 μm by 30-42 μm, are brown, barrel-shaped and contain a very characteristic transparent cap at either end (pole) of the egg (Dunn, 1978; Soulsby, 1986).

2.5.1.1.2 Life History

Once on pasture, the eggs reach the infective third stage within three weeks under optimal conditions (28-32°C). However, development is delayed at lower temperatures (less than 20°C), with no development occurring under 6°C. Eggs can survive on pasture for several years (Dunn, 1978; Soulsby, 1986). The eggs require to be ingested before they can hatch because the mucoid plug found at either end of the egg needs to undergo digestion before the larvae can emerge (Dunn, 1978). After hatching, the larvae migrate to the top of the small intestine where they remain for ten days before moving to the caecum where they develop to adults. The pre-patent period for *T.ovis* is seven to nine weeks (Dunn, 1978; Soulsby, 1986). *T.ovis* has been recorded as overwintering on pasture in the UK (Boag and Thomas, 1977).

2.5.1.1.3 Pathology

In sheep, infection levels seldom are high enough to cause clinical disease, but more usually contribute to the overall effects of generalised gastrointestinal parasitism. Host resistance can usually be found within two to three weeks after initial infection, with age resistance occurring naturally after eight months of age (Soulsby, 1986).

2.6 Epidemiology

Epidemiology is defined as the 'systematic characterisation and explanation of patterns of disease' (West, 1988). The majority of gastro-intestinal nematode parasites of sheep follow the same overall characteristic patterns of infection and have therefore been grouped together for the purposes of this discussion (Section 2.6.1). *N.battus*, however, follows a completely different pattern and is therefore discussed separately in Section 2.6.2.

2.6.1 Generalised Epidemiological Infection Pattern

2.6.1.1 Spring Rise

A major source of infection to the lamb crop arises as a result of the relaxation of resistance status in the ewe during late pregnancy, parturition and early lactation which causes an increase in ewe faecal egg output at this time. This leads to the phenomenon colloquially referred to as the "spring rise" in worm egg output. This should, more correctly be termed the peri-parturient rise in faecal worm egg count (Crofton, 1958; Reid, 1976). This phenomenon has also been observed in barren ewes, although at a much lower level than in the pregnant/lactating ewe (Crofton, 1958; Brunsdon, 1964). It has been shown that the "spring rise" plays a major role in laying down contamination responsible for the August-September infection in lambs (Reid and Armour, 1975_b). The number of eggs passed during this period constituting approximately one third of the total annual pasture contamination. The possibility of seasonal factors affecting the spring rise have been considered, but evidence strongly supports the relaxation of the host animal's immune status as being the main contributory factor. For example, it was found that in autumn lambing ewes, the post-parturient rise occurred in autumn and not spring (Crofton, 1958). This relaxation in immune status is thought to be associated with circulating levels of the lactogenic hormone prolactin. This immunity is restored at the end of weaning when prolactin levels drop (Urquhart *et al*, 1987). Waning immunity is not thought to be caused by decreased antigenic stimulation (Thomas and Boag, 1973). However, it has been found that as *H.contortus* larvae age, their antigenicity declines (Thomas *et al*, 1975). As third stage larvae overwinter in the ewe, this causes an ageing population which could be a contributory factor to the peri-parturient rise by permitting higher larval establishment before provoking an immune response.

Three components which are known to affect the peri-parturient rise in egg output are:

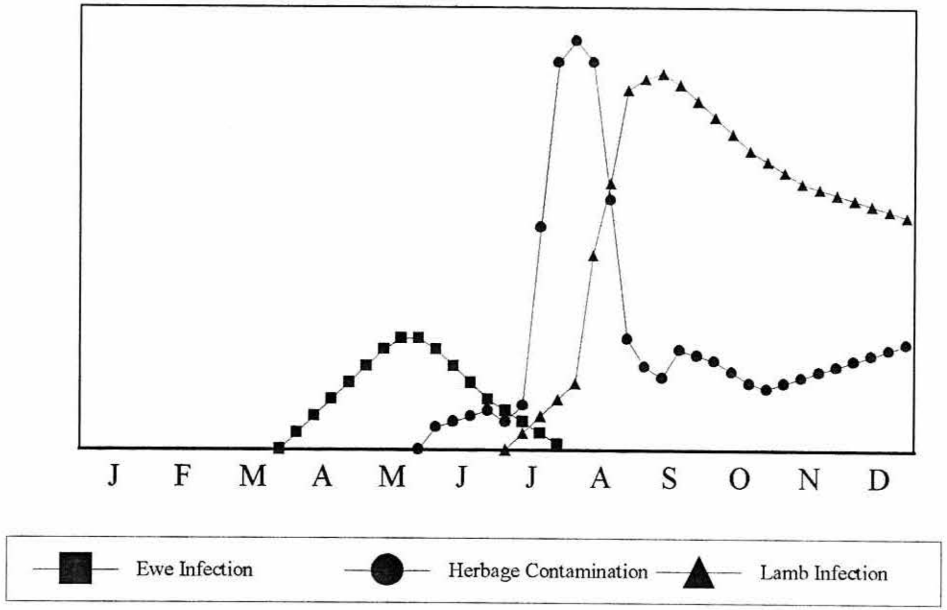
1. Maturation of inhibited larvae (Reid and Armour, 1975_a) due to the host's altered immunity status (Crofton, 1958; Urquhart *et al*, 1987).
2. Increased fecundity of existing female adult worms (Reid, 1976; Urquhart *et al*, 1987).
3. Re-infection due to ingestion of overwintering larvae during late pregnancy, parturition and early lactation (Reid, 1976; Urquhart *et al*, 1987) with unimpeded development to adulthood..

In the UK, *T.circumcincta* is generally considered to be the dominant contributory species, occurring in the majority of ewes at this time. Most other species of gastrointestinal nematode do contribute to the contamination of the pasture with eggs, but on a smaller scale, with most species only occurring in a few individuals within a given flock (Crofton, 1957). It has also been found that the relaxation in immune status may differ between individual parasite species. In one study, ewes in their last 6 weeks of pregnancy were found to be highly resistant to *T.vitrinus*, while at the same time highly susceptible to *T.circumcincta* (Jackson *et al*, 1988). Any differences in immune status of the ewe to different parasite species at this time will not only affect the overall contribution to pasture contamination, but may also affect the succession of species within a given season.

2.6.1.2 Clean Pasture (see Figure 2.4)

Pasture larval counts are low during spring and early summer, but rise to a peak during July (Thomas and Boag, 1968; Boag and Thomas, 1971; Waller and Thomas, 1978). After

Figure 2.4 Spread of Generalised Nematode Infection (Originally Clean Pasture)



the peak in faecal egg output associated with the peri-parturient rise, a gradual rise of infective larvae occurs, followed six to eight weeks later by a significant rise in larval numbers. It has been suggested that this could be caused by an accumulation of the pre-infective stages, which then develop almost simultaneously with improved climatic conditions in July (Waller and Thomas, 1978). This initial wave of pasture contamination is taken up by the new lamb crop and results in a peak lamb faecal egg output by mid/late August. This leads to a second smaller rise in pasture larval levels during September (Boag and Thomas, 1971). Larvae picked up during this period will develop through to early 4th stage after which inhibition will occur (Reid and Armour, 1975_b). These larvae then persist within the host animal in this form until climatic conditions improve in the spring (Reid and Armour, 1975_a).

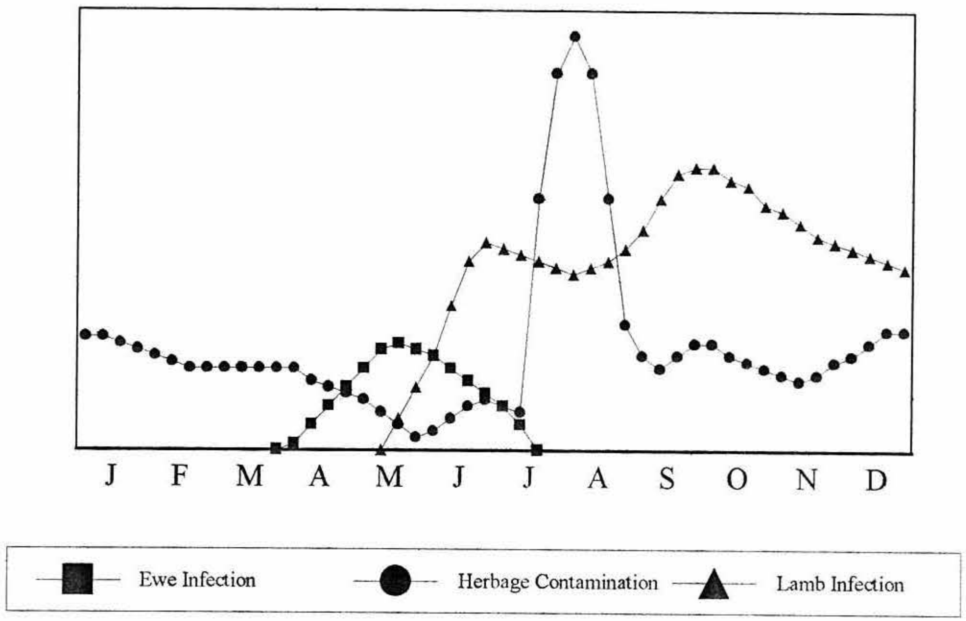
The first peak in infective larvae on pasture followed 4-6 weeks later by a peak in faecal egg output from the lamb crop strongly suggests that the first wave of lamb infection is initiated by the peri-parturient rise or "spring rise" in faecal egg output of the ewe during pregnancy/early lactation. Therefore, it is the scale of the "spring rise" which largely determines the severity of the lamb infection rather than the gradual build up of repeated re-infection over a number of generations (Boag and Thomas, 1971).

As the first generation occurs early in the year when climatic conditions are not as favourable, their generation time is 3-4 months. The minimum generation time of 5-6 weeks (Boag and Thomas, 1970) only occurs at the height of the season. Because of this, it is unlikely that there would be more than two generations before weather conditions become unfavourable again in October (Boag and Thomas, 1971).

2.6.1.3 Dirty Pasture (see Figure 2.5)

Infective larvae of many common roundworms can survive winter conditions on pasture (Thomas and Boag, 1970). Overwintering of infective larvae on pasture has a variable

Figure 2.5 Spread of Generalised Nematode Infection (Contaminated Pasture)



role in infectivity from year to year depending on the worm species. *T.colubriformis/T.vitrinus* numbers fall rapidly over winter, to disappear completely by April. *T.circumcincta* larvae, on the other hand, survive until the end of May (Boag and Thomas, 1970; Thomas and Boag, 1973). Therefore, overwintered *T.circumcincta* larvae will play a much more important role in initiating infection in the new lamb crop than will *T.colubriformis/T.vitrinus* (Connan, 1986).

On permanent pasture, two sources of infection occur, namely, overwintered larvae and the "spring rise" in ewe faecal egg output. If lambs are spring born (March/April), this will lead to a large faecal output from the lambs May/June. This can have two effects: firstly there will be a check in the development of the lamb during a period when fast growth occurs which could be very costly in terms of economic return for the farmer. Secondly, as the first wave of infective larvae was large, the build up of infection levels will be greater, with the possibility of a further two generations before climatic conditions restrict worm development (Waller and Thomas, 1978). The effects of the presence of overwintered larvae on pasture will further be exacerbated if the stocking rates are high in spring (Connan, 1986). The second generation of adult worms occur in the host during August as a result of a peak in pasture larval levels in July, which could generate a third larval peak on pasture in September/October.

2.6.1.4 Arrested Larvae

This is defined as a "temporary cessation in the development of a nematode at a precise point in its parasitic development" (Urquhart *et al,* 1987). It usually only affects a proportion of the population.

There are two possible stimuli for arrested development to take place:

1. An environmental stimulus received by free-living stages. This appears to be a mechanism

designed to avoid adverse conditions such that the progeny, by remaining sexually immature in the host, can wait until more favourable conditions return.

2. Acquired/age immunity by host animals to infection. This is usually experienced by a smaller proportion of the worm population than those affected by environmental stimuli. Maturation of larvae in this case seems to be stimulated by relaxation of immune pressure resulting from host hormonal changes, occurring at and around the time of parturition (Urquhart *et al*, 1987).

In the case of *H.contortus* and *T.circumcincta*, arrested development appears to be caused by the effects of environmental conditions on the free-living stages. However, in the case of *Trichostrongylus* spp, host immunity has been identified as the main stimulus for inhibition (Eysker, 1978).

In the case of *H.contortus* the pattern of development of arrested forms appears to be affected by geographical location. A study carried out in Utrecht (Netherlands), where climatic conditions could be considered comparable to those of the southern counties of the UK, a similar pattern of inhibition was found to that of *T.circumcincta*. However, with *H.contortus*, inhibition commences earlier in the season and is more absolute than for *T.circumcincta* (Eysker, 1978; Thomas and Waller, 1979). However, in northeast England, the onset of arrested development in *H.contortus* appears to be the normal state, with the majority of larvae undergoing a phase of inhibition before re-commencing development in the spring. These larvae then mature and contaminate the pasture, contributing to the "spring rise", at a time when climatic conditions would prove most favourable to the development and survival of free-living stages of *H.contortus* (Waller and Thomas, 1975). Differences in climatic factors between the two regions is the most likely explanation for the differing characteristics of this species recorded. As the nematode moves northwards in the UK, it moves nearer to the extreme outer range of its distribution.

The differences recorded between the two worm species *H.contortus* and *T.circumcincta* could be a reflection of their differing abilities to overwinter on pasture. Infective larvae of *T.circumcincta* have been shown to survive effectively on pasture through the winter and to contribute towards the "spring rise". In the case of *H.contortus*, numbers of infective larvae on pasture fall dramatically towards the autumn. It is very rare to find overwintered larvae of *H.contortus* in the spring (Connan, 1971). Hence it can be seen how developing a hypobiotic state overwinter is crucial to the survival of *H.contortus* from one season to the next.

2.6.2 Epidemiology of *Nematodirus* Infection

Pasture larval patterns of *N.battus* and *N.filicollis* are distinctly different (Boag and Thomas, 1975_a).

2.6.2.1 *N.battus*

N.battus shows a unique cycle producing one generation per year. Eggs are passed in lamb faeces onto pasture from April to late June which develop slowly over summer. Infective third stage larvae are not present within the egg until the end of the year (Thomas and Stevens, 1956; Smith and Thomas, 1972). The eggs are highly resistant to freezing and desiccation and can survive on grass for up to two years (Reid, 1976). The majority of eggs hatch the following spring (Boag and Thomas, 1975_a), releasing the 3rd stage larvae onto pasture to be ingested by a new susceptible lamb crop in March/April. Larval contamination on pasture remains at a high level until June, then drops to a low level for the rest of the year (Thomas, 1958_b). This leads to a peak in faecal egg output in May (Thomas, 1958_b; Boag and Thomas, 1975_a). However, in the upland situation, the mass hatch is generally delayed, with the peak of larvae on pasture occurring in June. This can have serious implications for hill farmers who farm out their ewes to lamb on lowland sites (as is practised in North Wales). The lambs might miss the mass hatch on the lowland pasture, only to catch the upland mass hatch in June, which could result in clinical symptoms (Thomas, 1991). The stimulus for hatching appears to be a period of chill followed by a mean day/night temperature of more than 10°C (Thomas and Stevens, 1956; Dunn, 1978; Soulsby, 1986). Infective larvae have been found to be highly resistant to climatic conditions and can survive for up to 11 months on pasture (Thomas and Stevens, 1956). There is only one generation per year as development from egg to mature adult takes 12 months to complete. Development includes a prolonged inactive phase on pasture (Thomas, 1958_b).

The severity of the disease varies from year to year, but the length and timing of the season remains relatively constant (Thomas and Stevens, 1956). In a bad year for disease, a large number of infective larvae on pasture coincides with the presence of susceptible grazing lambs (Smith and Thomas, 1972; Soulsby, 1986). If the larval peak is too early, the lambs are not grazing therefore the disease has less of an effect. Likewise, if lambing is early, the lambs may have acquired a degree of age resistance to the parasite before the peak larval contamination arises and therefore suffer less from the disease (Thomas, 1974; Reid, 1976; Soulsby, 1986).

Host resistance, which builds up rapidly following the initial infection inhibits egg production and larval development, but does not cause immediate elimination of the adult worm burden. Nematodiriasis tends to be a lamb to lamb disease with hoggs and ewes playing a minor role only in maintaining the infection. However, small numbers of larvae do accumulate in the gut during winter. After lambing, ewes become exposed to extremely high levels of infection which may overcome resistance and lead to a measurable egg count. This would coincide with the period of high egg counts in lambs (Thomas, 1958_b).

It is usually found that before an outbreak occurs the flock was grazed on pasture grazed by sheep the previous year. No outbreaks can occur on maiden pasture which has not been previously grazed by sheep. However, worms can survive ploughing. Therefore, although new ley is safe to graze lambs, it cannot be regarded as worm-free (Boag and Thomas, 1975_a). Re-seeding pasture or changes in climatic conditions tend to limit recurrence (Reid, 1973). Also, grazing cattle on pasture to rest it from sheep has been found to be effective in control terms (Boag and Thomas, 1975_a), although care should be taken if the pasture was grazed by calves during the period of the mass hatch in the previous spring. It has been shown that *N.battus* is capable of cycling through calves and thus infection will be laid down which could develop on pasture over the summer, leading to a mass hatch in the following spring (Herbert and Probert, 1987).

2.6.2.2 *N.filicollis*

N.filicollis shows an infection pattern more similar to *Ostertagia/Teladorsagia* spp and *Trichostrongylus* spp than to *N.battus*, with two or three generations per season in the UK. There is no mass hatch of larvae in spring, but a gradual build up of larvae on pasture during the year. This leads to a peak in larval pasture contamination in February, which is taken up by the new lamb crop resulting in a second peak in May. A second generation of adult worms in the host results which translates into a steady rise in pasture larval levels during September which increase over winter to produce a peak in the following spring (Boag and Thomas, 1975_a). The rate of increase in larval pasture levels from year to year is much lower in *N.filicollis* than *N.battus* therefore it presents less of a disease risk (Boag and Thomas, 1975_a).

2.6.3 Pasture Management

Pasture plays a very important role in the development of nematodirasis as the size of the worm burden is directly related to the number of larvae ingested. Nematodes cannot multiply within the host (Boag and Thomas, 1970). Factors which are important when considering host-parasite relationships include:

1. Stocking density - nematode parasitism has become more important in recent years due to the increase in stocking rates and higher twinning rate which leads to lambs grazing earlier and harder than single lambs (Thomas and Boag, 1970; Connan, 1986).

2. Herbage growth levels - higher herbage growth levels dilute the number of larvae on pasture, but also provide protection for free-living stages. This could result in a higher survival rate to 3rd stage infective larvae (Taylor, 1957). If there is a dry spell of weather during the peak grass growth period (May-July), this will reduce both the growth of grass and the number of larvae reaching the third stage, due to increased exposure to adverse climatic conditions (Thomas, 1974; Boag and Thomas, 1975_b). However, this is counter-acted by the fact that if there is less grass laid down, the lambs will graze harder and the concentration of infective larvae on pasture could be higher than normal (Taylor, 1957). This problem is further exacerbated in twin lambs as they are more likely to graze more unpalatable pasture and more heavily contaminated grazing than their contemporary single lambs and hence will acquire a disproportionately higher challenge (Connan, 1986).

3. Reaction of the host to infection - it has been shown that resistant adult sheep can pick up as many as 72,000 larvae per day and remain healthy. Grazing adult sheep with susceptible young stock can prove effective at cleaning heavily contaminated pasture, even at high stocking rates (Taylor, 1957). The only period of the season when this could not be used is during later pregnancy, parturition and early lactation when adult sheep suffer a temporary relaxation in immune status.

4. Overwintering on pasture - many workers have shown that under temperate conditions,

prolonged survival occurs, and overwintering of infective larvae is the rule. However, the level of larval survival through to the spring will be dependent on winter climatic conditions.

5. Grazing management (Thomas, 1974). In a mixed farming situation, alternation of pasture between sheep grazing and arable cropping can provide an effective means of controlling the build up of PGE nematode larval contamination on pasture. Rotation of pasture between sheep and cattle can also provide a moderate means of controlling these worm parasites, however, it has been reported earlier that several species of nematodes which parasitise sheep can also be found in cattle. These species include: *O.trifurcata, T.axei, T.colubriformis* (Soulsby, 1986), *N.battus* and *N.filicollis* (Herbert and Probert, 1987).

2.6.4 Succession of Species

There is no period during the year when only a single species of gastrointestinal nematode will be present within an individual animal. All species of nematode are present within a proportion of the flock throughout the year. However, it has been found that at different times of the year, different species of nematode are more dominant than at other times (Crofton, 1957). The generalised order of succession of species in the UK has been recorded as *Nematodirus* spp and *T.circumcincta* in June, *H.contortus* in July, *T.vitrinus* in August and *T.axei, T.colubriformis* and *C.curticei* in September (Crofton, 1955; Boag and Thomas, 1977).

N.battus and *N.filicollis* overwinter on contaminated pasture to produce high worm egg counts in June. On pasture traditionally regarded as 'clean' because it was not grazed by sheep in the previous season, a smaller peak in worm egg counts may still be seen due to the ability of these species to survive up to two years on pasture (Boag and Thomas, 1977). As *H.contortus* numbers increase, it is thought that this parasite inhibits the development of *Nematodirus* spp at the 4th larval stage (Mapes and Coop, 1970; Mapes and Coop, 1971). The bulk of *T.circumcincta* infection in lambs occurs from the end of May until August and is generally considered the dominant species during this time. It remains numerous in September, but in most years is replaced by *Trichostrongylus* spp as the dominant species. *O.trifurcata* tends to follow a similar pattern as *T.circumcincta*, but at much lower levels. *T.vitrinus* is the first of the *Trichostrongylus* spp to appear in August, with *T.axei* and *T.colubriformis* appearing in September (Boag and Thomas, 1977). *T.vitrinus* is usually considered the predominant small intestine species during the autumn. However in some years the abomasal species *T.axei* appears almost as numerous. *C.curticei* is generally more numerous in autumn and may, on occasions overtake *T.vitrinus* as the predominant small intestine species. *Strongyloides* spp occur sporadically during the season reaching maximum burdens in the autumn (Crofton, 1955; Boag and Thomas, 1977). Incidence of this parasite in particular appears to be related more to feeding habits than to climatic factors. In a study by Crofton (1955) when the lambs were fed roots, rape or kale, increases in *Strongyloides* spp were recorded to a greater extent than when fed on stubble.

Due to the low levels of most other nematode species, it has proved extremely difficult to establish any trends. However, in general *B.trigonocephalum* has been recorded more frequently in summer and *C.ovina* and *Oesophagostomum* spp more frequently encountered in autumn and winter (Crofton, 1955). The actual worm burdens carried by a flock varied considerably from year to year, but with minor variations, the order of succession remains the same both within and between farms in the same area. This pattern of seasonal incidence is thought to be associated more with the generation times of the individual species, than being attributable to seasonal climatic changes. The generation time of a species is controlled by the effect of climatic factors upon the free-living stages. However, changes in the order of succession of species is only possible through changes in climatic conditions if an individual species is at the limit of their distribution range (Crofton, 1957).

Any factor which reduces the chances of a parasite encountering a host can also be considered as a factor which increases the generation time of a nematode species. The majority of control measures could therefore contribute to increasing the generation times of worm species. The main difference between clean and contaminated pasture results from the ability of larvae on contaminated pasture to overwinter and hence contribute to an earlier initial wave of infection the following spring (Boag and Thomas, 1977). However, only those control measures which are selective towards a species or small group of species of nematodes (eg narrow spectrum anthelmintic drugs) are capable of changing the order of succession within a given season (Crofton, 1957).

2.7 Discussion

In this chapter, the biology of the different nematode species responsible for causing parasitic gastro-enteritis in sheep have been discussed. There are two distinct phases within the life-cycle of these parasites: a free-living phase on pasture and a parasitic phase within the host animal. The free-living phase is very important in determining the severity of nematode parasitism within a given season because the size of the worm burden is directly related to the number of larvae ingested and the number of larvae ingested to the success of the free-living phase. If climatic conditions during winter are severe, smaller numbers of larvae will overwinter on pasture, therefore smaller numbers of infective larvae will be available to infect the new lamb crop in spring. Also, climatic conditions during spring and summer can play a highly significant role in affecting the development time of the free-living stages and hence can affect the number of generations of a species during a single season.

Availability of the host animal during different periods within a season can affect the infection build up during a single season. If in spring, the flock is put on a pasture which has not been grazed by sheep for at least 12 months, this pasture can be considered clean. The only nematode contamination likely to arise will have originated from the worm burden currently carried within the flock at the time of the move. This will have significant implications regarding the build up of infection during the season. The peak in faecal egg output during the peri-parturient rise will be much smaller than if the ewes were grazing on contaminated pasture. This, will in turn, lead to a smaller, more gradual build up of infective larvae on pasture as the season progresses. If the lambs are moved at weaning onto clean pasture (eg silage aftermaths) this can significantly alter the build up of infection during the second half of the season. Lambs moved at this time, are being removed from the main bulk of infection laid down at the beginning of the season due to the reduced immune status of the ewe during lambing. Therefore, numbers of infective larvae on their new pasture will remain low for the rest of the season, reaching a small peak in late September/early October. This greatly reduces the risk of clinical symptoms at the back end of the year. Availability of susceptible animals is of increased importance in the case of *Nematodirus battus* which has a very short season of infectivity (six to eight week period) in the spring. If lambing occurs early, lambs may have developed age resistance to *Nematodirus* by the time the mass hatch of larvae occurs. On the other hand, if lambing is late in comparison to the mass hatch of larvae, the lambs may not be grazing sufficiently to build up large enough worm burdens to cause clinically symptoms to occur.

The importance of the pasture phase in the life-cycle of these parasites offers a variety of opportunities for controlling the effects of parasitism within the flock as a whole. Up until now, only those opportunities regarding pasture management alone have been discussed. In Chapter 3, the use of anthelmintics will be introduced, with an account of what drugs are currently available in the UK and problems associated with using the drugs effectively.

Chapter 2 - References

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Chapter 3 - Anthelmintics used for the Control of PGE Nematodes in Sheep

3.1 Introduction

Gastrointestinal nematodes of sheep have always been economically important to the farmer, with symptoms occurring such as weight loss, general unthriftyness, diarrhoea and in some cases death, depending on the worm species involved and the size of the worm burden acquired. With pressure on farmers to increase their productivity during the last 30 years, this has led to an increased need for a better quality, more effective and more widely available drug product. This has caused a significant expansion within the anthelmintic industry during this time. However, with the more intensive farming strategies employed this has resulted in the development of anthelmintic resistance in all major sheep rearing countries of the world. In some countries this has threatened the future of all groups of broad spectrum drugs. Therefore, it has become more important than ever to recognise which drugs are available, how to use them properly and how to achieve the most effective worm prevention strategy in combination with grazing management techniques. In this chapter, the anthelmintic drugs currently available for use in sheep are introduced, together with the types of formulation that can be chosen to administer the drug to the flock. A comprehensive account of anthelmintic resistance follows, which forms the basis of a review article which has since been published by Hazelby *et al* (1994), and finally a discussion on good wormer practice concludes the chapter. Methods by which these drugs can be incorporated into an integrated control strategy involving pasture management are discussed in Chapter 6.

3.2 The history of anthelmintics

Before 1938, there had been very few changes made in the treatment of gastrointestinal roundworms since the 4th Century AD. Disease specific drugs were rare and treatment consisted of using potentially toxic chemicals such as lead arsenide, nicotine, copper sulphate and carbon tetrachloride, or herbal remedies eg. oil of *Chenopodium*, extract of male fern, santonin and quassia, which had limited use (Brander, 1986; Campbell and Rew, 1986).

In 1938, phenothiazine was introduced and although it was not very potent it was virtually non-toxic. However, the major breakthrough in helminth treatment came in 1961 with the introduction of the first benzimidazole compound thiabendazole. During the 1960's and 70's other benzimidazoles were produced which were more potent than thiabendazole and some of which were also effective against lungworms, tapeworms and liver flukes (Campbell and Rew, 1986).

During the late 1960's two new groups of drugs were introduced. Tetramisole, an imidazothiazole, was introduced in 1965, and consisted of a racemic mixture of two optical isomers. Subsequently it was discovered that it was the laevo-rotatory isomer that conferred the majority of the anthelmintic activity. This was then separated and marketed as the compound levamisole. During the same period the tetrahydro-pyrimidines pyrantel and morantel were developed (Campbell and Rew, 1986).

In 1979, another breakthrough was made with the introduction of the avermectins. These chemicals have a large spectrum of activity, controlling some arthropod parasites as well as nematodes. The only drug currently marketed for sheep in the UK in this group is ivermectin (Campbell and Rew, 1986).

Therefore it can be seen that in a very short period of time, this particular area of animal health products has developed from a primitive ideal of 'kill or cure', using extremely dangerous compounds (to both animal and farmer), to a more controlled scientific approach towards animal health.

3.3 Drugs in current use in the UK

Broad spectrum wormers (which are defined as having a wide range of activity against many nematode species and life stages within each species) have been available since the early 1960's, with new products released at regular intervals. However, despite the large number of products available, all the broad spectrum wormers fall into one of four groups according to mode of action:

Group 1 - Benzimidazoles/Probenzimidazoles (white drenches)

Group 2 - Imidazothiazoles (eg. Levamisole)

Group 3 - Avermectins (eg. Ivermectin)

Group 4 - Tetrahydropyrimidines (eg. Pyrantel/Morantel)

Until recently, pyrantel/morantel were placed in Group 2 alongside levamisole, but recent evidence found during resistance studies, has led us to believe that morantel uses a different mechanism of activity to that of levamisole (Burr-Nyberg, 1994, personal correspondence) .

3.3.1 Benzimidazoles

Thiabendazole was the first representative of this group of wormers to be introduced in 1961 and is best known for revolutionising the anthelmintic market when launched. It has since been overshadowed by more effective analogues. Benzimidazoles constitute the largest group of broad spectrum anthelmintics available. The second-generation benzimidazoles were the first anthelmintics to confer good efficacy against arrested nematode larvae (Brander *et al*, 1991) which is particularly important for use in stock which are housed over winter. Because all benzimidazoles are insoluble compounds, they are formulated as drenches (hence the alternative name of white drenches), pastes, boluses or in-feed preparations (Henderson, 1990).

Figure 3.1 Table to show dates of introduction of the various benzimidazoles and their relative dose rates

Compound	Dose Rate (mg/kg)	Date of Introduction
Thiabendazole	66	1961
Mebendazole	15	1971
Oxibendazole	10	1973
Fenbendazole	5	1974
Oxfendazole	5	1975
Albendazole	5	1976
Ricobendazole	5	1980's

It can be seen that the newer benzimidazoles are effective at lower dose rates than the earlier ones.

Different benzimidazoles marketed include thiabendazole, oxibendazole, mebendazole, fenbendazole, oxfendazole, albendazole and ricobendazole (Brander, 1986; Campbell and Rew,1986). Febantel, thiophanate and netobimin are also included in this group as pro-benzimidazoles because benzimidazole products are produced by *in vivo* hepatic metabolism and it is these metabolites which confer the anthelmintic activity (Campbell and Rew, 1986).

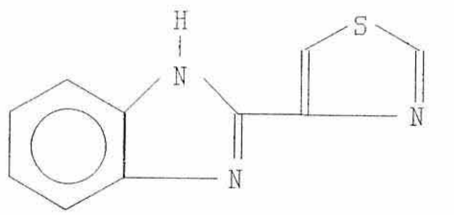
Although these chemicals are given by mouth, the active ingredient reaches all parts of the gut via the bloodstream. As they are all relatively insoluble compounds, this is a very lengthy process, with the active ingredient being removed from the blood very slowly. This accounts for the long witholding periods for meat and milk (Henderson, 1990). This does have the advantage of prolonging the exposure of the parasites to the drug and those benzimidazoles which are least soluble often have added efficacy against arrested larval stages and lungworms (Armour, 1983)

The main setback in the use of benzimidazole products over the years has been the spread of benzimidazole resistance on a global scale. However, it is still fair to say that benzimidazole products continue to constitute the most widely used group of anthelmintics for the control of gastrointestinal nematodes in sheep.

3.3.1.1 Thiabendazole

(2-(4-thiazoyl)-1*H*-benzimidazole)

Figure 3.2 Chemical Structure of Thiabendazole



This was the first benzimidazole developed and was introduced in 1961 (Brander, 1986; Campbell and Rew, 1986). This drug was marketed in the UK until 1995, therefore it has been included for completeness. It was marketed for sheep as an oral drench formulation at a dose rate of 44 mg/kg (Soulsby, 1986). Good efficacy could be achieved against adult, immature stages (excluding arrested larvae) and of most gastrointestinal nematodes (Brander *et al*, 1991). However, to be effective against nematodiriasis, an increased dose rate of 88 mg/kg was required (Gibson, 1973; Soulsby, 1986; Campbell and Rew, 1986). The highly effective nature of the drug dose had its disadvantages as it prevented the development of immunity against the worms, therefore the host was more susceptible to reinfection (Alexander, 1985).

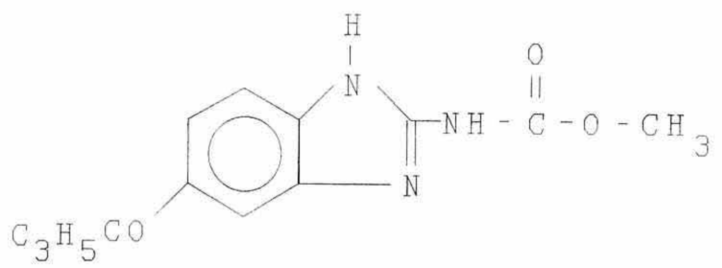
Reduced efficacy was seen not only against *Nematodirus* spp (Campbell and Rew, 1986; Soulsby, 1986), but also *Strongyloides* spp and *Bunostomum* spp (Soulsby, 1986).

It had a relatively high safety index of 16-27 times the recommended dose rate (Brander *et al*, 1991). However, at significantly increased dose rates, teratogenic effects could be seen (Alexander, 1985).

3.3.1.2 Mebendazole

(Methyl[5-(benzoyl)-1*H*-benzimidazol-2-yl]carbamate

Figure 3.3 Chemical Structure of Mebendazole



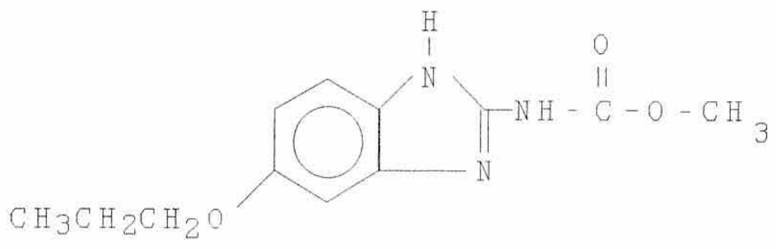
Mebendazole is effective against adult and immature stages of nematode parasites at the recommended dose rate of 15 mg/kg (NOAH, 1995). Good efficacy is also conferred against the adult tapeworm *Moniezia* (Soulsby, 1986; Brander *et al*, 1991) and the lungworm *Dictyocaulus* spp (Soulsby, 1986).

This drug has a good safety index (over 20 times the recommended dose rate). It shows no teratogenic effects in sheep (Alexander, 1985; Brander *et al*, 1991), but effects have been found in rodents (Brander *et al*, 1991).

3.3.1.3 Oxibendazole

(Methyl[5-(n-propoxy)-1*H*-benzimidazol-2-yl]carbamate)

Figure 3.4 Chemical Structure of Oxibendazole



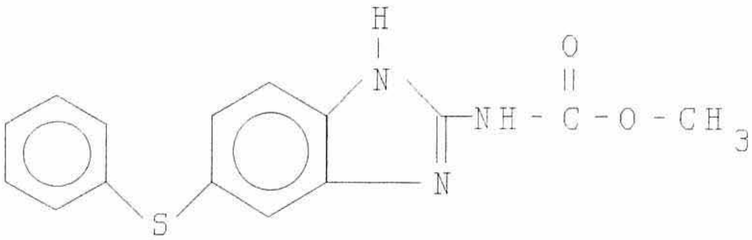
Oxibendazole was until 1995 marketed in the UK therefore, it has been included in this account for completeness. It is a parbendazole derivative (Alexander, 1985) and showed good activity against adult and immature stages of gastrointestinal nematodes and the lungworm *Dictyocaulus* spp (Brander *et al*, 1991).

The safety index of oxibendazole was recorded at 60 times the recommended dose rate, but significantly higher doses were known to cause teratogenic effects (Alexander, 1985; Brander *et al*, 1991).

3.3.1.4 Fenbendazole

(Methyl[5-(phenylthio)-1*H*-benzimidazol-2-yl]carbamate

Figure 3.5 Chemical Structure of Fenbendazole



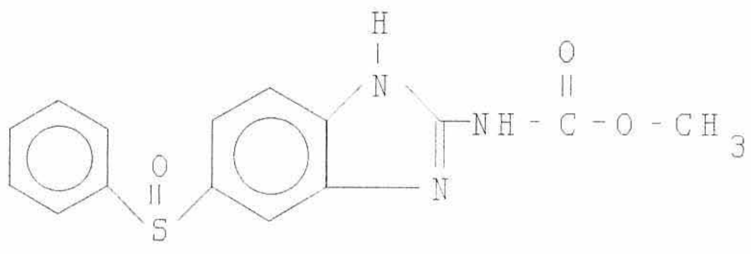
Fenbendazole at the recommended dose rate of 5 mg/kg confers good activity against adult, immature nematode stages, including inhibited larvae and eggs of gastrointestinal nematodes and the lungworm *Dictyocaulus* spp, and some activity against the tapeworms *Moniezia* spp (Alexander, 1985; Soulsby, 1986; Brander *et al*, 1991). At significantly increased dose rates, some activity against the liver flukes *Fasciola hepatica* and *Dicrocoelium dendriticum* can also be seen (Soulsby, 1986), although no claims are made in this respect.

This is one of the most non-toxic benzimidazole compounds, with a safety index in excess of 100 times the recommended dose rate and no teratogenic effects (Brander *et al*, 1991).

3.3.1.5 Oxfendazole

(Methyl[5-(phenylsulphinyl)-1*H*-benzimidazol-2-yl]carbamate)

Figure 3.6 Chemical Structure of Oxfendazole



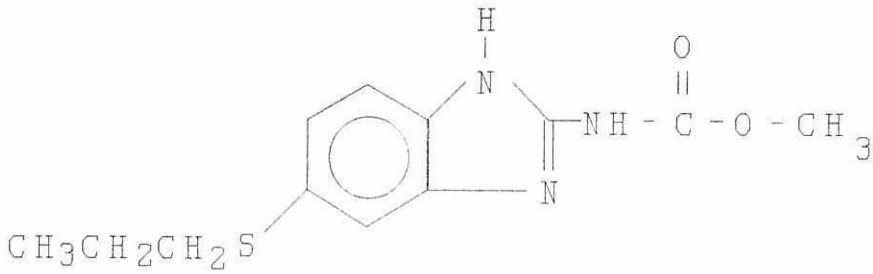
Oxfendazole, at the recommended dose rate of 5 mg/kg is highly effective against adult, immature stages (including arrested larvae) and eggs of gastrointestinal nematode species, *Dictyocaulus* spp and *Moniezia* spp (Soulsby, 1986; Brander *et al*, 1991). At increased dose rates, the efficacy extends to include *F.hepatica* (Soulsby, 1986), although no such claims are made.

Oxfendazole is the sulphoxide metabolite of fenbendazole and it is thought that it is this compound which confers the anthelmintic activity of both drugs (Brander *et al*, 1991). It has a safety index of around 10 times the recommended therapeutic dose rate, but at significantly higher dose rates can show teratogenic effects in pregnant animals (Alexander, 1985; Brander *et al*, 1991).

3.3.1.6 Albendazole

(Methyl[5-(propylthio)-1*H*-benzimidazol-2-yl]carbamate)

Figure 3.7 Chemical Structure of Albendazole



Albendazole shows good activity against adult, immature stages, including arrested larval forms and eggs of gastrointestinal nematodes (Brander *et al*, 1991). At the recommended dose rate of 5 mg/kg, it also shows good activity against *Moniezia* spp and *Dictyocaulus* spp. In addition, an increased dose rate of 7.5 mg/kg confers good activity against the adult forms of *F.hepatica* (Soulsby, 1986). This is the first anthelmintic compound for sheep to become available as a controlled release bolus (Hallas, personal communication).

The safety index is between 7.5 and 20 times the recommended dose rate (Alexander, 1985; Brander *et al*, 1991). Albendazole does show teratogenic effects, however, and is contra-indicated at the fluke and worm dose of 7.5 mg/kg for ewes between tupping time and for up to one month after removing the rams (NOAH, 1995).

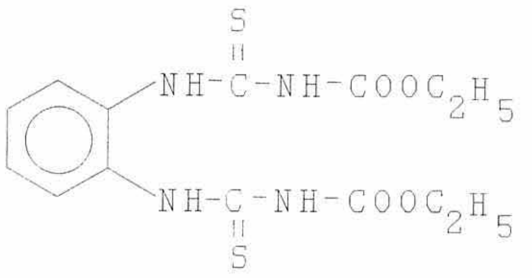
3.3.1.7 Ricobendazole

At the recommended dose rate of 5 mg/kg, ricobendazole exhibits good activity against adult worms, immature stages and eggs of gastrointestinal nematodes and *Dictyocaulus* spp. At an increased dose rate of 7.5 mg/kg, good activity is also seen against *Moniezia* spp and *F.hepatica.* Care should be taken not to exceed the recommended dose during the first month of pregnancy. The withdrawal period in meat is ten days after the last treatment and it is not suitable for use in milking flocks (NOAH, 1995).

3.3.1.8 Thiophanate

(4,4'-*o*-phenylenebis(3-thioallophanic acid)diethyl ester)

Figure 3.8 Chemical Structure of Thiophanate



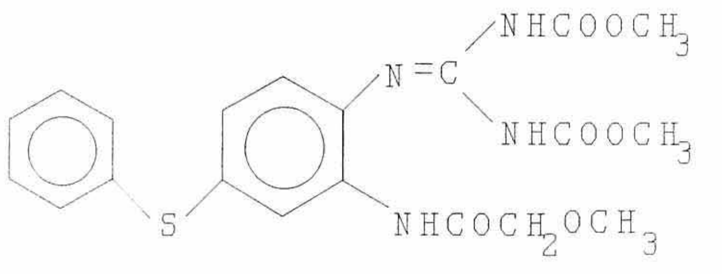
Thiophanate is not a benzimidazole compound, but undergoes *in-vivo* metabolism to produce the benzimidazole lobendazole (2-ethylbenzimidazol-2-yl-carbamate) (Soulsby, 1986; Brander *et al*, 1991). At the recommended dose rate of 50 mg/kg good efficacy against adult, immature stages and eggs of gastrointestinal nematodes is found (Brander *et al*, 1991). It shows some efficacy against *Dictyocaulus spp* at dose rates of 50-100 mg/kg. At a dose rate found in in-feed preparations (1-10 mg/kg) given daily, worm burdens and faecal egg outputs are decreased (Soulsby, 1986).

Thiophanate is probably the safest of this group of anthelmintic compounds with a dose rate of 1 g/kg proving non-toxic to most livestock (Brander *et al*, 1991).

3.3.1.9 Febantel

(*N*-{2[2,3-bis(methoxycarbonyl)guadino]-5-(phenylthio)phenyl}-2-methoxyacetamide)

Figure 3.9 Chemical Structure of Febantel

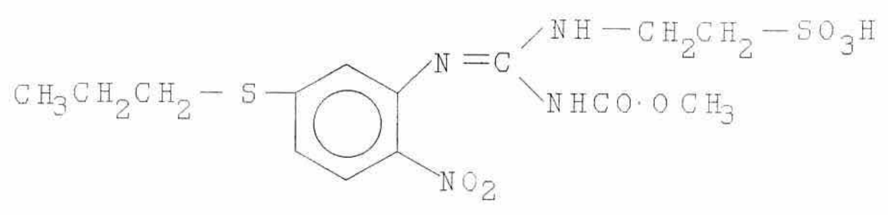


Febantel is not a benzimidazole compound, but is metabolised *in-vivo* to the benzimidazole fenbendazole (Brander *et al*, 1991). At the recommended dose rate of 5 mg/kg good efficacy is conferred against adult, immature stages and eggs of gastrointestinal nematodes and lungworms *Dictyocaulus* spp (Soulsby, 1986; Brander *et al*, 1991). Febantel has a high safety index of 40 times the recommended dose rate (Brander *et al*, 1991).

3.3.1.10 Netobimin

(*N*-methoxycarbonyl-*N*'-(2-nitro-5-propyphenylthio)-*N*''-(2-ethylsulphonic acid)guanidine).

Figure 3.10 Chemical structure of netobimin



Netobimin is not a benzimidazole, but undergoes *in vivo* metabolism to produce the benzimidazole drug albendazole and then ricobendazole, which confers the anthelmintic activity. Good efficacy can be achieved against adults, immature stages (including inhibited larvae) and eggs of gastrointestinal nematodes, *Dictyocaulus* spp, *Moniezia* spp and liver flukes (*F.hepatica* and *Dicrocoelium* spp). The drug is administered as an oral drench at a dose rate of 7.5 mg/kg (20 mg/kg for control of adult liverflukes) (Marriner, 1981).

Highly teratogenic effects have been found at high doses in rats, and its use is contra-indicated in pregnant sheep during the first 5 weeks of pregnancy (Brander *et al*, 1991).

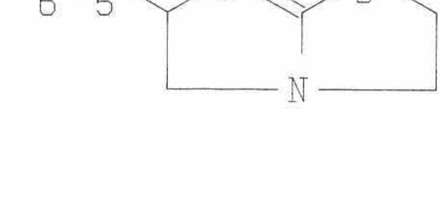
3.3.2 Imidazothiazoles

The first compound produced was a mixture of two optical isomers (tetramisole). After separation of the isomers, a pure solution of the laevo-rotatory isomer became marketed as levamisole (Alexander, 1985; Brander *et al*, 1991). At the present time only levamisole hydrochloride is marketed for use in sheep in the UK in oral drench or injectable preparations

3.3.2.1 Levamisole

(6-phenyl-2,3,5,6-tetrahydroimidazo(2,L-*b*)thiazole hydrochloride)

Figure 3.11 Chemical structure of levamisole



3.3.2.1.1 Spectrum of activity

Levamisole has proved a very effective anthelmintic against stomach and intestinal roundworms of sheep at the recommended dose rate of 7.5 mg/kg (Soulsby, 1986; Brander *et al*, 1991). It is also effective against mature and immature *Dictyocaulus* spp lungworms (Armour, 1983; Brander *et al*, 1991). It has also been shown experimentally that if levamisole is combined with clostridial vaccine, it seems to increase the antibody response to the vaccine in sheep (Hogarth-Scott *et al*, 1980; Forsyth and Wynne-Jones, 1980).

3.3.2.1.2 Toxicology

The safety index is on the border of acceptability for an anthelmintic i.e. 5-6 times the therapeutic dose rate (Gibson, 1973; Brander *et al*, 1991). Overdosage results in signs of cholinergic toxicity eg depression, muscle tremors, salivation, brachycardia, respiratory embarrassment and constriction of the pupils (Armour, 1983; Soulsby, 1986; Brander *et al*, 1991). Liver damage has been shown to make sheep more susceptible to potential levamisole toxicity (Alexander, 1985). It is advised in the majority of levamisole preparations that it should not be used concurrently with organophosphorus compounds. This is due to the anti-cholinesterase activity shown by levamisole (Campbell and Rew, 1986).

Toxicity has been seen in lambs, therefore doses should be calculated carefully, especially if administration is by subcutaneous injection as this gives higher blood concentrations than does drenching (Campbell and Rew, 1986). No teratogenic effects have been reported (Brander *et al*, 1991). Levamisole acts quickly and is cleared from the body quickly (Henderson, 1990).

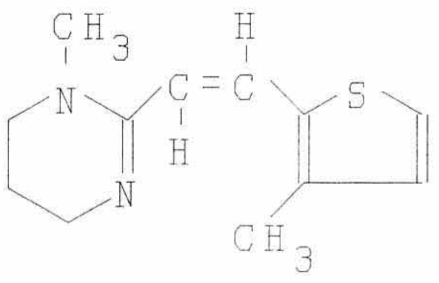
3.3.3 Tetrahydro-pyrimidines

This group includes the compounds pyrantel and morantel They have a more limited usage, however, when compared with other Groups of broad spectrum anthelmintic as activity is confined to stomach and intestinal roundworms (Brander, 1991).

3.3.3.1 Morantel

((*E*)-1,4,5,6-tetrahydro-1-methyl-2-[2-(3methyl2(thienyl)ethenyl]pyrimidine)

Figure 3.12 Chemical structure of morantel



Morantel, at the recommended dose rate of 10 mg/kg, confers good activity against adult and the later developing larvae (Soulsby, 1986; Brander *et al*, 1991). There is little or no ovicidal activity or activity against arrested larvae or adult lungworms (Brander *et al*, 1991). The meat withdrawal period of morantel is relatively short (3 days) and it has a safety index of 30 times the recommended dose rate (Brander *et al*, 1991).

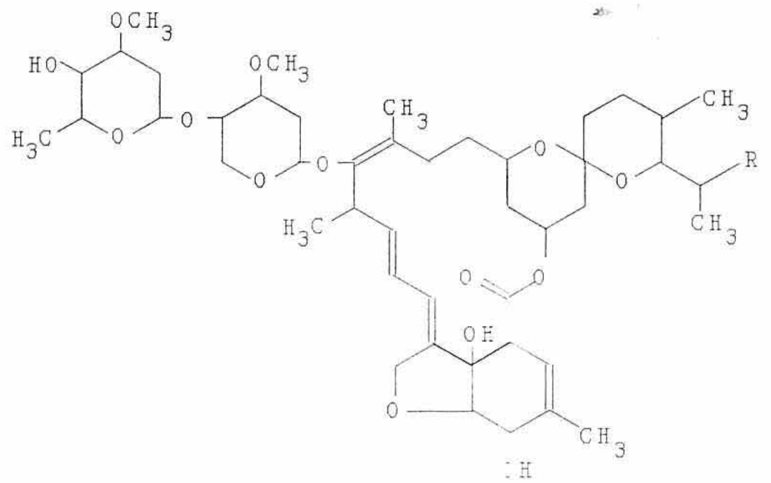
3.3.4 Avermectins

This group of chemicals was first reported in 1979 (Brander, 1986). The avermectins are fermentation products of the fungus *Streptomyces avermitilis* (Soulsby, 1986). The only compound currently marketed for use in sheep in the UK is ivermectin although other derivatives are marketed in some other countries. The usual dose rate recommended for treatment of sheep is 0.2 mg/kg for ivermectin.

3.3.4.1 Ivermectin

Ivermectin consists of a mixture comprising of mainly 22,23-dihydroavermectin B_{1a} (80%) with some B_{1b} (20%) (Brander *et al*, 1991).

Figure 3.13 Chemical Structure of Ivermectin



3.3.4.1.1 Spectrum of activity

Ivermectin is highly effective against gastrointestinal nematodes and *Dictyocaulus* spp lungworms (adult and larval stages) and shows variable activity against arthropods (insects, ticks and mites) (Brander, 1986; Benz *et al*, 1989; Brander *et al*, 1991). However, it does not possess ovicidal activity, and is inactive against tapeworms and liver flukes (Brander, 1986; Brander *et al*, 1991).

3.3.4.1.2 Toxicology

Because ivermectin acts on GABA-mediated nerves, it is not thought likely to have much effect on mammals where this neurotransmitter is only found in the CNS. Little ivermectin has been shown to cross the blood-brain barrier (Brander, 1986). However, gross over-dosage has been shown to cause paralysis (Alexander, 1985). The witholding period is 14 days in meat (NOAH, 1995). Alternatively if milk is to be used for human consumption, ewes should not be treated within 28 days prior to the commencement of lactation.

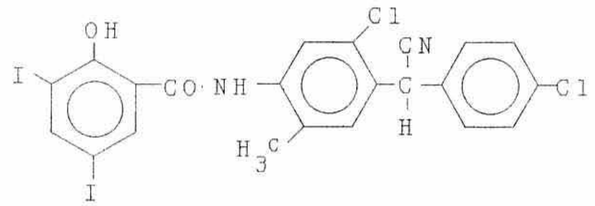
3.3.5 Narrow spectrum anthelmintic/flukicide drugs

3.3.5.1 Salicylanilides

3.3.5.1.1 Closantel

(*N*-[5-chloro-4[(4-cholorophenyl)cyanomethyl]-2-methylphenyl]-2-hydroxy-3,5-diiodobenzamide).

Figure 3.14 Chemical Structure of Closantel

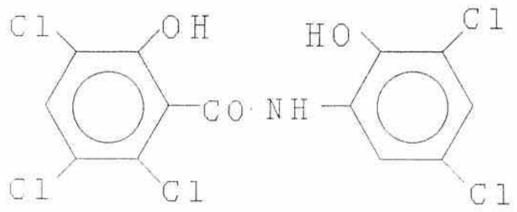


This is an effective flukicide (adult and 6 week old *F.hepatica*) (Brander *et al*, 1991), with good activity against certain blood sucking nematodes (e.g. *Haemonchus contortus* (Hall *et al*, 1981). It has also been shown to possess variable efficacy against a variety of arthropods (e.g. *Oestrus ovis*) (Soulsby, 1986). It has a relatively low safety index, however, of 6 times the recommended dose rate, but has shown no teratogenic effects (Brander *et al*, 1991). Withdrawal periods are 42 days in meat and it is not recommended for use in milking flocks (NOAH, 1995)

3.3.5.1.2 Oxyclozanide

(3,3',5,5',6-pentachloro-2'-hydroxy-salicylanilide)

Figure 3.15 Chemical Structure of Oxyclozanide

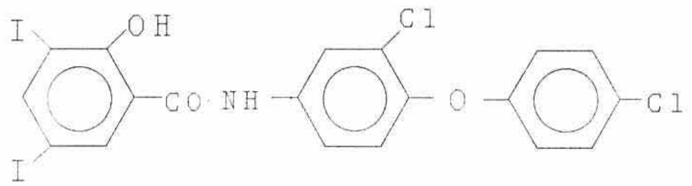


This compound was the first derivative of this group of chemicals introduced in 1966 (Brander, 1986). It is usually recommended at a dose rate of 15 mg/kg in sheep. It is highly effective against adult liver flukes (*F.hepatica* spp) and has a safety margin of 4-6 (Brander, 1986; Brander *et al*, 1991). Safety is extremely important in liver fluke treatment because extensive liver damage may be present in the animal at the time of treatment. It is given orally and has a 28 day witholding period after treatment. It is not recommended for use in milking flocks (NOAH, 1995).

3.3.5.1.3 Rafoxanide

(*N*-[3-chloro-4-(4-chlorophenoxy)phenyl]-2-hydroxy-3,5-diiodobenzamide)

Figure 3.16 Chemical Structure of Rafoxanide

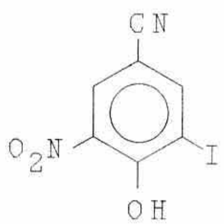


This chemical has been shown to be 99% effective against adult and 86-99% effective against six week old *F.hepatica* (Brander, 1986) at the recommended dose rate of 7.5 mg/kg Brander, 1986; Brander *et al*, 1991). It also has some activity against blood-sucking nematodes (eg *Haemonchus contortus*) (Brander *et al*, 1991). Rafoxanide has a safety margin of 5-6 times the recommended dose rate (Brander, 1986; Brander *et al*, 1991) and a 28 day witholding period after treatment. Because of the long witholding period, it would not be recommended in milking flocks.

3.3.5.1.4 Nitroxynil

(4-hydroxy-3-iodo-5-nitrobenzonitrile)

Figure 3.17 Chemical Structure of Nitroxynil



At the recommended dose rate of 10 mg/kg, nitroxynil is effective against adult fluke, and at a 50% increase in dose rate this drug shows good activity against 6 weeks old immature flukes. It also confers some activity against nasal bot fly larvae (*Oestrus ovis*) and blood-sucking nematodes (eg. *H.contortus*). Nitroxynil has a long withdrawal period of 30 days, which makes it an unsuitable drug for use in milking flocks. The safety index for nitroxynil is approximately four times the recommended dose rate (Brander *et al*, 1991), therefore extra care must be taken when dosing against immature flukes.

3.4 Methods to increase the efficiency of a wormer at the farm level

In order for a pharmaceutical company to receive a licence to market a drug, that drug must pass rigorous testing procedures, including efficacy and safety trials in order to ensure that the end product is safe at the recommended dose rate, but will also perform effectively in the field situation. However, the efficacy level can only be achieved if the recommended procedures for administering the drug are adhered to. More often, misuse of these drugs occurs which leads to disappointing results. In this section, the major areas were inaccuracies can occur are highlighted and methods to improve the efficiency of a particular drug discussed.

3.4.1 Choosing a suitable wormer

There are a number of criteria which require consideration when deciding whether a particular drug is suitable for use as an anthelmintic compound:

1. A correct diagnosis of the problem is very important since gastrointestinal nematodes are not the only cause of diarrhoeas in lambs (Henderson, 1990).

2. The drug should be effective against as many species of parasites and as many classes of helminths as possible (Urquhart *et al*, 1987). Some anthelmintics show activity against species of nematodes, trematodes and cestodes (Brander *et al*, 1991). Others are limited to

only one group of worms.

3. The drug should be non-toxic to the host, or at least have a wide safety margin (Urquhart *et al*, 1987). A safety index of at least six times the therapeutic dose rate is expected for all modern anthelmintics marketed (Brander *et al*, 1991). This is particularly important when dosing old or very sick animals. Also, some products may be detrimental to the foetus (teratogenic) eg parbendazole and therefore should not be used in pregnant, or suspected pregnant animals (Henderson, 1990).

4. There are considerable differences in the witholding periods needed for the different wormers available prior to marketing the milk and meat of treated animals. This may influence the choice of wormer made (Urquhart *et al*, 1987), especially in the case of milking flocks (Henderson, 1990; Brander *et al*, 1991). However, where prolonged protection is desirable in non-milking flocks, a longer withdrawal period maybe considered desirable (Brander *et al*, 1991).

5. Ease of administration (Urquhart *et al*, 1987) is particularly important on hill farms where difficulties associated with gathering the flock may mean medicated feed blocks are utilised.However, although easier to use, they are often less efficient at controlling worm problems (Henderson, 1990).

6. The drug should have no unpleasant side-effects or hazards to the human operator (Brander *et al*, 1991).

7. Costs should be minimal (Urquhart *et al*, 1987) and it should be relatively easy to integrate the drug into the management system i.e. easy to administer, stable to the effects of sunlight, temperature and moisture and should not necessitate the need for complex dosing schedules (Brander *et al*, 1991).

8. The type of role played by an anthelmintic within a nematode control programme can also

be an important factor when choosing a product. If the drug is being used to cure nematode parasitism (therapeutic role), it should be effective against the pathogenic stage of the parasite and stop clinical signs of disease, leading to rapid recovery through removal of the parasite. If the drug is being used as a preventative measure (prophylactic role), the cost of administering the preventative strategy should be offset by the increased production brought about, i.e. the cost-benefit should compete with other control measures eg. pasture management and it should not interfere with the development of the host's natural immunity to the disease (Urquhart *et al*, 1987).

3.4.2 Correct usage of a wormer

It is important that all individuals within the flock receive an accurate therapeutic dose of the wormer selected in order to achieve the optimum efficiency for that drug. In most farm situations, there are areas where improvements could be made regarding correct usage of these drugs and these will be highlighted in the following discussion.

Ensuring that all individuals are dosed is very important as if a significant minority of animals escape dosing, this can have serious consequences upon the level of contamination occurring on pasture. This situation is normally encountered on hill farms, where the terrain and facilities available for handling the flock are far from ideal. It has also been found that if an animal avoids being rounded up for dosing once, the same animal often manages to avoid being dosed again (Rowlands, 1989_a), resulting in a proportion of the flock never being dosed.

General areas where problems could arise regarding efficiency of a drug include compliance with the manufacturer's recommendations. The product requires storing as specified by the manufacturer and using within the "use-by" date usually stamped on the side of the container. If non-compliance occurs the drug is unlikely to perform as well as expected and could even produce harmful results (Rowlands, 1989_b).

In most situations, however, the most common inaccuracies encountered in worming the flock result from administration of the incorrect dose. If the individual animal is underdosed, selection for resistant nematodes is more likely to occur. On the otherhand although most anthelmintics have a reasonable margin of safety, overdosing may lead to toxicity symptoms occurring. This is most likely to occur in those sick or pregnant animals, or those in poor body condition through undernutrition, parasitism or old age (Henderson, 1990). There are several reasons for inaccurate dose administration which will now be discussed. Firstly in order to calculate the correct dose required, each animal should be weighed accurately. However, since this is not an economical proposition, it is recommended that the flock is divided into groups based on age and sex class and that a sample of the heaviest animals within each group is weighed to estimate the dose required for that group of animals (Rowlands, 1989_b). Unfortunately, in most farm situations this policy is not followed. In a study conducted in 1992 of farms in the North Wales area, 79% of farmers said they estimate the liveweight of their flock by sight or touch alone (see Chapter 5). This has since been backed up by a more nationwide survey where 54% of farmers were reported as not weighing their stock to calculate drug dose rates (Anon, 1993). A study conducted by Besier and Hopkins (1988) in Australia, reported how large the errors can be of calculating the dose rate in this way. When 237 farmers were asked to estimate the mean body weight of a small group of sheep only 27% of farmers came within 20% of the correct value, and 86% of the estimations would have led to underdosing to some degree. Not only does this level of inaccuracy reduce the efficiency of the dosing carried out, but with current concerns on a global scale regarding anthelmintic resistance, this degree of underdosing is likely to aid the development and spread of resistant genes, a subject which will be discussed more fully later in this chapter.

Another factor, which often affects the dose level of drug administered to the flock is the maintenance of the equipment used. This is most important with oral drenching, since this is the administration method most favoured by sheep farmers. In the North Wales survey referred to above, 57.9% of farmers said they did not maintain or calibrate the equipment after every dosing session, and 20.8% of farmers maintain the equipment less frequently than once in two years, if ever (see Chapter 5). On a nationwide scale, 25% of farmers were found not to calibrate their dosing equipment (Anon, 1993). The difference between these figures is probably an indication of different worming practices occurring in different areas of the country. On the other hand, the differing survey techniques used could have played a large part in causing these differences. The 1993 survey included areas of southern England, where benzimidazole resistance is now fairly widespread. Therefore, it is more likely that farmers in these areas are more aware of the implications of good worming management than in other areas where the problem has not yet been identified, leading to a more complacent attitude in these areas. Common problems with drenching equipment is sticking valves and incorrectly calibrated dosing guns, which generally leads to the livestock receiving a reduced dose. Care needs to be taken regarding the handling of the drug since many anthelmintic preparations are suspensions, which require shaking before use. However, if the suspension is shaken too violently, excessive air bubbles are produced, which if taken up as part of the measured dose, can again lead to underdosing (Rowlands 1989_{a+b}).

3.4.3 Specific seasonal requirements of a wormer

Different species and different lifestages of a particular species of nematode may be present at different times of the year (Henderson, 1990). Therefore different problems arise at different times of the year thereby requiring different treatments. For example, nematodiriasis in young lambs is a serious problem during April-June. Certain wormers require to be used at a higher dose rate to control nematodiriasis than is normally recommended for worm control. Therefore, in order to obtain an optimal control strategy, background local epidemiological information is an important consideration. There are occasions during the year when roundworm and liver fluke problems may coincide. This has led to the development of a number of combination fluke and worm drenches. However, care is needed if one of these products is chosen as the relative dose rates of the two components may not provide the optimal solution required at individual farm level (Henderson, 1990).

A number of anthelmintics have also been developed to include trace elements eg cobalt and selenium. However, in cases of suspected cobalt deficiency, this is not the most efficient way of providing this element since a continuous daily supply of cobalt is necessary. Selenium levels in some products may provide protection against deficiency if dosing is carried out on a regular basis i.e. the flock is being grazed on dirty pasture. If, on the other hand, the flock is being grazed on clean pasture and regularly dosed, these products would prove inappropriate as selenium would need to be supplied separately (Henderson, 1990).

3.4.4 Alternation of chemical groups

With the appearance of a large number of reports indicating increases in the prevalence of anthelmintic resistance over recent years, the action of alternating the group of wormer used on an annual basis has become adopted in many situations. This will be discussed more fully in the "Anthelmintic Resistance" section of this chapter.

3.4.5 Worm and move strategy

One of the commonest mistakes made is to dose the flock and leave them on contaminated pasture (Henderson, 1990). If an anthelmintic is only given as a single dose, it will kill those parasites passaging through the individual animal at the time of dosing, but the animals are likely to become reinfected almost immediately after treatment. Therefore, wherever possible, animals should be dosed, yarded for at least 24 hours and then moved to alternative clean pasture. It should be pointed out, however, that if resistant genes are already present within the flock, this procedure could exacerbate the problem because only resistant worms would survive to contaminate the clean pasture.

In a number of cases, this worm and move is not possible due to lack of alternative pasture and therefore the flock will require repeated dosings with a wormer throughout the season.

3.4.6 Mixing different wormers

Products should not be combined or used consecutively, unless formulated together by the manufacturer (Henderson, 1990). Only products specifically designed for use in sheep should be used and only by the route of administration recommended by the manufacturer.

3.4.7 In-feed formulations

In general, this method of administration is not recommended as it is impossible to ensure each animal has received the correct dosage. However, in some situations this remains the only practical way of administering an anthelmintic. While an in-feed medicated block is being used, all other non-medicated feedstuffs should be removed.

3.5 Safety precautions

3.5.1 Human risks

It should always be remembered that drugs are potentially toxic chemicals and should always be handled with care by the operator. Hygiene after dosing must be rigorously adhered to, especially if the operator is a smoker or nail biter (Henderson, 1990).

3.5.2 Administration technique

Using the dosing equipment correctly is also very important. Horrific injuries can occur to the animal if the drenching gun is not operated with care, leading in the most extreme cases to death or the need for humane destruction of the animal. It is also important to ensure that the drug is swallowed by the animal before it is released, otherwise the drug may be spat out. If dosing is carried out in a pen, it is important to mark each sheep when dosed to prevent some animals receiving a double dose and some missing being dosed at all.

3.6 Anthelmintic resistance

The basis of this section of Chapter 3 has already been published (Hazelby *et al*, 1994). Anthelmintic resistance, defined as "the ability of an increased number of individuals to tolerate a dose of a compound that would prove lethal to the majority of individuals in a normal population" (Kelly and Hall, 1979), has been recorded in gastrointestinal nematodes during the last thirty years. It is thought to have come about through the more intensive livestock husbandry practised in modern farming regimes throughout the world. These include new techniques to maximise growth during a single season and also to maximise the carrying capacity of the land by increasing the stocking density. One method which may be used to measure the change in resistance status of a parasite population (the resistance factor (R_f)) was defined by Kelly and Hall (1979) as "the concentration of anthelmintic required to kill 50% of resistant parasites divided by the concentration of anthelmintic required to kill 50% of susceptible parasites".

The majority of reported cases of anthelmintic resistance in the southern hemisphere involve the species *Haemonchus contortus*, but in the northern hemisphere *Teladorsagia* spp (formerly *Ostertagia* spp. (Thomas and Probert, 1993)) and *Trichostrongylus spp.* are more usually implicated. On a worldwide scale, representatives of all groups of broad spectrum anthelmintics, and of some narrow spectrum drugs have been reported to varying degrees as having gastrointestinal nematodes resistant to them.

Side resistance, where "resistance to a compound is the result of selection by another compound with a similar mode of action" (Prichard *et al*, 1980) i.e. between drugs within a single chemical group, is most prevalent between the benzimidazole drugs. However, this type of resistance mechanism is more complicated in the case of levamisole and morantel. Originally, these two drugs were considered to possess the same mode of action and were placed in the same drug group. However, research workers have recently discovered that whereas morantel resistance confers side resistance to levamisole, if levamisole resistance is found, morantel may still exhibit good activity against these levamisole-resistant nematodes (Burr-Nyberg, personal communication). Through this, it is now suggested that morantel and levamisole should be placed in different chemical groupings.

Multiple resistance, which can occur through exposure of the nematode population to several different groups of anthelmintic over a number of years following extensive usage of each drug, has been recorded in the benzimidazoles, imidazothiazoles (levamisole), tetrahydropyrimidines (morantel), salicylanilides (closantel, rafoxanide), organophosphorus compounds (naphthalophos) and avermectins (ivermectin) (Green *et al*, 1981; Coles, 1991).

The southern hemisphere tends to suffer worst from resistance problems due to the warmer climate leading to a shorter generation time and hence quicker establishment and spread of resistant populations and the implied need for more frequent dosing. The most widely reported areas include Australia, New Zealand, South America and South Africa (Donald, 1982; Coles, 1991).

3.6.1 Benzimidazole resistance

3.6.1.1 The Southern hemisphere

Australia is one of the best documented areas where anthelmintic resistance has been reported. Prevalence of benzimidazole resistance is widespread, with 80-90% of properties being affected in some of the worst affected zones. The two most likely causes of this extensive build-up of resistant genes are the hot climate, as already discussed, and the high frequency of dosing (Hotson *et al*, 1970) caused by the ever increasing intensity of livestock production. The list of species reported at the current time to exhibit benzimidazole resistance include *H.contortus, Teladorsagia* spp, *Trichostrongylus* spp, *Cooperia curticei, Nematodirus* spp and *Oesophagostomum* spp (Anon, 1989).

The first reported case of benzimidazole resistance in New Zealand was recorded during a parasite control trial in Ruakura where *H.contortus* was found to be resistant to albendazole (Vlassoff and Kettle, 1980). A subsequent survey carried out by Kettle *et al* (1981) revealed that whereas benzimidazole resistance was prevalent in North Island, no resistant strains could be located on South Island - apart from the Nelson Region (Kettle *et al*, 1981; Kettle *et al*, 1982). In 1982, Kemp and Smith reported benzimidazole resistance in *Trichostrongylus* spp. At the current time, the following species are known to contain benzimidazole-resistant strains: *H.contortus, Teladorsagia* spp, *Trichostrongylus* spp, *Nematodirus* spp, *Cooperia curticei, Chabertia* spp and *Oesophagostomum* spp (McKenna and Watson, 1987; Hughes, 1988).

In South Africa benzimidazole resistance, combined as multiple resistance with closantel, rafoxanide and ivermectin has been reported (van Wyk and Gerber, 1980; van Wyk and Malan, 1988; van Wyk *et al*, 1989). At the present time, there are more than 25 strains of *H.contortus* and 1 strain of *Ostertagia spp* reported as showing benzimidazole resistance (van Schalkwyk *et al*, 1983; van Wyk, 1990).

3.6.1.2 Benzimidazole resistance in Europe (excluding the UK)

Until the early 1980's there had been no reported cases of benzimidazole resistance in Europe and until recently anthelmintic resistance played a very minor role in terms of parasite management.

The first reported case of benzimidazole resistance came from Switzerland in 1980, where Jordi (1980) described a strain of *H.contortus* which was found to be partially resistant to thiabendazole. Since 1980, there have been no further reports of resistance of any kind in Switzerland.

In France, the first confirmed case of benzimidazole resistance in sheep was reported by Kerboeuf *et al* in 1988 in the Loire valley. However, resistance in goats had been confirmed three years earlier in the same region (Kerboeuf and Hubert, 1985). At the present time, reports of resistance have been confined to three areas: the Limousin area, Loire Valley and Monts de Lyonnais (Dorchies, 1992).

In the Netherlands, Boersema *et al* (1987) reported incidences of benzimidazole resistance as high as 47% by 1983. However, this figure was calculated from visiting farms with known parasite control problems and therefore does not reflect a true picture of resistance prevalence in the Netherlands. The first case of benzimidazole resistance in *Cooperia* spp in Europe was reported in the Netherlands by Borgsteede (1986).

In Germany, resistance to several benzimidazole compounds has been reported in *H.contortus* (Bauer *et al*, 1987).

Bjorn *et al* (1991) described the first benzimidazole resistance in Denmark where *Teladorsagia* spp resistance to benzimidazole products was found in seven out of the twenty two flocks tested.

3.6.1.3 The UK situation

In the UK, benzimidazole resistance was first reported on a Cheshire farm, where thiabendazole was found to be ineffective against *Teladorsagia* spp at twice the recommended dose rate (Britt, 1982). This was further investigated by Britt and Oakley (1986) who found that the strain of *Teladorsagia circumcincta* located on this Cheshire farm exhibited resistance to both thiabendazole and fenbendazole when tested using the faecal egg count reduction test (F.E.C.R.T) and the controlled anthelmintic efficacy test (Britt and Oakley, 1986). While this work was being carried out, benzimidazole resistance was also being investigated in a closed flock of breeding ewes at the Ministry of Agriculture Central Veterinary Laboratory, Weybridge, Surrey in 1983. Again, *T.circumcincta* was considered to have developed resistance after thiabendazole had been used for fifteen years at monthly intervals (Cawthorne and Whitehead, 1983). Also in 1983, resistance was reported from a commercial flock in southern England (Cawthorne and Whitehead, 1983). In both cases side resistance was found to fenbendazole and oxfendazole, and in the case of the commercial farm, to albendazole too. The first incidence in the UK of benzimidazole resistance in *Cooperia curticei* was confirmed by Hunt *et al* (1992) in Cornwall during 1990.

In recent years surveys have been conducted by a number of workers attempting to determine the prevalence of resistance in the UK. However, at the present time these surveys have been confined to localised areas, mainly in the southern counties. Therefore, although this work provides invaluable information at the local level, a true picture of the current UK situation has not been achieved to date. In the southern counties, there appears to be an increase in benzimidazole resistance. In 1984 13.5 % of farms surveyed were found to have benzimidazole resistance (Cawthorne and Cheong, 1984). By 1989, this figure had increased to 36% (Taylor and Hunt, 1989). In 1992, a more extensive survey was carried out in three counties of southern England using the egg hatch assay and larval development test to locate benzimidazole resistant genes (Coles, 1992; Hong *et al*, 1992). The percentage of farms where positive results were confirmed with both test procedures was found to be 36%. However, if all suspected cases of resistance recorded (i.e. positive results from only one test procedure) were included, the prevalence rate was found to be as high as 51%. A resistance level of 68% was postulated by the authors, but this is open to criticism since the only farms included in this sample were those from which adequate faecal samples were taken to carry out both *in vitro* tests. Both *Ostertagia* and *Haemonchus* species were implicated in this study, however resistance by *O.circumcincta* was found to be more prevalent than that of *H.contortus* (Hong *et al*, 1992).

The area sampled for survey purposes is relatively small in terms of the whole of the UK, and it is also one of the most intensively farmed regions of sheep production in the UK. However, although this does not mean that resistance problems are not likely to occur in other regions, it is much less likely that such high incidence levels will exist, partly due to differing management systems, but also due to the less favourable climate for survival of helminths in the more northern regions of Britain. A survey conducted by Evans (1988) during the early 1980's failed to identify anthelmintic resistance in Northeast England, an area which maintains approximately 20% of the national sheep flock (Scott *et al*, 1991). More recently, an incidence of 24.3% has been suggested in Scotland, *O.circumcincta* being the main species implicated (Mitchell *et al*, 1991) in an area which is calculated as being home to approximately 22% of the national flock (Scott *et al*, 1991). No specific data exists on the incidence of any benzimidazole resistance in Wales despite containing approximately 25% of the national flock (Scott *et al*, 1991). However it has been recently found in a survey carried out during 1992 on farm management practices of North Wales farmers that the possibility for the development of resistance is present (see Chapter 6). Hence, it should be recognised that the potential does exist for resistant genes to develop further in other parts of the country.

3.6.2 Morantel resistance

Morantel tartrate resistance was first confirmed in Australia in 1979 (Sangster *et al*,

1979) where field strains of *T.colubriformis* and *T.circumcincta* were found to show multiple resistance to thiabendazole, levamisole and morantel tartrate. At the time in South Africa, there have been at least two field strains of *H.contortus* and one strain of *T.colubriformis* reported (van Wyk *et al*, 1989; van Wyk *et al*, 1990).

3.6.3 Levamisole resistance

3.6.3.1 The worldwide situation

In Australia, levamisole resistance has been widely reported in the worst affected zones for roundworm problems (Hotson *et al*, 1970). In New Zealand, levamisole resistance has not yet been confirmed; the only case of possible levamisole resistance was reported by McKenna and Watson (1987) where levamisole was shown to have reduced efficacy against *Nematodirus spp*. However, the following year, the same response was reported in goats dosed with levamisole at the same dose rate as that recommended for sheep. This led to the suggestion that perhaps the lack of efficacy was due to drug failure at the dose rate used, rather than to the development of resistance (Hughes, 1988). In South Africa, there have been two reported cases of resistance in *H.contortus* and one strain of *T.colubriformis* showing resistance to levamisole (van Wyk *et al*, 1989; van Wyk *et al*, 1990).

At the present time, the only European country reported to have a recognised incidence of levamisole resistance is Denmark (Bjorn *et al*, 1991), which is perhaps a little surprising considering that this country was the latest to record anthelmintic resistance of any kind.

3.6.3.2 The UK situation

There have been a couple of cases of suspected levamisole resistance in Great Britain. The first report came from a farm in the Peak National Park where it was thought that both *Trichostrongylus axei* and *Ostertagia spp* had developed resistance to levamisole after the drug had been used for nematode control for ten years (Britt, 1986). However, subsequent follow-up studies, involving detailed laboratory investigations failed to confirm levamisole resistance in this nematode population (Rowlands, 1989_b). The second case of suspected levamisole resistance was recorded during the 1991 survey conducted by Hong *et al* (1992). It is still unclear, however, whether this is a case of true resistance or a breakdown in drug efficiency.

It is possible that levamisole resistance could be more prevalent than has been shown in the studies undertaken to date. However, it is equally likely that the lower efficacy often experienced when using levamisole could be misinterpreted as being the first sign of developing resistance. What is required is a reliable test procedure for detecting levamisole resistant genes.

3.6.4 Avermectin resistance

In an initial report during 1987, intensive drug usage and favourable climatic conditions were highlighted as leading to the emergence of the first field strains of *H.contortus* showing resistance to ivermectin in South Africa (Carmichael *et al*, 1987). Ivermectin resistance was confirmed by van Wyk and Malan (1988) when one strain of *H.contortus* was found to have developed resistance after ivermectin had been used on only three occasions. A year later, four out of a further five strains of *H.contortus* tested showed varying levels of ivermectin resistance. It was also pointed out that the strains tested to date covered three out of the four provinces of South Africa, a fact which indicated that ivermectin resistance could be a widespread problem (van Wyk *et al*, 1989). At the present time there are more than nine strains of *H.contortus* reported as showing ivermectin resistance in South Africa (van Wyk, 1990).

Development of ivermectin resistance in *H.contortus* has also been reported in Brazil after regular dosing with ivermectin during a 4.5 year period (Echevarria and Trindade, 1989).

In the UK, ivermectin resistance was reported in goats (Jackson *et al*, 1991) after ivermectin had been used under intensive conditions for over two years. It was also found that when these resistant worms were passaged through sheep, the resistance characteristics were retained. Because goats do not develop as good an immunity to gastrointestinal nematodes as do sheep, dosing regimes tend to be more intensive and therefore the likelihood of resistance problems developing is high. The fact that these resistant worms could then transfer and passage through sheep could have serious implications for the hill farmer who, to date, has suffered fewer resistance problems than the lowland farmer.

3.6.5 Narrow spectrum drug resistance

The first case of *H.contortus* resistance to rafoxanide in South Africa was reported by van Wyk and Gerber (1980). A further two strains were later identified during more extensive trials (van Wyk *et al*, 1987). The authors were surprised, however, that so little rafoxanide resistance had been reported during the 15 years of marketing in South Africa, as the high frequency of dosing combined with climatic conditions found in South Africa appear to be highly favourable to the development of resistance. At the current time there are six strains of *H.contortus* known to show rafoxanide resistance (van Wyk, 1990).

The first case of *H.contortus* showing resistance to closantel in South Africa was reported by van Wyk *et al* (1982). During more extensive investigations during 1988, one of five strains of *H.contortus* tested showed closantel resistance (van Wyk and Malan, 1988). At the current time there are four reported strains of *H.contortus* known to exhibit closantel resistance (van Wyk, 1990).

3.6.6 Techniques for detecting drug resistance

3.6.6.1 *In-vivo* techniques

3.6.6.1.1 Faecal egg count reduction test (FECRT)

This technique is still the one most widely used in the field for routine diagnosis of worm problems (Presidente, 1985). Faecal egg counts are used to estimate worm burdens carried by individual sheep immediately before and 10-14 days after drug usage which evaluates the anthelmintic efficiency of the drug used.(Waller, 1986; Martin *et al*, 1985). In order to achieve useful results, each group of test animals should consist of at least ten animals whose pre-dose egg counts show a mean of >200 eggs per gram of faeces (Presidente, 1985).

The %FECR is calculated in the following way:

$$FECR\% = \left(1 - \frac{T_2}{T_1} \times \frac{C_1}{C_2}\right) \times 100$$

Where:

T_1= geometric mean egg count of the treated group before treatment
T_2 = geometric mean egg count of the treated group after treatment
C_1 = geometric mean egg count of the control group before treatment
C_2 = geometric mean egg count of the control group after treatment

Because there is no requirement for highly skilled personnel, facilities or resources the FECRT is a relatively inexpensive procedure. Other advantages include no requirement to move or slaughter livestock and the fact that the operation can be carried out on the farm (Waller, 1986; Johansen, 1989).

If all that is required is an overview of whether or not a particular anthelmintic drug succeeds in controlling egg production and hence the level of faecal contamination on pasture, this procedure is quick to undertake. If more complex results are required, i.e. larval identification and/or *in-vitro* testing, the test could take 2-3 weeks to complete, making it longer than other efficacy tests available (Presidente, 1985; Johansen, 1989).

3.6.6.1.2 The critical anthelmintic test

This test was first described by Hall and Foster (1918), but is very rarely used these days because it is very labour intensive and time consuming thereby making it very expensive to perform. It also often produced inaccurate results. The animals were dosed with the test anthelmintic and a total faecal collection was made every day after treatment. On the fourth day the animals were killed and the remaining worms collected and counted. The percentage efficacy of the drug was then assessed by comparing the number of worms passed to those retained within the animal.

3.6.6.1.3 The controlled anthelmintic efficacy test

This technique has been described by a number of workers during the last 30 years (Gibson, 1964; Arundel, 1967; Prichard *et al*, 1980; Powers *et al*, 1982). Lambs are artificially infected with a single species of trichostrongylid nematode. At a specified time after infection, designed to coincide with the development time to adult emergence of the nematode species under investigation, an anthelmintic is used. At a set time after drug administration, all groups of lambs are slaughtered and worms collected from the gastrointestinal tract using a dilution technique. Similarly, infected but undosed animals are also slaughtered and processed for control purposes. The worm burdens are recorded and dose response parameters (ED_{50} and $ED_{90)}$ calculated.

Because of the large numbers of animals needed to achieve accurate results, combined with the large requirements of time and labour, this is a costly procedure to carry out. Due to the high reliability of the results obtained, however, it is suited for research purposes and final confirmation of resistance primarily suggested by *in-vitro* assays. Animal models have been developed to carry out this procedure. Guinea pigs (Kelly *et al*, 1981) and immunosupressed rats (Gration *et al*, 1992) have both been found to be suitable for such trials. However, whereas economic considerations seem to make the use of such animal models attractive, much more research is needed before such a method could be used as a bonafide alternative technique.

3.6.6.2 *In-vitro* techniques

3.6.6.2.1 *In-vitro* egg hatch assay (benzimidazole)

Benzimidazole resistance has also been shown to occur within the egg stage of the nematode species *H.contortus* and *T.colubriformis* (Coles and Simpkin, 1977). This has led to a number of techniques being developed to detect resistance using incubated eggs (Le Jambre, 1976; Coles and Simpkin, 1977; Hall *et al*, 1978; Whitlock *et al*, 1980; Donald, 1982). Eggs are recovered from rectal faecal samples and then concentrated. Because it is important that the eggs are fresh, or at least at the same stage of development, anaerobic storage techniques are now widely used since Hunt and Taylor (1989) discovered that this procedure has no detrimental effect upon the efficiency of the assay, as long as the eggs are used within seven days of collection. This is a very important development as it means samples can be sent by post to laboratories with the facilities to undertake the assay, making it a more widely available technique for resistance screening. A set of serial dilutions of the test drug are produced which are added to a known quantity of eggs and the larvae which hatch are counted after a set period of incubation. The percentage hatch of larvae can then be calculated for each dilution and plotted using log probits to determine the LC_{50} values. The resistance factor (R_f) can then be recorded using the following formula:

$$R_f = \frac{LC_{50} \text{ resistant strain}}{LC_{50} \text{ susceptible strain}}$$

The procedure has proved easily repeatable, due to the detailed and well documented methodology, although results can be highly variable, even under controlled conditions

(Johansen, 1989). It is much more sensitive than *in-vivo* techniques, not only detecting the presence of benzimidazole resistance, but also confirming the level of resistance within the nematode population (Hall *et al*, 1978). Although it is cheaper, more accurate and less time consuming (1-3 days) to undertake than the FECRT (if larval identification is required), it requires more skilled personnel and is therefore more suited to research purposes than widespread primary screening (Donald, 1985).

3.6.6.2.2 *In-vitro* egg hatch assay (levamisole)

A comparison is made in the recovery rate from paralysis between resistant and susceptible unhatched larvae in serial dilutions of levamisole (Dobson *et al*, 1986). Faecal samples are taken and incubated at 26 °C on microtitration plates. One hour before hatching, anthelmintic is added and then the plates are further incubated. The plates are then snap cooled to -15 °C for five minutes and chilled formaldehyde added.

This technique is highly involved, requiring a high level of expertise to achieve accurate results. It would therefore not be suitable for routine screening as inter-laboratory comparisons are not possible (Dobson *et al*, 1986; Johansen, 1989).

3.6.6.2.3 Tubulin binding assay

This assay procedure has been developed through the knowledge that tubulin extracts from benzimidazole resistant nematodes have been shown to bind significantly less drug than those from susceptible nematodes (Lacey and Prichard, 1986). The technique is capable of detecting very low frequencies of resistance which can be related to the field situation (Lacey and Snowdon, 1988; Johansen, 1989) and has been found to be more rapid and standardised than other assay procedures. However, due to the need for radio-isotopes and expensive equipment requiring trained personnel and approved laboratory facilities, the assay is not suitable for every day screening purposes. It is also a controversial technique as it only tests one biochemical site and there are several reports documented which suggest that anthelmintic resistance is based on polygenic (Le Jambre, 1982) modes of action.

3.6.6.2.4 Larval development assay

This assay is based on a procedure developed to test the ovicidal and larvicidal effects of anthelmintics (Georgi and Le Jambre, 1983; Johansen, 1989). The eggs are recovered from faeces, placed suspended in bacteriological nutrient broth and incubated on microtitration plates at 27 °C for 24 hours. The egg suspension is then divided into a number of equal groups. The test groups are poured onto individual agar plates with differing concentrations of a known anthelmintic and nutrients. The control group is poured onto an agar plate with added nutrients and distilled water. After a further six days of incubation at 27 °C, the third stage larvae are collected and counted (Taylor, 1990).

Although the procedure is simple to carry out, with the added benefits of being able to test several different anthelmintics at once and also to differentiate between species of mixed infections, this species identification is time consuming and requires expertise. This assay is also not suitable for testing the effects of levamisole or ivermectin as dose responses between nematode species is variable making interpretation of results difficult. The assay is, however, suitable for both field screening and research work associated with benzimidazole resistance.

3.6.6.2.5 Larval motility assay

This assay was the first procedure developed for the detection of levamisole and morantel tartrate resistance (Martin and Le Jambre, 1979). Eggs are recovered from faecal samples and incubated until third stage infective larvae emerge. These are collected and incubated for 24 hours in serial dilutions of the test drugs. The larvae are then classified under the microscope into normal (moving) and paralysed (no observable movement within five seconds). The percentage of paralysed larvae for each dilution can then be calculated, converted to log probits and plotted as ld-p (log dose-probit) lines (Le Jambre *et al*, 1976).

Although the assay is quick and simple to carry out, inconsistencies occur in dose responses both between nematode species (Barton, 1983) and research workers. This makes it more suited for research purposes, than for widespread field screening.

A modification to this procedure has been developed by Folz *et al* (1987) where results are obtained with the use of a micromotility meter. However, this modification is not suitable for smaller worms for the following reasons: If there are too few larvae any movement occurring may be too slight to register any effect on the meter. On the other hand, if too many larvae are present, there could be an over-estimation in the number of motile worms recorded due to motile larvae knocking into the dead ones leading to dead larvae appearing to move. Also, it is not possible to test more than one sample at a time, making the procedure laborious and time consuming.

3.6.7 Factors which affect resistance development in a nematode population

3.6.7.1 Dose rate

The dose level received by an individual sheep is critically important in terms of resistance development. If the dose given is too low, heterozygotes for resistance will survive which leads to a higher percentage of resistant genes surviving within the worm population, which results in resistance build up. One the other hand, if the dose rate given is too high, only the most resistant worms will survive which leads to a build up of worms which are largely homozygous for resistance. Therefore it can be seen how important dosing the flock at the correct dose rate can be in preventing or at least reducing resistance problems at the farm level.

The main areas where inaccuracies can be found in administering the correct dose rate are: inaccurate weighing of stock and badly maintained equipment used to administer the dose. It is recommended that in order to produce an accurate therapeutic dose that a representative group of animals from each age/sex class should be weighed (Coles, 1986; Rowlands, 1989_{a+b}; Coles, 1991; Coop, 1991; Coles and Roush, 1992). The Western Australian department of Agriculture goes further, by recommending that the dose rate should be aimed towards the heaviest sheep in any age or sex class (Besier and Hopkins, 1988).

The other main area where inaccuracies can occur when administering the dose of a particular drug is the equipment. This is particularly important in the case of dosing using a drenching gun. If the gun has not been maintained or calibrated properly, the chance of the stock receiving the correct therapeutic dose is unlikely. Therefore it is recommended that the equipment is kept in a clean condition and is checked regularly eg. for sticking valves, and calibrated properly before each dosing session. Furthermore, it is important that if the compound requires shaking, it should not be shaken too violently. This can lead to excessive air bubbles which if taken up in the measured dose can lead to a seriously reduced dose being administered. In-feed preparations are the most inaccurate forms of dosing a flock as a controlled dose is impracticable if many animals are fed together as some animals will always eat more than others. Therefore, in-feed is usually a last resort option if other modes of administration are unsuitable.

3.6.7.2 Choice of anthelmintic

There are four main categories of broad spectrum anthelmintic:

Group 1: Benzimidazoles (and Probenzimidazoles)

Group 2: Levamisole

Group 3: Avermectins (eg. ivermectin) and other macrocyclic lactones

milbemycins etc. not yet available in the UK)

Group 4: Morantel

Until recently, there were only three groups of drugs, with morantel and levamisole both classed as Group 2 drugs. However, recent resistance studies would suggest a similar, but different mode of action and hence four categories is deemed more appropriate.

Controversy is also present regarding the Group 3 drugs at present, with two differing and opposing hypotheses. The first, advocated by Pankavich *et al* (1992) and Craig *et al* (1992) insists that the milbemycins are capable of controlling ivermectin-resistant nematodes. However, Shoop (1992) argues that the avermectins and other macrocyclic lactones have the same mode of action and eventually will promote side resistance to each other.

It is, however, generally recommended that a different group of anthelmintics should be used each year because this reduces the probability of resistance within a nematode population becoming sufficiently established that the advantage of surviving anthelmintic dosing outweighs the disadvantageous properties of resistant genes i.e. decreased survival (with adverse conditions) and decreased fecundity (Kelly and Hall, 1979; Coles, 1986; Taylor and Hunt, 1989; Coles, 1991; Coop, 1991; Coles and Roush, 1992).

In some situations in the southern hemisphere, where resistance to all groups of broad spectrum anthelmintic has occurred, narrow spectrum drugs have been recommended where a specific parasite (usually *H.contortus*) has proved problematical (Kelly and Hall, 1979). Initial studies applying this technique have proved highly successful with the narrow spectrum flukicide nitroxynil reducing the problem of benzimidazole resistance in *H.contortus* when used in a rotational programme (Jeannin, 1989). This technique has also proved to be an efficient worm control strategy in New South Wales, where the Department of Agriculture feature this option in their 'Wormkill' programme by advocating the use of the narrow spectrum anthelmintic closantel for control of *H.contortus* in situations where resistance to all other main groups of drugs has become established.

3.6.7.3 Frequency of drug usage

As more information has become available regarding the epidemiology of nematode parasitism and how resistance can establish, researchers have come to realise the importance of integrated systems of control. These systems combine pasture management techniques with dosing regimes to produce an efficient worm control programme without increasing the pressure on the nematode populations, resulting in an exacerbation of resistant gene development.

Dosing the flock and moving to clean pasture has been advocated as one method of increasing the efficiency of worm control. However, even with this system, care must be taken as only the resistant worms will survive after dosing and this will constitute the whole nematode population on the new pasture. Anderson *et al* (1980) suggested the use of a prolonged low level exposure of wormer as an alternative approach. This has since been proven by Fisher *et al* (1992) who revealed that albendazole administered in a controlled release intra-ruminal device was highly effective at controlling a benzimidazole resistant strain of *H.contortus*. This has been further confirmed by other workers (Bell and Thomas, 1992; Louw and Reinecke, 1992).

3.6.7.4 Movement of stock

With the widescale movement of livestock both within and between countries these days, this subject has become of increasing significance in terms of the spread of anthelmintic resistance. One example of this is the reported occurrence of the parasite *H.contortus* in areas of Britain which are usually considered highly unfavourable for the species' free-living development (i.e. northern-most regions of the UK). This is probably due to the transportation of stock from areas of the UK or abroad where the climate is more favourable for *H.contortus* development.

It is generally accepted that if animals are transported from one part of the UK to another, the stock should be dosed with a non-benzimidazole anthelmintic and yarded for twenty four hours as a quarantine procedure before being allowed to mix with the rest of the flock. This is because most cases of anthelmintic resistance in the UK to date occur within the benzimidazole drugs.

If stock is bought from abroad, in particular from the southern hemisphere, extreme caution must be taken to ensure that these animals are not harbouring multiple drug resistant nematodes or any drug resistance as this could lead to an unnecessary resistance problem in the UK which could have severe consequences to the UK sheep and goat industries.

3.6.7.5 Resistance in goats

Anthelmintic resistance in gastrointestinal nematodes of goats has recently been identified as a potential problem to sheep producers in terms of nematode parasitism and resistance problems. Unlike sheep, goats fail to build up a meaningful natural immunity to these parasites as they get older which means that dosing frequencies are much higher than in sheep leading to the faster development of resistance. Also, anthelmintics are metabolised differently by sheep and goats which means that if goats are given the same therapeutic dose as sheep, it is quite likely that drug failure will result due to underdosing (McKenna and Watson, 1987; Charles *et al*, 1989). Therefore, there is an obvious requirement to carry out further work on nematode control in goats to find out the optimum dose of each drug in order to be able to recommended a sound therapeutic dose level for these animals.

It has also been shown in recent work that these resistant nematodes can then be taken up by sheep and continue their lifecycle within this different host animal. This could lead to serious consequences, especially to the hill sheep farmer, who has until now run goats and sheep together and suffered relatively few, if any, resistance problems. Therefore in the light of these results, it has now been recommended that wherever possible goats and sheep should not have access to the same pastures (Coles and Roush, 1992).

3.7 Discussion

Anthelmintic resistance in the UK has not yet become a nationwide problem, but unless lessons from the southern hemisphere are learned, there is always that possibility. During the last thirty years, the quality of drugs marketed for the control of gastrointestinal nematodes in sheep has improved dramatically, with the introduction of the broad spectrum anthelmintics. The wide range of activity of these wormers (against many nematode species and life stages within a single species) has led to more effective control of ovine parasitic gastro-enteritis. This in turn has led to the possibility of increasing fat lamb production by increasing the stocking rates on pasture. However, although there are now a widespread number of products available, the majority of drugs fall within four categories relating to chemical composition and modes of action. The likelihood of introducing further groups of anthelmintics is low, with perhaps one new group being developed before the end of the century.

The increase in stocking density has led to new problems for the sheep farmer. Firstly, higher densities of animals running together leads to more illness problems within the flock. This is partly brought about by the increased competition for the finite food supplies available leading to the possibility that these animals will not obtain the same nutrient levels as they would under less intensive grazing management. This, combined with the increased stress levels brought about by being kept under high density situations, leads to a reduced immune status making the animals more susceptible to infection. Also, the fact that more animals are present within a defined field area raises the probability of a sick animal being present. In the case of gastrointestinal nematodes, increased stocking density also leads to increased levels of infective larvae on pasture and the potential to reach dangerous levels of contamination earlier in the season. This has led to increased frequency of wormer usage which has ultimately led to the development of anthelmintic resistance in some instances.

There are two reasons for drug failure at the farm level, namely the improper use of the product and drug resistance. Distinguishing between the two is not always straightforward, especially in the case of the non-benzimidazole drugs because the tests for detecting resistant strains to these groups of drugs are neither particularly easy to undertake nor always reliable. However, it is recognised that if a drug is being used less efficiently, this has the potential to ultimately lead to the development of a resistance problem. This has led in recent years to the increased number of articles in the lay-press to educate the farmer into using good worming practice on his farm. Recent reports, however, looking at worming practice by farmers have indicated that in areas of the UK where anthelmintic resistance problems have not been identified, the improvement of worming practice does not feature highly in the list of priorities.

In the UK, anthelmintic resistance is still at a relatively low level, compared with the southern hemisphere where resistance has now developed to all broad spectrum wormers and some narrow spectrum drugs. This is probably due to the climate being less favourable for nematode development in the UK. It is also possible, however, that more resistance problems exist which have not been highlighted due to the limited number of localised surveys reported to date. What is required is a totally random nationwide survey to create an overall picture of resistance problems in the UK. Also, tests for detecting non-benzimidazole drug resistance require improvement as there are no suitable field screening test procedures available for these drugs.

In conclusion, genuine cooperation is now needed between farmers, extension workers, the veterinary profession, research workers and the animal health companies to produce a policy for preventing the further development and spread of resistance. In order to achieve this aim, the long-term advantage of implementing a suitable strategy to overcome these problems needs to be shown to outweigh the short-term advantages of current control practices. To aid this objective, there is a potential role for the use of user-friendly computer programmes to help convince the user of the long-term advantage of maintaining efficient worm control programmes well into the next century. By this time perhaps our understanding of gastrointestinal nematode parasitism will have resulted in a completely new strategy for worm control, perhaps even dispensing with the need for chemical intervention on the scale practised today.

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Chapter 4 - Expert Systems

4.1 Introduction

Expert systems are one group of the general set of knowledge-based systems, i.e. programs that store, process and disseminate knowledge (Norton, 1990). An expert system is defined as a computer system which has been developed to store and interpret human expertise i.e. to perform like a human expert (Sell, 1985; Wicksteed, 1988; Heong, 1990; Norton, 1990; Jackson, 1992). It should be pointed out, though that expert systems cannot compete with face to face communication as a means of transferring skills (Collins *et al*, 1985). There are a great variety of terms used to describe expert systems such as production systems, rule-based systems and intelligent knowledge based systems (IKBS). Production systems and rule based systems, however, are generally considered a subset of expert systems, which in turn are considered a subset of IKBS which have been described as an intermediate between expert systems and "blue-sky artificial intelligence" (Anon, 1990). They are highly effective at manipulating knowledge of a defined domain to solve problems (Heong, 1990). In order to accomplish its objective, the computerised system must include a database of all known facts (Jackson, 1992) and a set of rules (heuristics) which describe what we do under differing circumstances when tackling problems (reasoning) (Jackson, 1992; Howe, 1987). A knowledge base is defined as a structure which combines both data and instructions on how the data should be processed. This makes an expert system more flexible to use than conventional software as it can be used to present a wider range of human knowledge and can be modified or updated much easier and efficiently (Wicksteed, 1988). As well as retaining the knowledge and reasoning capabilities of an expert, the computer system must also be able to interact with the user to explain why a particular question was asked or why a particular decision was reached (Yost *et al.* 1988; Jackson, 1992).

The main reason for developing expert systems is to increase the availability of what is described as expert knowledge. Experts in a field tend to be a scarce and expensive commodity. The computer systems incur an initial setup cost, which is later offset by increased availability of the knowledge to less trained personnel (Collins *et al*, 1985). Expert system applications also remove the transportational costs associated with an expert travelling to the site of a problem, but more importantly prevent the loss of knowledge when an expert dies. Expert systems can also be considered as useful training tools for education establishments due to their ability to interact with the user. They have also been developed as an alternative to written computer manuals, to give low-level advice in more remote areas of the world where expertise is non-existent. They can also be designed to provide advice in situations which may be considered too dangerous for human experts eg. seabed investigations of faults (Jackson, 1992).

The first step towards producing an intelligent machine came about during the second World War with the advent of computers. However, the turning point for the idea of 'Artificial Intelligence' (AI) came about in 1950 when Alan Turing produced his famous paper 'Can a machine think?' Within six months, a range of problem solving programs appeared eg. programs to play chess and checkers, solving integrals and learning concepts - all of which up until then had only been achieved by man. A general problem solver was developed by 1957 by Newell, Shaw and Simon (Sell,1985). In certain areas of problem solving, the 'General Problem Solver' was very successful. However, with limited information available at the time about how the brain solved problems there were many problems which could not be solved using this program. The main breakthrough came through the shift from trying to develop general problem solvers to developing domain specific knowledge based systems. The first program to be developed using domain-specific information was called DENDRAL short for DENDRitic ALgorithm, which was used to identify molecular compounds from analytical data. The development of DENDRAL, therefore, laid the foundations for the development of expert systems (Sell, 1985).

The first expert systems were developed using conventional programming languages such as Fortran, Basic and Pascal (Eager, 1989). During the last thirty years many different techniques have been devised for the handling and storage of large quantities of knowledge. These include production rules systems, semantic nets, frames and predicate logic. In order to represent knowledge in such a variety of ways the development of new AI languages such as LISP, POP-2 and PROLOG (Howe, 1987; Eager, 1989) occurred. LISP was developed at Massachusetts Institute of Technology, USA and PROLOG was developed at the University of Aix, France. LISP tends to be more widely used in the USA, whereas PROLOG is favoured in Canada, Europe and Japan (Anon, 1990). These languages have three main advantages over conventional programming languages:

1. They have the ability to use a wider range of non-numerical computations for data expression eg lists, arrays, strings, words, procedures, processes etc.
2. Their data structures are type-free - lists can contain arbitrary objects and code can be treated as data (Howe, 1987).
3. They are extensible - thereby making it easy to develop a small application and expand as required. (Howe, 1987; Anon, 1990).
4. They can cope with uncertainty and are capable of functioning even when important data are missing (Anon, 1990).

Writing applications within these environments therefore has two main advantages over conventional programming:

1. A complex system can be programmed using the method of 'structured growth'. A small initial system can be developed which can then be expanded incrementally as the programmer increases his understanding of the problem. This contrasts with the conventional approach where the design of the system has to be mapped out at the start of the project.

2. The AI development environment greatly speeds up the program building compared to traditional programming which separates the activities of building, compiling, editing and documenting a program. (Howe, 1987).

3. Expert systems can be useful for programming purposes to test the logic and functionality of a system before it is re-programmed into a more conventional programming language (Wicksteed, 1988).

The decision making processes involved in creating an expert system can prove very useful in terms of Research and Development. They can provide a means of defining the problem being tackled, recognise restraints encountered when assessing all possible outcomes and identifying important areas where future research should be targeted. The expert system pulls together research findings to date, the needs of the ultimate end-user and assesses possible management strategies. They design specific recommendations for a specific problem and can prove highly useful for training purposes (Norton, 1992).

4.2 Characteristics of an Expert System

The most important aim of an expert system is to demonstrate a high level of expertise, equivalent to that achieved by a human expert in some quantifiable domain. This includes rules of thumb and tricks of the trade which in a human expert have built up over years of experience in the field (Brachman *et al*, 1986). In order to achieve this aim, the following characteristics should be considered during the early development stage:

1. High performance - the system must be capable of responding at a level of competency equal to or better than an expert in the field. That is, the quality of the advice given by the system must be very high (Giarratano and Riley, 1989). This characteristic is not always easy to assess in a new system, especially in domain areas where there is no single answer to a problem (Brachman *et al*, 1986).

2. Adequate response time - the system must also perform in a reasonable time, comparable to or better than the time required by an expert to reach a decision (Giarratano and Riley, 1989) i.e. they need to be efficient. An expert system which takes a week to reach a decision compared to an expert's time of one hour would not be too useful. The time constraints placed on performance of an expert system may be especially severe in the case of real-time systems, when a response must be within a certain time interval. An expert possesses the ability to eliminate a significant number of possible hypotheses/conclusions during each inference step. A computerised application must also achieve this fundamental characteristic in order to be usable (Brachman *et al*, 1986). In a large number of applications it is possible to find domain-specific information which can guide the search process towards the ultimate goal. This information is called heuristic information. As soon as the goal has been reached, the heuristic search stops (Stefik *et al*, 1986).

3. Good reliability - the expert system must be reliable and not prone to crashes or else it will not be used (Giarratano and Riley, 1989).

4. Understandable - rather than just being a 'black box' that produces a miraculous answer, the

system should have an explanation capability in the same way that human experts can explain their reasoning (Brachman *et al*, 1986; Giarratano and Riley, 1989). This explanation is usually in the form of a rule trace which records the order in which rules have been fired during the course of a problem solving session (Brachman *et al*, 1986). A rule is said to have "fired" when all the conditions specified within the rule have been met.

5. Flexibility - because of the large amount of knowledge that an expert system may have, it is important to have an efficient mechanism for adding, changing and deleting knowledge. One reason for the popularity of rule-based systems is the efficient and modular storage capability of rules (Giarratano and Riley, 1989).

4.3 History of Expert System Technology

See Figure 4.1 for an overview of the history of expert system technology. In the late 1950's and 1960's a number of programs were written with the goal of general problem solving. The most famous program developed was the General Problem Solver (GPS) created by Newell and Simon (Giarratano and Riley, 1989; Jackson, 1992). One of the most significant results demonstrated by Newell and Simon was that much human problem solving or cognition could be expressed by IF-THEN type production rules (Giarratano and Riley, 1989). A rule corresponds to a small, modular collection of knowledge called a chunk. One theory is that all human memory is organised in chunks. Newell and Simon popularised the use of rules to represent human knowledge and showed how reasoning could be done by rules. Cognitive psychologists have used rules as a model to explain human information processing. The basic idea is that sensory input provides stimuli to the brain. The stimuli trigger the appropriate rules of long term memory which produce the appropriate response. Long term memory is where our knowledge is stored. Long

Figure 4.1 Summary of important dates in the history of expert system development

Date	Important developments
1956	Official birth date of Artificial Intelligence (Jackson, 1992)
late 1950's	Programming language LISP developed by John McCarthy
early 1960's	General Problem Solver developed by Newell and Simon
1965	The first expert system DENDRAL was developed at Stanford University
1970's	The expert system MYCIN was developed at Stanford University. The expert system language PROLOG was developed
early 1980's	Development of the expert systems PROSPECTOR and XCON Introduction of expert system shells

term memory consists of many rules having the simple IF-THEN structure. In contrast, short term memory is used for the temporary storage of knowledge during problem solving. Although long-term memory can hold hundreds of thousands or more chunks, the capacity of the "working memory" (short-term memory) is surprisingly small - 4 to 7 chunks. The other element necessary for human problem solving is a cognitive processor. The cognitive processor tries to find the rules that will be activated by the appropriate stimuli. If there are multiple rules that are activated at once, the cognitive processor must perform a conflict resolution to decide which rule has the highest priority. The rule with highest priority will be executed. The inference engine of modern expert systems corresponds to the cognitive processor. The Newell and Simon model of human problem solving in terms of long term memory (rules), short term memory (working memory) and a cognitive processor (inference engine) form the basis of modern rule-based expert systems (Giarratano and Riley, 1989).

Until the mid-60's the major quest of AI was to produce general problem solvers. Although the methods of reasoning used by these general problem solvers was very powerful, the machines were eternal beginners. When presented with a new domain, they had to discover everything from first principles and were not as good as human experts who relied on domain knowledge for high performance.

By the early 1970's it became apparent that domain knowledge was the key to building machine problem-solvers that could function at the level of human experts (Giarratano and Riley, 1989; Jackson, 1992). Although methods of reasoning are important, studies have shown that experts do not primarily rely on reasoning for problem solving. Instead, experts rely on a vast amount of knowledge of heuristics and experience that they have built up over the years

(Giarratano and Riley, 1989). If an expert cannot solve a problem based on expertise, then it is necessary for the expert to reason from first principles and theory (or more likely ask another expert). The reasoning ability of an expert is generally no better than that of an average person in dealing with a totally unfamiliar situation. The insight that domain knowledge was the key to building real-world problem solvers led to the success of expert systems (Giarratano and Riley, 1989; Jackson, 1992). While expertise is known as experience in the field and heuristic knowledge that is specialised and known only to a few, factual knowledge is generally found in books, periodicals and other widely available resources.

During the 1970's a number of successful prototype expert systems were created:

DENDRAL - to interpret mass spectrograms to identify chemical constituents.

MYCIN - to diagnose illness.

DIPMETER - to analyse geologic data for oil.

PROSPECTOR - to analyse geologic data for minerals. It now includes about a dozen knowledge bases for different types of deposit.

XCON/R1 - to configure computer systems.

4.3.1 DENDRAL

The DENDRAL project started in 1965 was the first program of its type using symbolic reasoning to represent expert heuristic knowledge. It also introduced the concept of "data directed search control" (Brachman *et al*, 1986). DENDRAL was developed to analyze mass spectromographs, nuclear magnetic resonance and other experimental data and propose possible chemical structures for unknown compounds. It creates partial molecular structures consistent with the data and then elaborates on this initial frame until it finally produces all plausible structures to fit the data. It is very accurate and can often find possible structures that a human expert may overlook (Hayes-Roth *et al*, 1986).

4.3.2 MYCIN

MYCIN uses a simple structure of approximately 400 IF-THEN production rules using a backward chaining control strategy (Brachman *et al*, 1986; Hayes-Roth *et al*, 1986). The main aim of the system is to diagnose and propose treatment for infectious blood diseases. MYCIN also gives reasons for the decisions reached by the system (Brachman *et al*, 1986). When the system was evaluated against human experts in the field, it was proved as good as or superior to the human experts (Hayes-Roth *et al*, 1986).

This expert system was important for several reasons:

1. It demonstrated AI could be used for practical real-world problems.
2. Mycin was the testbed of new concepts such as the explanation facility, automatic acquisition of knowledge and intelligent tutoring.
3. It demonstrated the feasibility of the expert system shell (Giarratano and Riley, 1989).
4. This type of knowledge base structure became the main methodology behind most modern expert system applications (Hayes-Roth *et al*, 1986).

4.3.3 PROSPECTOR

PROSPECTOR is a system which interprets soil and geological deposit data in a way comparable to that of expert geologists. The knowledge is represented by using semantic net models and it achieves comprehensive explanations for the reasoning processes. It has proved very accurate in predicting mineral deposits to date eg. it predicted a molybdenum deposit would be found at a certain location. This prediction was realised when a deposit worth $100 million was found at the said location (Brachman *et al*, 1986).

It is, however, only since the early 1980's that expert system programming has taken off, with large numbers of new applications being developed. Despite the wide range of uses which expert system technology have been used in recently, there have been relatively few new ideas, concepts or break-throughs being reported. The modern expert systems developed show very few additional features when compared with the older, pioneering systems (Merry, 1985). There has been a massive increase in the number of hardware and software tools available for building expert systems, including more powerful programming languages, expert system tools and artificial intelligence development environments (Bramer, 1987). This has made it easier and quicker to program a prototype expert system application.

4.4 Uses of Expert System Technology

There are a number of categorical types of knowledge bases which maybe employed to build an expert system. Figure 4.2 shows these and gives a brief description of each one. The majority of expert systems built would probably only consist of one definitive categorical area, however a few may contain characteristics of several types in order to function effectively.

Interpretation systems analyse sensor data and from this infer situation descriptions i.e. explain the observed data by assigning symbolic means to them and describe the situation or system state accounting for the data. Such systems include surveillance, speech understanding, image analysis, chemical structure elucidation and signal interpretation (Hayes-Roth *et al*, 1986).

The earliest and most well known expert systems built to date occurred in the medical field and are defined as diagnostic systems. One of the most famous systems - MYCIN was developed for the diagnosis and treatment of bacterial infections. However, MYCIN could also

Figure 4.2 Categories of possible knowledge bases

Application Type	Description
Interpretation	Analyse sensor data and provide situation descriptions
Prediction	Analyse given situations and provide likely outcomes
Diagnosis	Analyse observed signs and provide most probable malfunctions
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Observing situations and predicting vulnerable areas
Debugging	Prescribe remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing, debugging and repairing student behaviour
Control	Interpreting, predicting, repairing and monitoring system behaviours

been defined as an instruction tool. Once a conclusion has been reached, the application asks the user if the conclusion is appropriate for the situation specified. If the user chooses 'No', then the system presents each individual step in turn and asks the user to confirm that the logic is correct. Each rule could be modified in order to enhance the accuracy of the diagnosis being presented to the user. Many other diagnostic systems have since been developed eg TRACKER which carries out diagnostic tests on power supply equipment and COUNSELLOR which identifies and gives advice on the treatment of pest infestations affecting winter wheat. Some systems are partly run as a diagnostic tool, but are also capable of giving predictions eg weather forecasts. PROSPECTOR was a system designed for mineral exploration, but can also give predictions of what minerals may be located in certain geographical areas. Also, the winter wheat disease control advisor COUNSELLOR is also capable of predicting the financial benefits of using a recommended treatment by means of cost-benefit analysis.

Expert systems may also be used for the design or customisation of other systems eg the expert system XCON is used by the computer company DEC to process customer orders and test that the proposed configurations requested for a Vax operating system are both available and compatible with each other.

Planning systems have also been developed eg GATES is a system used at JFK International Airport to assist ground controllers in the task of assigning gates to arriving and departing flights. Another system PLANPOWER has been developed to give personalised financial advice.

Another area where expert system technology can be utilised is in monitoring, i.e. using the system to predict a problem and diagnose the most appropriate remedy for solving the problem. ESCORT is a system used on oil rigs to monitor performance, anticipate any problems which may arise and recommend evasive strategies to avoid the problem taking place. Another system called FRAUDWATCH is used by Barclays bank to detect fraudulent credit card behaviour. The system monitors customers accounts searching for patterns in the types of regular customer transactions which occur whilst looking for changes in behaviour (Hayes-Roth *et al*, 1986).

Debugging systems use planning, design and prediction in order to provide a recommendation for correcting a diagnosed problem. There are other systems available for debugging computer programming and text editors which do not qualify as expert systems. Repair systems use debugging, planning and execution in order to provide a remedy for a diagnosed problem. Instruction systems use the student as the system of interest and use diagnosis and debugging capabilities to identify the student's knowledge and interpret the student's behaviour. They can then highlight the student's weaknesses and propose an appropriate remedy which incorporates a plan of tutorial interaction.

Finally, expert systems can be used in the area of control, where the application governs the overall behaviour of the system. To perform this role effectively, the system must interpret the current situation repeatedly, predict the future, anticipate problems, formulate a remedial plan and monitor the execution of the remedy to ensure success. Areas where control systems can be used include air traffic control and business management (Hayes-Roth *et al*, 1986).

The advantage of all expert systems is that they encapsulate expert knowledge. Knowledge and expertise no longer needs to die along with the human expert. It can be kept and used as a training tool for trainees in a particular field or to amplify the knowledge of an expert. It can also be used for the interpretation of complicated subjects such as law and social security benefits. There have been a number of systems developed to give advice on legal and tax matters (Jackson, 1992).

4.4.1 Agriculture

It is estimated that there are over one hundred different systems under development for the Agriculture industry world-wide. The majority of these systems have been developed for the arable industry (Walker and Miller, 1990). The earliest knowledge-based system used in the UK for crop protection purposes was COUNSELLOR, developed as an advisor for cereal disease (Norton, 1990) Other areas covered by these systems include financial and business (eg ANALYST ADVISOR and FINPAK), Crop management systems (eg COMAX and WHEAT COUNSELLOR), crop protection (eg INDUCE/PLANT, PLANT/cd) and advisors on fertilizer requirements (eg N-MAN, SOILPLAN) (Walker and Miller, 1990). At the present time, however, there are very few systems under development for the livestock industry.

There are four main areas where knowledge-based systems can assist in pest management:

1. Practical problem solving - diagnosing the problem and giving advice on the most appropriate treatment.

2 Information processing/provision - historical databases, presentation of future scenarios etc.

3. Problem structuring - to recognise areas where research should be directed and specify extension requirements for improved management.

4. Training - simulations help give experience in making decisions about a particular pest problem.

In order to consider the role that an expert system may play in solving a pest management problem an understanding is needed of the processes involved in decision making. There are six processes involved in reaching a decision in pest management:

1. Pest identification
2. Assessment of the level of pest attack
3. Assessment of the level of crop or animal loss
4. Determination of available options and their effectiveness
5. Cost/benefit assessment
6. Determination of other objectives and constraints.

Expert systems can be employed to help decision makers in all of these problem solving processes, although most existing systems only address one or a few processes (Norton, 1990).

4.5 Advantages of Expert Systems

1. Increased availability of expertise. This means available expertise within a company is spread more widely which therefore raises the performance levels of the company as a whole (Wicksteed, 1988; Eager, 1989).
2. Reduced cost in supplying expertise to an individual user.
3. Permanence - expert system knowledge will last indefinitely whereas a human expert may retire, quit or die.
4. The potential for expertise of multiple experts will be available 24 hours per day simultaneously (Giarratano and Riley, 1989) and unlike human experts they do not become ill, give inconsistent advice or leave their job (Eager, 1989).
5. Explanation - the expert system can explain in detail how a conclusion was reached. This increases the confidence that the correct decision has been achieved.

6. Fast response - an expert system may respond faster and be more available than a human expert.

7. Steady, unemotional and complete response at all times - this may be very important in real time and emergency situations when a human expert may not operate at peak efficiency because of stress or fatigue.

8. Intelligent tutor - the expert system may act as an intelligent tutor by letting the student run sample programs and explaining the system's reasoning.

9. Intelligent database - expert systems can be used to access a database in an intelligent manner. (Giarratano and Riley, 1989).

4.6 Limitations of Expert System Technology

There are five areas where expert system technology can be seen to perform less well than a human expert:

1. Lack of common sense - in the majority of problem solving situations, a human expert will rely on a global body of information known as "common sense", as well as domain based 'rules of thumb'. Because of the enormity of common sense knowledge gained through every day experiences, it would prove impossible to quantify such information in the form of symbolic reasoning required by expert systems (Heong, 1990).

2. Lack of learning ability - one of the main characteristics when defining human intelligence is the ability to learn. Expert systems can rely on pre-programmed rules in order to attempt to solve a new problem. They are, however, incapable of learning a new concept without being re-programmed.

3. An expert system always reacts to a problem in a predictable manner. It is incapable of

adapting to a new situation or coming up with new ideas of how to solve a problem like a human expert could (Yost *et al*, 1988; Heong, 1990).

4. Human experts have all five senses to call upon when attempting to solve a problem. In order to use such information within an expert system, sensory data has to be transformed into symbols. When this symbolic data is then transformed into rules, a lot of the sensory information is lost.

5. Knowledge acquisition is the most important part of any expert system. However, obtaining this information is not always easy for a number of reasons:

a. It may not be possible to interview a domain expert.

b. There could be communication problems between the domain expert and the knowledge engineer building the expert system. This will be discussed further later in this chapter.

These two factors can lead to a bottleneck as far as the timescale for building the expert system is considered. They can also lead to inaccuracies of the information contained within the knowledge base leading to an inferior system being built. (Heong, 1990).

6. Expert systems are limited to subjects with a very narrow domain (Anon, 1990).

7. An expert system cannot determine when a problem falls outside its area of expertise. If a human expert found himself in this situation, he could refer the enquirer to another expert who may be able to help.

8. In many areas of science there are as many exceptions to the rule as there are rules. However, expert systems are restricted by literal interpretations of the concepts which makes them inflexible (Yost *et al*, 1988).

9. An expert system is unable to find a parallel between two different situations. For example a car maintenance expert system may diagnose the fault detected to be caused by a flat battery.

However, the same rule may apply to a cordless drill which does not work. The car maintenance expert system would not be able to solve the problem with the cordless drill because it falls outside the domain of knowledge for which the application has been developed.

4.7 The architecture of an expert system

See Figure 4.3. There are four main components to any expert system:

1. The knowledge base.

2. The inference engine - makes inferences by deciding which rules are satisfied by the facts, prioritises the satisfied rules and executes the rule with the highest priority.

3. The user interface - the mechanism by which the user and the expert system communicate.

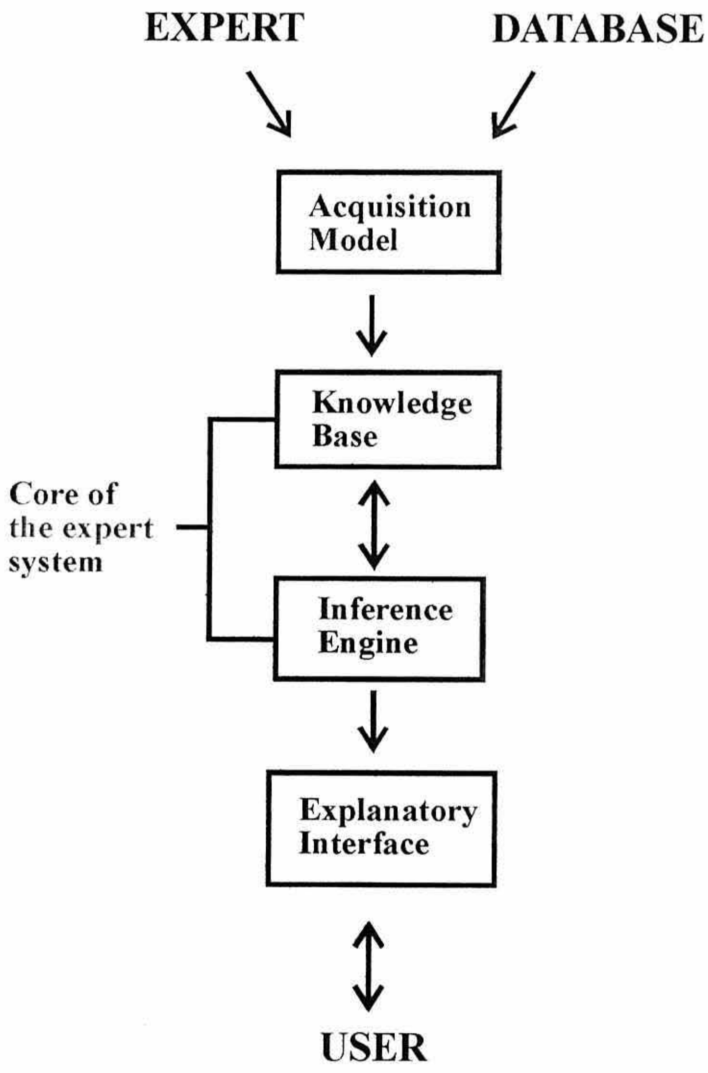
4. Explanation facility - explains the reasoning of the system to the user (Forsyth, 1984; Giarratano and Riley, 1989)

4.7.1 The knowledge base

A knowledge base is a representation of knowledge which an expert system utilizes during problem solving activities (Denne, 1988). A knowledge base consists of information concerning a pre-defined domain of knowledge and contains facts (assertions), rules (information about the facts) and higher level knowledge (meta-knowledge - which provides knowledge about the rules eg which rule should be fired first (Forsyth, 1984; Anon, 1990). Facts are pieces of short term information which change during a single consultation. Rules are pieces of information which form the basis by which hypotheses and new facts can be generated from what is presently known with conventional databases, facts are either present or missing. In the case of a knowledge base, the system actively tries to fill in missing information (Forsyth, 1984).

Production rules in the form of IF-THEN statements are the most common method of

Figure 4.3 The Architecture of an Expert System



encapsulating knowledge (Forsyth, 1984; Heong, 1990). However, some systems use decision trees, semantic nets and predicate calculus (Forsyth, 1984).

4.7.2 The inference engine

An inference engine is a means of using knowledge in an easy way which provides answers to queries in much the same way as a human expert would tackle a problem (Denne, 1988) i.e. contains the logic of problem solving (Heong, 1990). The function of the inference engine is to determine what data is required to solve a problem, extract this information from the knowledge base and lodge it in the working memory, draw inferences from the data and record these in the working memory (Sell, 1985). In order to select the order in which rules are fired, one of two strategies are used - forward chaining and backward chaining (Black, 1986). Forward chaining is defined as 'a line of reasoning that starts from known facts and fires rules to infer conclusions' (Black, 1986; Giarratano and Riley, 1989; Jackson, 1992). For example, there is a fungal disease found on a crop of wheat. The plant pathologist would examine the fungus, identifying characteristic features with the use of a taxonomic key which would ultimately lead to the identity of the individual fungus. Backward chaining involves working in reverse, starting with the conclusion and then fires rules which would result in that conclusion (Black, 1986; Giarratano and Riley, 1989; Jackson, 1992). For example, when embarking on a train journey, we would need to know what time we had to reach our destination in order to work out what time we would need to leave the house. This is thought to be closest to the way in which an expert consultant might make a diagnosis (Jackson, 1992). These two methods of reasoning are described as goal-driven. However, it is not always possible to specify a conclusion or goal to be achieved. The purpose of a system could be to infer as many new facts as possible, given the data provided. This type of reasoning is described as data-driven (Jackson, 1992).

Whichever method of inference is used by a particular system, the chances are it will have to cope with uncertainty. There have been many ways of dealing with uncertainty developed eg fuzzy logic, bayesian logic, multivalued logic and certainty factors. However, the simplest method to overcome the problem of uncertainty is to allow the expert system to reach correct conclusions by a number of different routes (Forsyth, 1984).

4.7.3 The user interface (human window)

The user interface allows the user to interact with the computer and receive answers back concerning questions asked (Denne, 1988). One of the main ways an expert system differs from conventional programming is that it allows the user to ask why the system made a particular deduction or asked a particular question (Forsyth,1984; Heong, 1990). This subject will be discussed more fully later in this chapter.

4.8 The expert system development lifecycle

4.8.1 Feasibility and appropriateness

1. Does the application have the functional characteristics of expert systems? Does it involve providing advice on problem cases from within a well defined area of expert knowledge?

2. Is there certainty in the knowledge of the problem domain?

3. Should the program be expected to accept uncertain input from the user and still come up with qualified advice?

4. Is the problem area an important one where the user's confidence in the program's conclusions is an issue? Is justification of the line of reasoning required?

5. More importantly, is an expert on the application available? (Black, 1986)

If the answer to one or more of these questions is 'yes', then the use of expert system technology would appear appropriate for the proposed application. Once it has been recognised that an expert system is required to solve a problem there are several points which need consideration to produce a useful application:

1. The expert system developed should be able to perform as well as a human expert. However, there are some obvious advantages to a computerised advisor - it will be able to work twenty four hours per day, will not suffer mood swings or fatigue and will not discriminate between people as to the advice given.

2. The system should be usable i.e. the knowledge domain should be narrow enough to be workable, but wide enough to be useful.

3. The system must be able to communicate in a way which the user finds comfortable and understandable.

4. The system must be able to explain how a conclusion was reached and why it requires a particular piece of information.

5. The system should be able to run at a reasonable speed. A system which requires twenty four hours to reach a conclusion would have a very limited usage (Sell, 1985).

It is also important to know what you wish to achieve by building a particular expert system. Do you require a specific problem solver which answers one problem and nothing else, or do you require a more general advisor which can provide the answer to a number of different problem areas? Do you require a system which provides the user with an information package concerning an area of expertise and do you require a system which can integrate with other software packages, such as databases or spreadsheets (Moralee, 1987)? Will the system be used in an office, over the phone or in the field? What computer facilities are available (machine type, processor speed, peripherals etc) (Norton, 1990) These are all questions which need addressing before embarking on the building of an expert system application.

4.8.2 Using the Right Tools

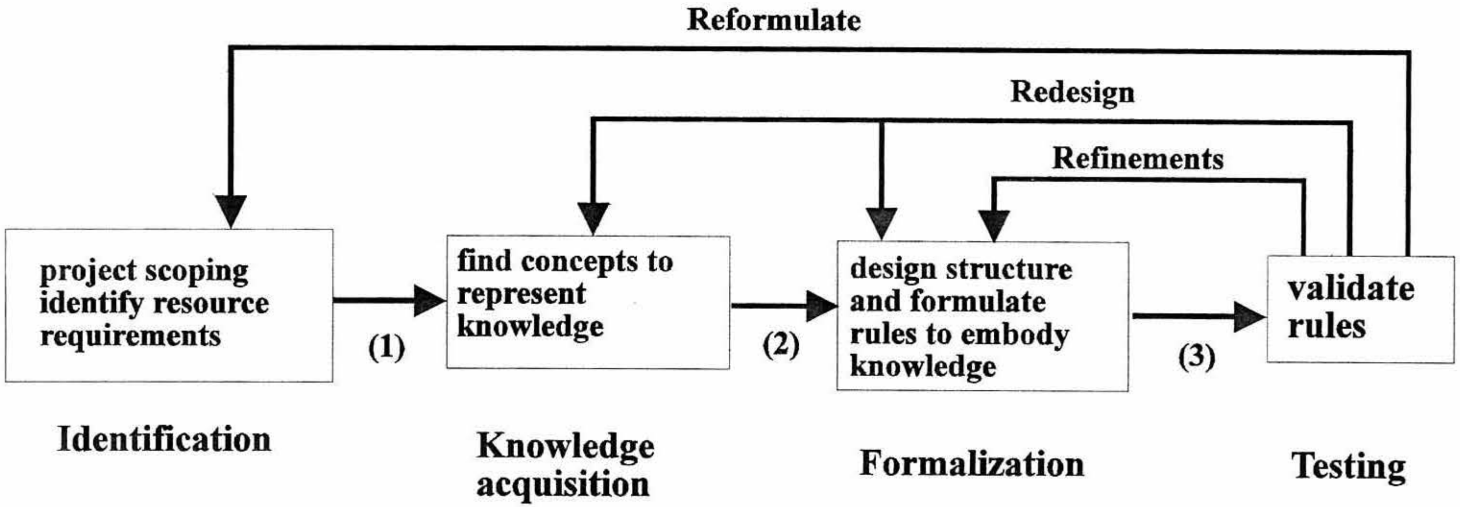
After identifying the requirements of a proposed system, it is important to find the most appropriate software to meet the needs for developing the system (Moralee, 1987). Do you wish to program the system using a suitable AI language, or would an expert system shell be more appropriate (Moralee, 1987; Norton, 1992). An expert system shell is a program with the inference engine and user interface already programmed. By using such a tool, the developer can concentrate on the development of the knowledge base to solve a particular problem (Sell, 1985; Norton, 1990). There are a number of products on the market in a variety of forms and ease of use, therefore it is important to recognise the difference in order to make a suitable choice (Norton, 1990). For example, if the system requires a link to other software packages, such as a database, it is important to choose a package which is compatible with this other software. One of the main disadvantages of expert system shells over conventional programming languages is the way restrictions are imposed onto the way knowledge can be entered by both the developer and end user. There are some shells, however, which have overcome this problem by allowing the developer to add extra features in a programming language which can be included in the finished product (Denne, 1988).

4.8.3 Building an Expert System

See Figure 4.4. There are four main stages important in the evolution of a new system:

1. Identification

Figure 4.4 Expert System Development Cycle



(1) - Requirement
(2) - Concepts
(3) - Rule structure

2. Knowledge acquisition

3. Knowledge formalization

4. Testing

4.8.3.1 Identification

During the identification stage, the knowledge engineer and domain expert discuss the scope of the proposed problem area. They also identify resources required to complete the task, including any additional experts needed, additional computer resources and time constraints to complete the project. At this stage the goals or objectives are drawn up (Hayes-Roth *et al*, 1986).

4.8.3.1.1 Participant identification and roles

The traditional model has involved the interaction between a single expert and a knowledge engineer. However, with the advent of expert system shells making it much simpler to program the system, the expert may also assume the role of knowledge engineer. If the knowledge domain is large or complex, extra domain experts and/or knowledge engineers may be enlisted for the development life cycle.

4.8.3.1.2 Aims and objectives

It is extremely important to formally define the aims and objectives of the project before commencing the development process. This includes defining the problem area, identifying the nature and extent of relevant knowledge, predicting possible problems which may be encountered and anticipating how they may affect the end product. It is also important to recognise important terms and their inter-relationships and also what a solution looks like and what concepts are used within it (Buchanan *et al*, 1986).

4.8.3.1.3 Identifying resource requirements

The most common areas of resource needed to develop a system are:

1. Knowledge sources - these include the domain expert, literature about the domain areas and building expert systems, established databases of domain knowledge and personal experiences.
2. Time - this will probably be a limiting factor. Most prototype systems take several months to develop and several months (or sometimes years) to refine before a usable product is achieved.
3. Computing facilities - it is important to realise the limitations of the hardware and software available before the start of the project. It would be totally unrealistic to attempt to produce a complex expert system consisting of over 1,000 rules using software normally designed for small applications of up to 200 rules.
4. Money.

4.8.3.2 Knowledge Acquisition

"Knowledge acquisition is the transfer and transformation of problem-solving expertise from some knowledge source to a program" (Buchanan and Shortliffe, 1984, Buchanan *et al*, 1986). The quality of the advice given by a knowledge-based system will depend on the information provided during development (Norton, 1990). This development cycle has created the need for a new type of specialist - the knowledge engineer (Anon, 1990). The knowledge engineer must elicit knowledge in small units, forming associations between hypothesised causes and observable evidence for them (knowledge acquisition) (Sell, 1985). Knowledge consists of descriptions, relationships and procedures for manipulating these descriptions and relationships in some domain of interest (Hayes-Roth *et al*, 1986) and tends to fall into one of three distinct categories (Lenat *et al*, 1986):

1. Factual knowledge found in literature consisting of theorems, equations, categories and operations etc.

2. Heuristic knowledge - this consists of rules of thumb and judgemental criteria built up by experience in the field.

3. Meta-knowledge - this is knowledge about the knowledge, used to refine the system and make it run more efficiently. For example it could be possible that two rules could be fired given a certain situation. Using meta-knowledge would determine which would be the most appropriate rule to be fired, given a specific situation. Meta-knowledge can also be used in systems containing several knowledge bases in order to choose which knowledge base should be used to solve a particular problems. For example, a car maintenance expert system could exist with knowledge bases on Ford, Vauxhall and Nissan models. It would be inappropriate and inefficient for the system to use all three knowledge bases when solving a specific problem about a Ford Escort.

Sources of knowledge include human experts, literature, databases and personal experiences (Buchanan *et al*, 1986). The knowledge needs to be in a format which makes it usable by the system and at the same time understandable to the user. The knowledge engineer also needs to be able to test the accuracy and completeness of the system and also design the inference mechanism (Anon, 1990) Other methods of representing knowledge include using simulation models, databases and real time information from sensory devices (Denne, 1988) Production rules are a suitable notation for encoding these associations. At the initial stages of elicitation, it is advisable to write down the conditions and conclusions/actions in natural language. At a later stage a method of representing this knowledge within the computer system will be required (Black, 1986).

The main bottleneck in developing a new expert system tends to be knowledge acquisition (Forsyth, 1984; Bramer, 1990)]. The traditional approach has been to get a domain expert together with a knowledge engineer to negotiate a rule based version of the knowledge the expert knows (Forsyth, 1984). This process can be further slowed down if more than one expert is being utilised to provide the necessary information (Bramer, 1990). Disagreements between the experts can lead to lengthy discussions which can ultimately lead to a significantly longer development cycle. On the positive side, however, utilising a group of experts can lead to development of a less biased system. Techniques used by a knowledge engineer to extract information from a domain expert in the past have included:

1. Watching the expert solve real problems out in the field.

2. Using a specific problem to explore what kind of data, knowledge and procedures are required to solve it.

3. Have the expert describe the types of problem which would lead to a typical conclusion for a particular knowledge domain (Heong, 1990).

4. Present the expert with a problem which he has to solve aloud in which he can be questioned at any point in order to work out some of the reasoning steps used (Yost *et al*, 1988; Heong, 1990).

5. Once a set of prototype rules and conclusions has been developed, ask the expert to review the reasoning behind the logic structure.

6. Once the system has been prototyped with the help of one domain expert, test the system using a number of other field experts, if available. (Heong, 1990).

The crucial drawback with the knowledge engineer-domain expert cycle of knowledge acquisition is that of communication. It is very difficult to extract from a domain expert the processes of reasoning he uses to come up with a recommendation. Also, the knowledge engineer is likely to misunderstand key reasoning processes due to his unfamiliarity with the vocabulary specific to the domain (Buchanan and Shortliffe, 1984). This process is costly in terms of time and money (Forsyth,1984; Jackson, 1992). With the advent of expert system shells to overcome the more complex programming, it has become possible for the domain expert to engineer his own system. This methodology can have the advantage of increasing the person's understanding of the subject area (Jackson, 1992). This method of knowledge acquisition includes information collated from journals, information gained from the communication with other field experts and knowledge currently known to a particular individual (Denne, 1988; Jackson, 1992). However, there has been a great demand to devise machine learning systems using induction strategies (developing generalisations from a specific known fact). There are several workers who have been actively developing such systems during the last 15 years, but they have not yet replaced other more conventional methods of obtaining knowledge (Forsyth, 1984).

4.8.3.3 Knowledge Formalization

Once the knowledge has been accumulated, it requires coding and storing within a data storage structure (Sell, 1985) (knowledge formalization). This is the most important task undertaken in the building of an expert system. Knowledge formalization involves the mapping of key concepts and relationships into an appropriate formal knowledge representation (Buchanan *et al*, 1986). There are several different ways of representing knowledge (Black, 1986; Jackson, 1992):

1. Production rules

2. Semantic nets

3. Frames

4. Interaction matrices

5. Working from examples

6. Decision trees

4.8.3.3.1 Production rules

The most commonly encountered method of representing knowledge is the production rule notation (Black, 1986). Production rules are a development of production systems which were first described by Emil Post in 1943 (Sell, 1985). Production rules, which have an IF ... THEN structure are very useful to represent 'rules of thumb' and can prove very powerful as only relevant rules are fired which means only appropriate knowledge is accessed during a problem solving session (Jackson, 1992). There are basically two parts to any production rule:

1. Conditions or antecedents.
2. Actions or consequents (Black, 1986; Young, 1987).

RULE: Conditions(s) $\rightarrow$ Action(s)

i.e. the actions are executed if the conditions are satisfied (Denne, 1988).

It is feasible that the conclusion (actions of one rule) may provide an IF for a subsequent rule. This leads to rules being linked in a logical way which simulates reasoning (Yost *et al*, 1988).

Using production rules to build an expert system is popular for the following reasons:

1. The modular nature of the rules make it easy to encapsulate knowledge and expand the expert

system by incremental development.

2. Explanation facilities - these are easy to build with rules since the antecedents of a rule specify exactly what is necessary to activate the rule. By keeping track of which rules have been fired, an explanation facility can present the chain of reasoning that led to a certain conclusion.

3. Similarity to the cognitive process - based on the work by Newell and Simon; rules appear to be a natural way of modelling how humans solve problems. The simple IF-THEN representation of rules make it easy to explain to experts the structure of the knowledge that you are trying to elicit from them (Giarratano and Riley, 1989).

An expert system would typically involve a large number of production rules (from around 50 to several thousand rules). Individual rules in themselves appear trivial, however the power of the system lies in the aggregate of all the rules (Black, 1986). However, a large system may also be considered a weakness because maintaining or modifying a large set of rules is not easy, and inaccuracies could develop. Firing the rule means that all the conditions on the left-hand side of the arrow are true and therefore the actions on the right-hand side must be obeyed (Young, 1987). The process is repeated in a recognise-act cycle, continuing from rule to rule until a conclusion is reached (Denne, 1988).

4.8.3.3.1.1 Production Rule Architecture

There are three areas which make up the basic structure of a production system:

1. Rule memory which is the memory that stores the rules which have been described previously.

2. Working memory which is the memory which is involved with the current problem solving activity. The only information held in this area is that required to provide a solution to a particular problem.

3. Fact memory which contains a database of permanent knowledge associated with the particular knowledge domain covered by a particular production system. This could, for example, include knowledge about specific drugs if the application was a medical system. (Young, 1987).

Explantation or amplification is generally provided in most expert systems by simply having help text associated with each question the system may ask the user. In this respect, an expert system is no different from any interactive program following current good practice (Black, 1986).

All expert systems are basically the same structurally. The most important way in which one expert system differs from another is in terms of the knowledge domain used (Black, 1986). The inference engine never changes and the user interface only changes in terms of cosmetic appearance. The knowledge base comprises of the rules and the working database (contains the facts concerning a particular case while it is under consideration) (Black, 1986). Production rules provide information in a way in which it can be used to solve a problem and does not represent the scientific knowledge which justifies it (Black, 1986).

4.8.3.3.1.2 Propositional Logic

Propositional logic is concerned with "how the truth of complex propositions may be established from that of atomic propositions from which they are made" (Black, 1986). Atomic propositions correspond to what could be described as declarative sentences in ordinary language. Propositions can be combined to create formulae which are connected by AND, OR, NOT and implies (THEN) which can be concluded to be true or false.

For example:

If Susan is a child then she goes to school

One of the disadvantages of propositional logic is, however, that significant generalisations cannot be made.

eg. For any individual x, if x is a child, then x goes to school

This is an example of predicate logic.

4.8.3.3.2 Semantic Nets

See Figure 4.5. Semantic nets are considered very powerful (Sell, 1985). A semantic net consists of a graph of nodes and linking arcs. Nodes are used to represent objects and the linking arcs are used to represent the relationships between the various objects This was a popular method of knowledge representation during the 1970's, but is rarely used today due to its increased complexity as the number of relationships increased.

4.8.3.3.3 Frames

See Figure 4.6. This type of knowledge representation looks at objects in a stereotypic fashion. A special slot is produced for the type of object. There then follows a fixed number of slots to represent the properties of the object. The fillers within the slots can be values, relationships to other frames or rules. A collection of frames can be classified as a scene or situation (Jackson, 1992).

4.8.3.3.4 Interaction matrices

The same factors are listed in the vertical and horizontal axes, each dot indicating the variable at the head of the column has a direct effect on the row variable. A domain expert is required for the construction of the matrix and to specify interactions between the various variables. There are a number of problems which occur when using this type of approach. It is not always obvious what level of detail will be needed when constructing the matrix, the

Figure 4.5 An example of a semantic net

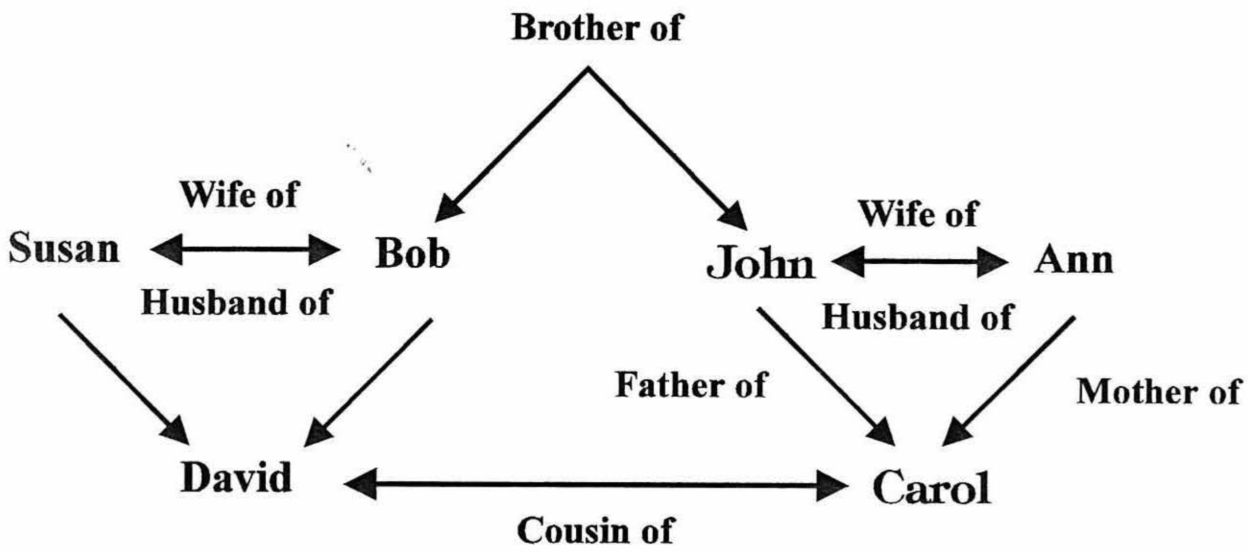
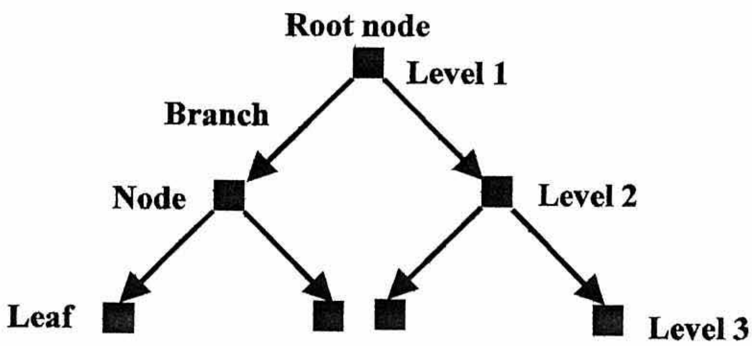


Fig 4.6 An example of a Frame

Slot	Filler
Manufacturer	Phillips
Product	Toaster
Model	T100
Location	(home,work,mobile)
Status	(working,faulty)
Warranty	(yes,no)

Fig 4.7 Decision tree structure



interactions between different variables are rarely simple and it is not always obvious what information is actually required in order to come up with a suitable recommendation (Denne, 1988).

4.8.3.3.5 Working from examples

This is a situation where a number of situations are defined which you work through in order to solve each problem individually (Denne, 1988).

4.8.3.3.6 Decision trees

See Figure 4.7. A decision tree uses a hierarchial data structure which consists of nodes, where information or knowledge is stored and branches which connect the nodes. In effect, it could be considered to be a special form of semantic net whereby every node, except the root, has exactly one parent and zero or more child nodes (Girarratano and Riley, 1989). It is easy to convert decision trees into rules, making it an ideal choice for developing prototype systems (Denne, 1988).

4.8.3.4 Testing

Testing involves evaluating the performance of the prototype system, both in terms of the accuracy and consistency of the conclusions given and the time taken to reach these conclusions. Traditionally, the evaluation of a new system would be carried out by the domain expert who would advise the knowledge engineer of further revisions necessary to refine the system (Hayes-Roth *et al*, 1986). However, in more recent times, a more formal structure of system validation has been developed which is carried out by the knowledge engineer for a more in depth analysis on the effectiveness and efficiency of the developed tool. The validation process is discussed in depth in Section 4.8.6 of this chapter.

4.8.4 Prototype development

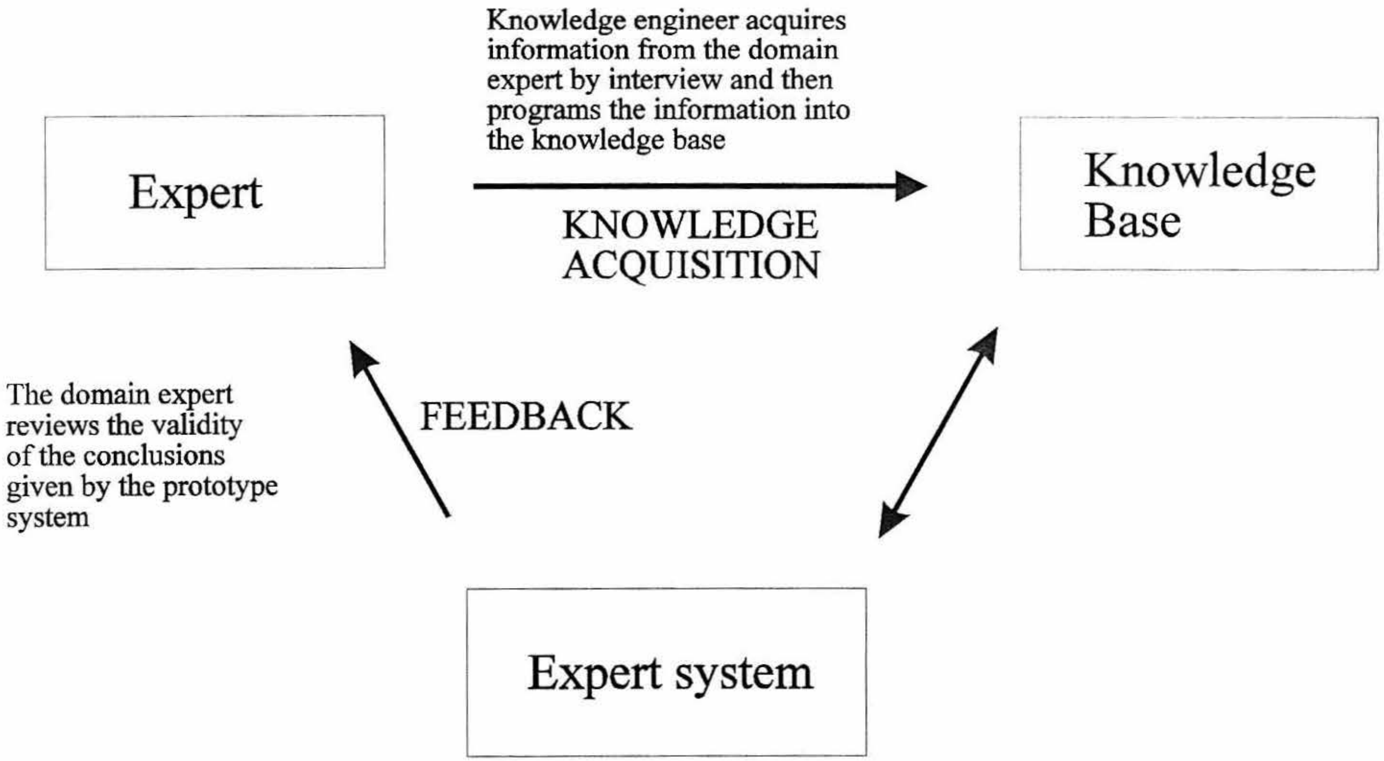
See Figure 4.8. It is widely accepted that prototyping a system is an important process when developing a large, complex expert system (Bramer, 1990). There is however a conflict concerning the use of the term 'prototype'. One definition put forward by Ince (1989) is that a prototype is a "mocked up initial version of a system which is thrown away after use". The more traditional definition is that a small knowledge base is developed on the computer very quickly which is then tried out in practice.The system would normally be tested against the original scenarios used to develop the system and then further testing would be carried using different problem situations. The system would then be modified or have new rules added in the light of the problems which occurred (Buchanan and Shortliffe, 1984; Black, 1986; Heong, 1990). The feed-back cycle of the prototype/refinement approach can be summarised as follows:

1. Select new set of test cases.
2. Elicit rules or rule refinements from an expert to account for new problem cases.
3. Encode new rules in the language of the selected software.
4. Test new knowledge base against current problem set with the expert as critic.
5. Repair rules until they work for the current problem set.

There are, however, a number of other requirements which need to be addressed by an expert system at the prototyping stage, irrespective of the application:

1. It should represent adequately the knowledge of the chosen problem domain.
2. It should apply the knowledge in a reasoning strategy that is both efficient and intelligible to the user (Black, 1986).
3. It should have a good human interface if it is to overcome natural resistance to innovation and

Figure 4.8 The traditional approach to developing an expert system using the prototyping method



to remain in day to day use (Black, 1986; Gaschnig *et al*, 1986).

4. It should integrate where possible with existing sources of information and other software, so as not to ask the user questions that might be considered superfluous (Black, 1986)

4.8.5 The human interface

It is important to ensure that a system appears user-friendly to a user. If a system is too difficult to use, no-one will use it. There are several areas where this can be achieved:

4.8.5.1 Question type

The most commonly used question type is the multiple choice question. A question is asked and it is immediately obvious to the user what range of replies are expected. This leads to a reduction in the number of ambiguities which may occur during the questioning process. Other types of question type used are:

a. Yes/no.

b. Free answer eg. name, occupation.

c. Numerical within a certain acceptable range set within the program (Sell, 1985).

4.8.5.2 Explanation

An expert system has to be capable of explaining all stages from the start of a consultation until an end recommendation/conclusion is reached. There are three types of explanation and the majority of expert systems contain all three types:

a. Interpretive, where terminology used within the questions and conclusions is defined.

b. Descriptive, where a particular process or level of reasoning is explained.

c. Justification, where an explanation is given as to why a particular question is asked or why a particular conclusion has been reached (Sell, 1985).

4.8.5.3 Provision of HELP screens

A new user will expect that adequate help is provided both at the beginning of the dialogue and at any point when input is solicited. Three forms of help should be provided:

1. Help on the system options the user may exercise in the course of the dialogue.
2. Help on selecting a hypothesis for the system to test (especially where the reasoning strategy is backward chaining).
3. Amplifications on the meaning of a particular question in the form of associated help text (Black, 1986).

4.8.6 Validation

It is very important that an expert system gives the end users accurate advice or correct solutions to their problems, therefore the system should undergo stringent validation procedures (Suwa *et al*, 1984; Denne, 1988). There are two main areas where the system requires checking for reliability. The first check is to ensure the correctness of the knowledge base. The second is to ensure that the program interprets and applies the information correctly (Suwa *et al*, 1984). It was recognised during the development of the earliest expert systems that proving a judgemental system to be correct is not an easy process. In order to validate the advice given by an expert system, there are five requirements which need consideration:

1. Consistency.
2. Completeness.
3. Soundness.
4. Precision.
5. Usability (Sell, 1985).

4.8.6.1 Consistency

Any system should be able to reproduce the similar answers when similar questions are asked (Sell, 1985; Denne, 1988). There is no generalised method for proving a system is consistent, but tests can be carried out to give greater confidence to the advice given (Sell, 1985). In rule based systems, three areas of consistency which can easily be checked are: conflict, redundancy and subsumption. A conflict occurs when two rules are capable of succeeding in the same situation but with conflicting results. Redundancy, on the other hand, is where two rules are capable of succeeding in the same situation leading to the same results. Subsumption is when two rules have the same end result, but one contains an additional condition before it can succeed. However, if the more restrictive rule succeeds then the second, less restrictive rule can also succeed making this rule redundant (Suwa *et al*, 1984).

4.8.6.2 Completeness

Any system should include enough information concerning a specific domain of knowledge to produce a reasonable level of confidence in the recommendations given. Does the system include enough problem areas? Within each problem area, is there enough information available to produce a recommendation? (Denne, 1988). This is called semantic completeness (Sell, 1985).

A second area of completeness defines the form of the knowledge base rather than the content and is called formal completeness (Sell, 1985). There are a variety of ways to check the formal completeness of a system:

a. Check that all the conclusions included within the system can be produced from the rules. In systems where a relatively small set of conclusions can be found, missing rules can be detected fairly easily by following each logical path to a conclusion (Suwa *et al*, 1984; Sell, 1985).

b. Check that the conditions within the rule structure are sufficient to differentiate between different conclusions available.

c. Check that all possible conditions within the knowledge base will ultimately lead to a conclusion. If not, there is a possible information gap which may require building new rules which in turn may generate more conclusions (Sell, 1985)].

4.8.6.3 Soundness

The information represented should be as accurate as is possible, given the information currently available. In other words, does the information agree with expert opinion i.e. is the expertise correct? (Denne, 1988). This can be tested by producing a number of test cases. The system can be then used to process the information and produce recommendations which can be tested against recommendations made by a human expert (Sell, 1985).

4.8.6.4 Precision

This is required if an expert system is designed to deliver probabilistic or qualified judgements. Precision requires that a conclusion is presented 'with a certainty appropriate to the case'. One way of testing the precision of a rule structure is to carry out a sensitivity analysis. A question can be considered non-sensitive if the conclusion remains the same regardless of how the question is answered. If, however, small differences in the answer given lead to large difference in the conclusion, the question is said to be sensitive. Some expert systems have been developed which automate this process (Sell, 1985).

4.8.6.5 Usability

It is important to produce a system which the end user will want to use. In order to achieve this, the system must appear user friendly, easy to use and answer the problems required. The are several ways to test the usability of a system:

a. The information should be repeatable, therefore a group of users should be asked to work through a problem on the system. These same individuals should then be asked to repeat the same procedure a week later. There should be no significant deviation between the two sets of answers.

b. A representative group of users should be allowed to use the system after a quantified level of training. A questionnaire should then be filled in by these users to report their comments on the system which can be analysed afterwards (Sell, 1985).

4.9 Discussion

Over the last 30-40 years, one area of artificial intelligence has grown into an important area of computer science in its own right. It was through the development of the General Problem Solver that researchers realised a more practical approach to problem solving would be to develop more domain-specific systems. Therefore, the concept of building an expert system was born. To produce a computer program with expertise in a limited field, it was necessary to understand the mechanics of how a human expert solves a problem. One hypothesis put forward described long term memory consisting of a large number of IF-THEN rules. This information was thought to consist of facts gained through reading literature and "rules of thumb", or heuristics built up through day to day experiences. During problem solving, the cognitive processor in the brain tries to locate rules which will be activated, given the appropriate stimuli. This model has been used to develop the basic expert system program.

Since the early 1980's in particular, the number of new applications being developed has significantly increased. The cause of this sudden explosion of new applications seems to coincide with the development of the expert system shell. Traditionally, during the development of a new expert system there were two distinct roles: the domain expert and the knowledge engineer. The role of the knowledge engineer was to elicit information regarding the domain area from the expert in a way that could be easily translated into a more formal symbolic notation. Because the knowledge engineer was not familiar with the subject area, frequent misunderstandings could occur, leading to a mis-interpretation of the knowledge in the database. However, with the development of the expert system shell which provides the inference engine and user interface ready built, programming a new application has been made much simpler. This means that now it is much more likely that the domain expert will program the application himself.

Expert systems provide a good opportunity to produce a prototype system, incorporating new concepts and ideas very quickly and economically, when compared with conventional programming methods. They provide an efficient and reliable means of disseminating what was once considered "expert knowledge" to a much wider audience. This makes them very useful as training resource in schools and institutes of higher education. However, the main advantage of expert system technology over conventional programming is the justification facility. This provides the end user with a great deal more confidence in the advice being given because the system can explain the logic behind the problem solving route taken.

It would be dangerous, however, not to be made aware of the limitations of expert system technology. These include lack of common sense and intuition, lack of learning ability and being unable to adapt to new situations. It should also be pointed out that as with any other computer application, the information is only as good as the person who entered it into the system. There is always the risk of human error. Because the majority of information incorporated into an expert system tends to be qualitative rather than quantitative, this makes it difficult to test the accuracy of an application. In order to overcome these problems, a number of validation procedures have been specifically devised for testing new applications. Some of these checks have been described in Section 4.8 of this chapter.

The domain areas covered by the expert systems currently developed fall mainly within the realms of pure and applied science. However, there are a number of commercial systems developed eg. for banks/building societies, insurance companies and even the department of social security. In the area of Agriculture, there have been a large number of expert system applications developed since the early 1980's. The majority of such systems built to date have been developed for the arable farming industry. There are a number of factors which could account for this phenomenon. The cost/benefit ratios for pest control tend to be more quantifiable regarding the final yield of a cereal crop. Therefore the benefit of using a computerised advisory system is more easily calculable. There are a number of reasons why this is not the case for livestock farming:

a. The unit price for livestock tends to fluctuate significantly on a seasonal basis. Therefore, the cost of ineffective pest control is not merely due to the time delay in sending an animal to market, but also due to reduced profit caused by a fall in the unit price. This makes it much more difficult to calculate the cost/benefit ratio of pest control.

b. The effect of a pest on a cereal crop tends to be relatively uniform due to the genetic breeding to enhance production in the modern cereal crop. However, the effect a particular parasite has on individual animal tends to vary significantly.

c. Arable cropping tends to be a closed model, with very few external factors affecting pest control strategies. This is not the case with livestock farming eg movement of stock both within and between farms can have significant implications to pest control.

Therefore it can be seen that the overall model is much more complex than for a cereal crop. One of the main aims of this project is to determine the suitability of expert system technology as a platform for developing advisory pest control systems for the livestock industry.

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Contents - Chapter 5

Chapter 5 - Survey to Monitor the Control Methods used against Worm Parasites of Sheep by North Wales Farmers

5.1 Introduction

In Chapter 2, the nematode species responsible for causing parasitic gastro-enteritis in sheep were introduced, together with the symptoms characteristic of infestation with the individual species. In Chapter 3 the drugs currently available to control these worm parasites were described, together with problems of resistance caused by drug over-usage. However, this information is based on a review of the literature, and is primarily concerned largely with research investigations carried out in a laboratory situation. The most recommended strategies from these investigations may well be the most efficient ways of controlling worm problems in a controlled environment, but in the real-life farm situation there could be factors which make implementation of certain procedures impractical.

Therefore, the present survey was designed to ascertain which control strategies are employed in the field by farmers at the present time and to obtain an insight into the reasons why such strategies are chosen. This information could then be used to highlight requirements for a computerised advisory control programme and to incorporate the needs of the farmer with the ideals designed by research scientists in producing an optimal worm control programme. The information allows the development of a computer program to aid in decision making concerning the optimal control measures appropriate to a particular farming enterprise, and in a format which should prove to be user-friendly to the ultimate user i.e the farmer himself.

5.2 Literature Review

There have been a very limited number of surveys carried out to investigate which management strategies are currently being used for the control of parasitic gastrointestinal nematodes of sheep, either on a local or nationwide scale. The following review looks at data supplied from four such surveys. The first was a localised survey carried out during 1984 in the Lanarkshire area of Scotland. This was followed by a series of nationwide survey results carried out during 1992/93 by ADAS.

The first survey (Survey 1) was a localised postal survey carried out by Glasgow University Lanark Practice during 1984 (Gettinby *et al*, 1987). Out of 300 questionnaire forms sent out, 100 (33%) were returned, out of which 74 (25%) were deemed suitable for the purposes of the survey. The survey was devised to obtain information from cattle farmers as well as sheep farmers. However, only the sheep farm data will be reviewed in this section. Forty six farmers of the seventy four replies kept sheep. All farmers said they used anthelmintics, with 61% using benzimidazoles, 22% using a levamisole/benzimidazole rotation, 15% using levamisole and only 2% using ivermectin. It is quite worrying, however, that 48% of all farmers questioned had used benzimidazoles continuously on their farm for at least five years, with 20% having used benzimidazoles for over 10 years without any break. The average number of ewe treatments per year per unit was 2.44 and the average number of lamb treatments was 2.19 per year. It is quite interesting that when these figures are broken down into farms where alternative grazing was either available or not available, fewer treatments were carried out if no alternative grazing was available.

The second survey (Survey 2) was carried out by ADAS in conjunction with Janssen

Animal Health during August 1992 using a sample of almost 1500 farmers (Stubbings, 1993). The majority of farmers questioned said they were happy with their own worm control procedures, although 26% did think that the internal parasites had become more of a problem during the previous five years. Dosing of ewes was generally carried out pre-tupping and again in the spring around lambing time. In the case of lambs, 58% of farmers said they dosed routinely (every 4-6 weeks or more frequently). It is quite interesting that of the hill farmers interviewed, 44% used similar dosing regimes as their lowland counterparts. Almost half of all farmers had increased their use of anthelmintics during the previous five years. When asked about anthelmintic resistance, 80% of farmers recognised that inaccurate dosing played a major role in the development of resistance. However, 50% of farmers did not know how many different groups of drugs were currently marketed in the UK. This is particularly surprising since 90% of those who replied had already taken some form of advice on worm control.

The third survey (Survey 3) was carried out by ADAS in conjunction with the National Sheep Association during 1993 (Anon, 1993). There appeared to be some confusion about the number of groups of wormer which were currently available in the UK as only 64% of farmers answered that there were three groups of broad spectrum wormer. Almost three quarters of farmers (74%) claimed to use an annual rotation of wormer, however, it was concluded that levels were probably not as high as claimed. An earlier survey (Survey 4) carried out showed that during 1992 60% of farmers used benzimidazoles, 22% used levamisole and only 18% used ivermectin (Anon, 1993). Only 46% of farmers weighed a sample of sheep before dosing but three quarters of farmers said that they checked the calibration of the drenching gun. The average number of ewe treatments given was 2.45, with the lambs receiving an average of 3.53 doses.

Generally, farmers used more than one control measure strategy. Approximately half of the farmers tended to dose when required with the other half dosing at a pre-determined time. The two most popular strategies of worm control involving pasture management were dose and move at weaning (46%) and move to clean pasture in the spring (35%). Very few farmers adopted quarantine measures for bought-in stock.

It can, therefore, be seen from all these results that benzimidazoles are the most commonly used drugs for nematode control. This is particularly surprising in the latter studies, considering that resistance to this group of chemicals has featured so predominantly in the farming press over recent years. It is quite likely that farmers having found that a particular benzimidazole has worked effectively are reluctant to change to a drug with which they are less familiar. It is also possible that farmers think they are rotating the group of anthelmintic used when they are in fact merely changing from one benzimidazole drug to another. In the case of Survey 2, 50% of farmers (and 36% of farmers in Survey 3) showed confusion regarding how many groups of broad spectrum wormers are currently marketed in the UK (Anon, 1993; Stubbings, 1993).

In Survey 2, 80% of farmers recognised that inaccurate dosing was an important factor in the development of anthelmintic resistance (Stubbings, 1993). However, in Survey 4, only 46% of farmers said that they weighed a proportion of their flock before dosing; furthermore, 25% of farmers did not calibrate their drenching gun before dosing (Anon, 1993). Both of these factors would cause inaccuracies in delivering the correct dose of wormer to the flock as a whole.

The frequency of ewe treatments within a single season seems to have remained constant during the last ten years (2.44 in 1984 (Gettinby *et al*, 1987), 2.45 in 1993 (Anon, 1993)).

However, lamb treatments appear to have increased from 2.19 per annum in 1984 to 3.53 in 1993 (Gettinby, 1987; Anon, 1993). This could be a reflection of farmers' awareness of worm problems on their farm. In Survey 2, 26% of farmers thought worm problems had increased during the previous five years and approximately half of farmers had admitted to increasing the frequency of their dosing regimes (Stubbings, 1993).

Even though a large number of articles have been written in the ley press regarding worm control practices, there still appears to be a great deal of confusion within the farming community. There has also been very little data collected from Welsh farmers, who manage approximately 25% of the UK National flock (Scott *et al*, 1991). Therefore, the present survey was designed to find out which methods of worm control are employed by North Wales sheep farmers. A comparison could then be made with data collected on a nationwide scale. This information would be useful in determining how accurate more localised studies can be in reflecting national trends in sheep husbandry.

5.3 Method

5.3.1 Sample size

The sample size of a survey reflects the overall objective of the study. If the idea of the survey is just to get a `feel' for the important issues, a small sample (eg tens of participants) is generally adequate. However, if a qualitative approach towards opinions or facts is desired, a large sample size (hundreds or thousands of participants) is required. In this case, an overview of the worm control practices by North Wales farmers was the overall objective and therefore it was concluded that a reasonably small sample size would be appropriate. Therefore a sample size of around 60 returns was targeted.

5.3.2 Survey method

Survey methods tend to fall into one of two broad categories: personal interviews and postal questionnaires. Personal interviews require face to face contact or questioning by telephone. This method is particularly important for opinion-based surveys where there is a need for considerable interpretation of the results and the need for follow-up questions. It is important, however when handling a personal interview not to lead the interviewee eg. placing emphasis on certain words rather than on others can completely alter the possible interpretation of a question leading to the introduction of bias.

Postal questionnaires are a cheap alternative to personal interviews, both in economic terms and in the amount of time required to conduct the study. Because of the nature of the work, together with the time and economic constraints, it was decided that a postal questionnaire would be more suitable for this survey. However, there are certain drawbacks to this survey method which require addressing and these are discussed below:

5.3.2.1 Return rate

The return rate of postal questionnaires tends to be very low (generally less than 30%). Since a sample of around 60 returns was targeted, it was decided to send out around 200 questionnaires. In an attempt to increase the return rate, an incentive (i.e free prize draw to win a voucher at the local farmers' supplies store) was introduced to try to encourage farmers to return the forms and a stamped addressed envelope was also included.

5.3.2.2 Question design

This is probably the most important area for consideration when designing questionnaires for postal surveys. If the overall impression given by the form is complicated, many potential respondents will discard the questionnaire as it appears to imply too much hard work to fill in. The questions should be designed to be as simple as possible, in order to avoid any ambiguities, which could lead to a reduction in the accuracy of the answers given. The overall design of the questionnaire was developed with the help of Dr J. Borland (Social Theory Department, U.C.N.W.), who has had many years of experience in questionnaire design. The following areas of question development were considered during the development process:

1. The questions were kept as simple as possible, requiring only a single response in the majority of cases.

2. The questionnaire was organised into three areas, to make it as psychologically acceptable to the respondent as possible. The opening questions were designed to ease the respondent into the questionnaire, asking for their name, address and farm type. This was then followed by the main thrust of the questionnaire, which involved a more probing approach to management procedures adopted on the farm. Finally, there were a couple of questions requiring an easy yes/no answer

eg whether the farmer would like his name putting into the free draw and whether he would like a copy of the survey results when available. The idea was that if the respondent could easily answer the first couple of questions he was more likely to complete the questionnaire. Likewise, at the end, if the questionnaire finished with a couple of easy to answer questions, the respondent was more likely to complete the questionnaire with a positive reaction towards the survey.

3. The questions were designed not to lead the farmer towards one particular response since this can lead to bias.

4. Positive questions (eg. do you use a wormer?) were used where appropriate since negative questions (eg. do you avoid using a wormer?) can lead to mis-interpretation at the analysis stage.

5. Embarrassing questions (eg. age and income) were avoided wherever possible, as this often alienates the respondent.

6. The questionnaire was kept as short as possible, to encourage completion and wherever possible, only questions directly necessary to the survey were asked, although a few additional questions were added to improve the flow of the questionnaire and avoid abrupt changes in direction.

7. It is recognised that the area in which the survey was to be undertaken consists of a large proportion of Welsh speaking farmers and therefore, a bi-lingual questionnaire was produced.

5.3.2.3 Question type

There are four possible types of question which can be used for survey purposes:

1. Open answer eg name, address. This type of question is easy for the respondent to answer. However, if the respondent does not fully understand the question, an undesired response may be given. Also, the responses are not easy to analyse, unless the answers are grouped together

in types at the analysis stage. this can cause inaccuracies of interpretation by the analyst since he may misunderstand the answers of the respondent. An additional problem in the present survey was its bilingual nature. If a significant number of questions had consisted of the open-answer format , the analysis phase would have been significantly prolonged by the need for translation.

2. Numerical eg number of farm workers employed on the farm. This type of question is easy to analyse, but may prove ambiguous if a ratio value or fraction is required.

3. Sliding scale eg please indicate by a cross on the scale how effective you consider your wormer to be:

ineffective ________________________________ very effective

Since the main disadvantage of this type of question is the difficulties encountered in analysing the results, it was avoided.

4. Multiple choice questions are generally considered to be the most appropriate for survey purposes. The respondent is immediately aware of the type of response required and the answers can be coded which makes them easier to analyse. This question format was the one used for the majority of questions used in this survey. Care must be taken, however, to avoid biasing the respondent. Thus, if a very narrow range of possible answers is presented, the respondent may be led to make a less accurate answer than if care has been taken to cover all possible eventualities. One way to test the response range to a question is to include an option called 'other' at the end of the choices given. If at analysis, it is found that the majority of respondents have chosen 'other', then it is quite likely that a vital answer (or answers) to a question has been missed. If this is the case, the design of that particular question should be reviewed. The respondent may also be biased if the scale of multiple choice answers leans in a particular

direction. For example, if a scale includes the answers 'bad' and 'very bad', then the opposite end of the spectrum should include 'good' and 'very good'. If only 'good' is present, this leads to a bias in favour of a 'bad' response.

5.3.2.4 Subject area

The subject areas of the questions asked fell into five categories:

1. General farm information eg. topography of the farm, size and overall farming system.
2. Grazing management regime used on the farm, including overwintering/lambing procedures and abundance/ lack of alternative grazing.
3. Worming regimes, including type of wormer used, frequency of use and maintenance of equipment.
4. How the farmer felt he could improve his worm control procedures and any reasons why these improvements could not be implemented on his farm.
5. Introduction procedures for bought-in stock.

5.3.3 Pilot study

A proposed questionnaire design was produced and tried on two members of the School of Biological Sciences, who had smallholdings and sheep stock. Neither individual had been involved in the questionnaire development or with any other part of this study. The forms were returned, with comments regarding how some questions could be improved in order to eliminate ambiguities.

After the modifications were completed the form was distributed. A copy of the finalised questionnaire appears in Appendix A.

5.3.4 Random sampling procedure

A major problem was encountered in attempting to access the names and addresses of farmers known to rear sheep in the Gwynedd area. Unfortunately, the Data Protection Act prevented access to appropriate details from recognised official bodies. Therefore, the names and addresses of 208 farmers were selected at random from a total of 1,350 registered in the Gwynedd area of the Yellow Pages telephone directory. This method has several disadvantages:

1. It was very time consuming.
2. Since there is no indication from the list of which type of enterprise is carried out, the identification of sheep-only enterprises was not possible.

The sample of 208 farms was chosen by highlighting every eighth farm address in Yellow Pages, which explains why 208 rather than the chosen sample of 200 questionnaire forms were sent out.

5.3.5 Analysis technique

As the ultimate aim of the survey was to provide a broad overview of worm control procedures used in North Wales, the analysis technique was kept simple. Each multiple choice answer within each question was number coded to ease the production of analysis tables. Because of the type of information being collected, production of tables using simple percentages was thought appropriate. No statistical analyses have been carried out on the data.

5.4 Results

5.4.1 Return rate

A total of 208 questionnaires were sent out, of which 78 were returned (37.5%). However out of this sample of 78 forms, only 57 could be used for the purposes of the study (27.4%). This is surprisingly close to the original target of 60 returns. The reasons for returned forms being excluded from the study included return of forms not filled in, farmers having retired and farms which did not keep sheep.

Unless otherwise specified, the percentages given in the following results are based on the total number of forms included in the study (i.e. 57).

5.4.2 General farm information

Figure 5.1 Farm Topography

Farm Type	% of replies
Lowland	36.8
Hill and Upland	19.3
Hill and Upland and Lowland	15.8
Upland	14.0
Upland and Lowland	7.0
Hill	3.5
Hill and Lowland	3.5

The largest number of returns were from lowland farmers (36.8%) followed by 19.3% from hill/upland farmers (Figure 5.1). The overall spread of farm topography is probably fairly representative of that expected for the Gwynedd area. The relatively high proportion of farms combining hill/upland and lowland situations (26.3%) is probably a reflection of the local practice used by hill farmers on the mainland of leasing lowland grazing on Anglesey to overwinter their flock.

The majority of farms in the area (87.7%) keep both sheep and cattle (see Figure 5.2 below).

Figure 5.2 Type of Farming Enterprise

Farm Type	% of replies
Sheep and Cattle	87.7
Sheep only	7.0
Sheep and Cattle and Arable	3.5
Other	1.8

5.4.3 Grazing management

Figure 5.3 Grazing System by Farm Type

Farm Type	% of replies	
	Set Stocking	Rotational Grazing
Hill and Upland	72	28
Hill and Upland and Lowland	57	43
Lowland	45	55

The largest proportion of farms employing a set stocking regime were those in the hill/upland category (72%), whereas with lowland farms over half (55%) practised rotational grazing (Figure 5.3).

Figure 5.4 Lambing routine by farm type

Farm Type	% of replies			
	Inside Lambing	Lambing Period	Outside Lambing	Lambing Period
Hill only	0		100	April
Hill and Upland	28	Feb-Apr	72	April
Upland only	88	Feb-Apr	12	Dec-Mar
Hill and Upland and Lowland	33	Feb-Mar	67	Feb-Apr
Lowland only	50	Dec-Mar	50	Feb-Mar

The housing of sheep in winter seems to be favoured by the majority of upland farmers (88%), but it is interesting that there appears to be no advantage in housing ewes in terms of earlier lambing dates (Figure 5.4). Again, the effect of hill farmers overwintering their flocks on Anglesey can be seen as a reduction of inside lambing in the hill and upland and lowland farm situation.

5.4.4 Worming practices

Figure 5.5 Type of wormer used during 1992

Drug Group	No. of farmers	% of Farmers
BDZ	33	61.0
BDZ and LEV	10	18.5
LEV	4	7.4
IVER	3	5.6
BDZ and IVER	2	3.7
BDZ and LEV and IVER	2	3.7

BDZ = Benzimidazole LEV = Levamisole IVER = Ivermectin

From Figure 5.5 it can be seen that more than three quarters of farmers used either a benzimidazole or benzimidazole-levamisole rotation during 1992. The main reasons for these choices were the efficiency of controlling the worms (91%) and ease of use (31.6%) (see Figure 5.6). There did appear to be some confusion amongst the farmers regarding the difference between chemical groups and different generic names of chemicals within the same chemical group. When asked how many groups of wormers were used on the farm in a single year, some farmers replied three, but then went on to say that they used only a benzimidazole and levamisole rotation. Of those farmers using a benzimidazole only in a year, 42.4% stated that they did not change the drug from year to year.

Figure 5.6 Reasons given for using the chosen wormer

Reason	No. of Farmers	% of Farmers
Efficient	52	91.0
Easy to use	18	31.6
Recommended	13	22.8
Economical	12	21.0

The farmer was allowed to circle more than one answer to this question

All farmers said they preferred oral dosing, but of these 57.9% said they did not maintain the drenching equipment after every treatment (Figure 5.7). This is worrying since later in the year when control is more important, because clinical symptoms are more likely to be seen, the equipment is likely to be less accurate. It is even more worrying that 22.8% of farms either failed to maintain the equipment at all or did so less than once in every two years.

Figure 5.7 Frequency of the maintenance and calibration of the drenching equipment

Frequency of equipment maintenance	% of farmers
After every treatment	42.1
Annually	33.3
Once in two years	1.8
Less frequently	8.8
Never	14.0

Figure 5.8 shows how the farmers estimate the liveweight of the stock for worming

purposes. The majority of farmers (79%) do not weigh even a small sample of their stock to determine correct dose rates and 54% rely on sight alone for estimating body weight.

Figure 5.8 Method for estimating the liveweight of stock by farmers

Technique	% of Farmers
By sight	54.4
Touch/lifting	24.6
Weigh random sample in each age/sex class	14.0
Weigh sample of the heaviest animals in each age/sex class	12.3

When asked at what time of year were ewe treatments carried out, the most common response was once pre-tupping and once post-lambing (38%). However, it can be seen from Figure 5.9 that the majority of farmers dose the ewes once in autumn and once in spring (92.9% in both cases (78.9+14/28+64.9)).

Figure 5.9 Periods in the season when ewe treatments are carried out

Time in the season	% of Farmers
Autumn, pre-tupping	78.9
Autumn, post-tupping	14.0
Spring, pre-lambing	28.0
Spring, post-lambing	64.9

The farmer was allowed to circle more than one answer to this question

In the lamb situation, 61.3% of farmers said that they treated the lambs at least once a month (see Figure 5.10). This shows that the majority of farmers are using very intensive worming programmes.

Figure 5.10 Frequency of Lamb Treatments

Frequency of Treatment	% of farmers
Weekly	1.8
Every 2-3 weeks	21.0
Monthly	35.0
When necessary	39.0
Monthly and when necessary	3.5

5.4.5 Farmers views on worm control

Figure 5.11 Improvements which the farmer considered could be made to his control programme

Change to control programme	% of Farmers
Better use of alternate grazing	51.9
Use a different drug	40.4
More frequent dosing of lambs	19.2
More accurate weighing of stock	11.5
Less frequent dosing of lambs	5.8
Better maintenance of dosing equipment	1.9
Other	1.9

The farmer was allowed to circle more than one answer to this question

Most farmers (91.2%) considered that their worm control programmes were effective. When asked where they felt improvement could be made, over half thought that they could make better use of alternative grazing and 40.4% thought improvements could be made if they used a different group of wormer (Figure 5.11). However, when asked what problems they could foresee in implementing these changes, the overall opinion was that changing the drug more frequently would be uneconomical and that better use of alternative grazing was too time consuming, uneconomical and in some cases impractical, as alternative grazing was not available on the farm (Figure 5.12).

Figure 5.12 Problems with implementing improvements onto the farm

Change to control programme	% of farmers who say change not practical on their farm	Problem
Better use of alternative grazing	74.1	economics (cost) too time consuming lack of labour lack of grazing
Less frequent dosing of lambs	33.3	economics (productivity)
More frequent dosing of lambs	20.0	economics (cost) too time consuming lack of grazing
Use a different drug	14.3	economics (cost/unknown benefits)

5.4.6 Introduction of new stock

Figure 5.13 Introduction procedures for bought-in stock

Introduction procedure	% of farmers
Worm and introduce	24.5
Worm and quarantine for a period	45.6
Introduce to flock immediately	14.0
Other	1.8
No stock is bought-in	14.0

Finally, the farmer was asked about the procedures used when introducing new stock onto the farm. Of those that did buy in stock 70% treated the new animals before introducing them to the main flock, but only 45% then quarantined these animals for a period before introduction (Figure 5.13). It is worrying that 14% of farmers (16.3% of all farmers who buy-in stock (8 farmers out of the 49 farmers who said that they buy in stock)) do not worm their new stock and introduce them immediately to the rest of the flock.

Of those farmers who did quarantine new stock, 65% introduced the new animals to the main flock within one day of dosing (Figure 5.14).

Figure 5.14 Duration of the quarantine period for bought-in stock

Quarantine period	% of farmers
A few hours	38.5
One day	26.9
2-3 days	11.5
One week	15.4
Other	7.7

5.5 Discussion

The return rate of 37.5%, was very encouraging and in that respect the survey can be considered a success. This is slightly higher than the postal survey carried out in 1984 (Gettinby *et al*, 1987), where a return rate of 33% was achieved. It is particularly surprising to achieve this level of return considering the original sample was taken from the Yellow Pages telephone directory and no farm type information was initially available. However, the incentive of entry into the prize draw appears to have improved the level of return quite significantly.

Since a large proportion of the land in the area sampled falls within the Snowdonia National Park, a large proportion of hill farms was expected. However, there could have been some confusion between the terms upland and hill, therefore the results of these two types of farm have been merged for analysis purposes. The larger proportion of set stocked land for hill and upland areas is very typical of this area, with much of the Snowdonia National Park grazed as open mountain. Hence, unlike the lowland situation, the land will have a low stocking rate and the management is a lot more extensive.

It can be seen from Figure 5.4 that the majority of housed sheep are from upland areas, but it is surprising how little influence housing appears to have on the lambing date. This could be because in the Snowdonia area those farmers who don't house their stock tend to lease land in a lowland area, such as Anglesey to overwinter their stock. Therefore no true comparison can be made between housed and unhoused stock.

The most popular group of wormers was found to be the benzimidazoles (white drenches), with levels of use similar to those found in the Lanarkshire survey (Gettinby *et al*, 1987) and nationwide survey of 1992 (Anon, 1993). Over three quarters of all farmers questioned used at least one benzimidazole drug in the year. It is worrying, however, that even with the wide coverage in the farming press concerning the development of anthelmintic resistance in recent years, over 42% of farmers questioned who used a benzimidazole product do not change the drug from year to year. This trend was also reported in the Lanarkshire survey where 79% of those farmers who claimed to use benzimidazoles had used the same drug for more than five years continuously. The value obtained in the current survey is probably higher than the figures show due to confusion encountered in differentiating between groups of drugs and different representatives within the same chemical group. There is a tendency, for example, to consider albendazole and oxfendazole as different chemical groups when they are indeed representatives of the same chemical series whereas levamisole is a different chemical group from the benzimidazole series as is ivermectin. This confusion has also been recorded in other surveys, for example 50% of farmers questioned in 1992 (Stubbings, 1993) and 36% of farmers in a survey in 1993 (Anon, 1993) did not know how many different groups of drugs were currently marketed in the UK. This is quite significant since side-resistance between different compounds in the same group is known to occur (Donald, 1982).

The threat of resistance becomes even more significant if the whole procedure involving worming practice is looked at. The majority of farmers (79%) admitted to not weighing even a small sample of their stock to estimate the correct dose rates required. Consequently this will almost certainly result in the wrong dose being given. This proportion is considerably higher than that found in the nationwide survey in 1992 (Anon, 1993) of 54%. In the more widescale study (Survey 3), a large proportion of farms within the southern counties of England would have been included. It has been well documented over the last five years that these areas have recorded a higher incidence of identified anthelmintic resistant populations. In 1984, the occurrence of benzimidazole resistance was reported to be 13.5% of farms surveyed (Cawthorne and Cheong, 1984). However, by 1992, this value was reported to have risen to 36%, with the possibility of incidences as high as 51% if all suspected cases were also included (Coles, 1992; Hong *et al*, 1992). It is, therefore, quite likely that there is an increased awareness of how husbandry practices can affect the development of resistance at the farm level in these areas.

In addition to the failure to weigh the sheep, 57.9% of farmers did not maintain and re-calibrate the drenching equipment after each treatment. This figure again is considerably higher than that found in the nationwide survey in 1992 (Anon, 1993) of 25%. The most likely result of both these deficiencies is that sub-curative doses of the drug will be given which means that a higher worm burden will survive treatment (Rowlands, 1989); this inherent lack of efficacy could mistakenly be interpreted as resistance. However, if this is repeated on a regular basis, a build-up of resistant genes in the field worm population will result (Michel *et al*, 1982). The problem of anthelmintic drug resistance in nematodes causing parasitic gastroenteritis of sheep in Britain is reviewed in Chapter 3 and the data published recently by Hazelby *et al* (1994). Only a small number of farmers (11.5%) admitted that there was a problem concerning their method of weighing the stock and only 1.9% considered that the drenching equipment could be better maintained. This leaves a large proportion of farmers who do not consider their worming procedures need improvement. The percentage of farmers who recognised the need to change the drug more often was 40.4%, but 14.3% claimed that economic considerations made it impossible to implement this on their farm.

The most popular strategy for dosing ewes was shown to be once pre-tupping and once post-lambing. This agrees with the results obtained from Survey 2 (Stubbings, 1993). It has been found that a single dose pre-tupping leads to an improvement in general body condition with a correspondingly higher rate of success at mating and a higher percentage lambing ratio. In the case of the post-lambing dose, its success lies in the pasture management procedures implemented on the farm. A dose and move strategy at this time will be highly successful (Michel *et al*, 1982), especially if the move occurs before the lambs are 6 weeks old (before concerted grazing takes place). Such a strategy means that the new pasture will not be contaminated with new eggs since the effect of the peri-parturient rise in faecal egg output by the ewe will have been dramatically reduced by drug treatment. However, if the ewes and lambs are left on the same pasture after lambing, the build up of larval contamination on the pasture would mean that re-infection immediately after treatment would greatly reduce the effectiveness of the drug. In this case a pre-lambing dose 6 weeks prior to lambing will also be necessary.

The most popular single regime for dosing lambs was to dose only when necessary (39%), but 61.3% of farms dose at a frequency of every 4 weeks or shorter (Figure 5.10). This agrees with results recorded in Survey 2 (Stubbings, 1993) where 58% of farmers were found to dose routinely every 4-6 weeks or less. In some cases this intensive dosing strategy is needed since lack of alternative grazing limits the movement of stock, and in the lowland areas especially, stocking rates will be high. However, in areas where stocking rates are low and/or there is more alternative grazing available, pasture management techniques could reduce the amount of dosing without compromising the well-being of the lamb crop. Dosing every three weeks will ensure, in the short term, that lambs remain healthy with low worm burdens. However in the long term, the probability of increasing the chance of drug resistance developing (Barton, 1983; Taylor and

Hunt, 1989), could well outweigh this short term advantage. Such a short interval between worming may also impair the development of immunity, leaving a permanently susceptible population of lambs. This message, however, has not reached many farmers since almost four times as many said that they should dose their lambs more frequently compared to those who said that they should dose less frequently (Figure 5.11).

Over 90% of farmers claimed that their worm control programme was effective, although the majority did admit that some improvements could be made. The most popular area where it was felt that improvements were needed was better use of alternative grazing. However, in nearly three quarters of all cases this was said to be impractical due to lack of grazing land, economic considerations and because it was felt to be too time consuming to implement. It is, however, probable that in a lot of cases there is alternative grazing available at some time of the year eg. silage aftermaths, and use should be made of it when considering worm control, as this pasture will be safe.

Finally, when looking at procedures for introducing new animals into a flock, 70% of farmers did worm the new stock before introducing to the main flock. However, only 45% then quarantine for a period of time before introduction. It is generally recommended that stock should be dosed with a non-benzimidazole drug and yarded for at least 24 hours after treatment (Hazelby *et al*, 1994). This is a very important procedure to allow the drug time to clear out all potential benzimidazole resistant parasites from the whole of the gastrointestinal tract. If the new stock is introduced before the gut has been cleared of these parasites, a new source of pasture contamination could be introduced. With resistance coming to the fore in recent years, this has become even more important because if a non-benzimidazole drug is given to the new stock (as is normally recommended in the UK when introducing new stock) and the stock is carrying benzimidazole resistant worms, viable worm eggs could still potentially be deposited onto pasture after dosing for at least 24 hours. This could introduce an anthelmintic resistance problem onto the farm which had not previously existed. Since the larval stages of nematodes are relatively slow moving and thus geographically restricted, the principal method of spreading resistance will *per force* occur by animals being moved around the country (or between countries). This means that the dosing and quarantining of stock is vitally important in restricting the spread of drug resistance. Of those farmers who do quarantine their stock, 38.5% only quarantine for a few hours. It is quite likely that this period of a few hours relates to the time interval the sheep are yarded whilst dosing is undertaken. If this is the case, then quarantine as such has not occurred and the results should be merged with those of 'worm and introduce immediately'. This leaves a minority of 27% of farmers who actively quarantine their bought-in stock. This agrees reasonably well with the results of Survey 4 in 1992 (Anon, 1993).

5.6 Conclusions

This survey has produced an interesting insight into the worm control methods currently practised by North Wales farmers. The wormer type used appears to be consistent throughout the country, completely independent of type of farm and management practices carried out at the farm level. It has been shown in this survey and previous ones that there are still a significant number of farmers who cannot distinguish between different groups of wormer and different representatives within a single group of wormers. It would be an interesting exercise to carry out a survey to quantify how well farmers know the chemical identity and range of wormers currently being marketed. This would also provide useful market research information into methods of improving the labelling of anthelmintics to make this information clearer.

It is also interesting that the results recorded from North Wales follow a similar overall pattern to those found in the more widescale studies reported in recent years. This indicates that small, localised studies can play an important role in displaying current trends of farm management practices.

Although a number of articles on effective worm control and methods to control resistance have appeared recently in the general farming press, this survey indicates that the uptake of such information by the farming community is slow. It is very worrying that the majority of farmers do not weigh even a small sample of their stock before dosing and that a significant number do not maintain and re-calibrate their dosing equipment before every dosing session. A system of quantifying the potential effects of these actions in order to demonstrate the economic implications involved is needed. This information could then be built into an advisory system which encourages good worming practice in a way which can be trusted and understood by the farming community. This is one of the aims which the expert system program WORMS (see Chapters 6-8) attempts to address.

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Contents - Chapter 6

Chapter 6 - Design and Building of WORMS

6.1 Introduction

In previous chapters, a wealth of knowledge has been accumulated in the following areas:

1. Important gastrointestinal nematode parasites of sheep, their pathological effects on the host animal and their annual epidemiological patterns on pasture (see Chapter 2).
2. Anthelmintic drugs currently marketed for use in sheep, how to use them effectively and the problems of nematode resistance to anthelmintic drugs reported in recent years (see Chapter 3).
3. Expert systems - what they are and how to use them to develop useful applications (see Chapter 4).
4. How the sheep farmer manages his sheep and control measures at the farm level to limit the effects of helminthiasis and to maximise productivity (see Chapter 5).

With the availability of this information it becomes possible to build an advisory system of control which was named, at this point WORMS. However, before starting an analysis of how this program should be constructed, the following questions needed an answer:

1. Is expert system technology appropriate for the task to be undertaken?
2. What factors need to be considered in order to build a useful application?

In Chapter 4, a number of factors were considered to be important when deciding if expert system technology was an appropriate method for building a new application:

"Does the proposed application involve providing advice on problem cases within a defined area of expert knowledge?" The knowledge domain suggested for this project would be developed primarily for control of gastrointestinal worm parasites within a sheep-only farming system in the first instance. The major role of WORMS is to provide advice on controlling parasitic roundworms, given the husbandry practices and historical dosing information provided. Therefore, the answer to the first question is "yes".

"Is there certainty in the knowledge of the problem domain?" The whole area of parasitic gastroenteritis in sheep has been well documented in the literature over the years by a large number of eminent researchers. Comparison studies have been carried out reporting the differences in the levels of parasitism with or without using a defined control strategy. Therefore, the answer to this question is "yes".

"Should the program be expected to accept uncertain input from the user and still come up with qualified advice?" In the initial prototype system, this issue will not be addressed. The farmer will only be asked questions dating back to the previous season, therefore the assumption being made is that all questions can be answered using the menu choices provided.

"Is the problem area an important one where user's confidence in the program's conclusions is an issue?" Farmers generally prefer continued use of a "tried and trusted" method of worm control that they have found to be effective for a number of years. If WORMS concludes that another method of control would be more appropriate, the farmer will need to feel comfortable that changing control strategy is beneficial and will not result in financial loss. Therefore, the answer to the question is "yes".

"Is justification of the line of reasoning required?" In order to help the farmer feel more comfortable with a new control strategy, he needs to know why the new control method is more suitable than his old method. This can be achieved by supplying an explanation of the decision route taken which concluded with the new strategy. This is a very important factor when deciding if expert system technology is appropriate for a proposed system because the justification facility is one of the main characteristics of expert systems which separate them from conventional programming methods.

"Is an expert on worm control procedures available?" The project supervisors Dr Allan Probert and Dr Dewi ap T. Rowlands, who both have many years of experience in this field, were available on a daily basis to provide technical advice in terms of nematode parasite control and husbandry practices adopted by the farming community.

It has been defined in Chapter 4 that if one or more of the above questions have been answered "yes", then expert system technology is considered appropriate. It can be seen that all but one question has been answered "yes", therefore it was decided to develop the proposed application in this manner. It was also mentioned earlier that as well as deciding whether expert system technology is appropriate, several factors should be considered to ensure developing a useful application. These will discussed below in Section 6.2.

In Chapter 4, the development lifecycle of a prototype expert system was fully described. Important phases within this development cycle include:

1. Aims and objectives.
2. Identification of resource requirements.
3. Knowledge acquisition.
4. Knowledge formalization.
5. Developing the human interface.
6. Prototype development.
7. Validation.

Phases (1) to (5) will be discussed fully in this chapter. Therefore, by the end of this chapter a full overview will have been provided of the structure and methodology used to develop WORMS. Chapter 7 will then provide details of prototype development and methods used to validate the system. This will then be followed by Chapter 8 which provides a user guide of how to use WORMS, introduce a few test cases to show the reasoning used by the system in a real-life situation followed by a description of the auxiliary programs incorporated into the overall application.

6.2 Aims and objectives

It is very important when developing any type of computerised system to fully define the aims and objectives of the prototype application. The main aim of this project was to produce a computerised system which could give advice on the most appropriate prophylactic method to control parasitic gastrointestinal worms in sheep in the coming season. In order to achieve this aim, the program would need information regarding the control strategy used in the previous season, combined with an overview of husbandry practices used on the farm. The system would be built primarily for use at the farmer level, however this would then be reviewed once a prototype system was built to see whether any other group of user would benefit from using it. In Chapter 4, it was reported that hardly any expert system application had been developed for use in the livestock industry. Therefore, the secondary aim of the project was to identify the potential for developing expert system applications for the livestock industry.

It has already been mentioned in the introduction that there are a number of points which need to be considered in order to develop a useful application:

1. "The program should be capable of performing as well as a human expert". In order to achieve this aim, it was considered appropriate to interview a number of researchers in this field from

around the UK. This information, combined with advice given by the two project advisors and review of the literature available should lead to the provision of an unbiased system capable of expert level recommendations.

2. "The knowledge domain should be narrow enough to be workable, but wide enough to be useful". It was decided to restrict WORMS to providing advice for sheep-only enterprises until the prototype had been developed. All possible types of sheep-only farming enterprise would be considered. WORMS could then be expanded to consider mixed farming enterprises if time constraints allowed. It was, however, considered more important to produce a more restricted system with good quality advice, than expand the system too quickly which could compromise the correctness of the recommendations being given.

3. "The system must be able to communicate in a way which the user finds comfortable and desirable". A great deal of time and thought was given to the appearance of the system to the end user. This included screen design, question type and overall architecture of the application. This subject will be discussed in more detail in Section 6.6.

4. "The system must be able to explain how a conclusion was reached and why it required a particular piece of information". Careful consideration was made to use a system for developing the application which could incorporate these two important characteristics. This is discussed further in Section 6.3.2.

5. "The system should be able to run at reasonable speed". It is important to create a system which uses minimal information supplied by the user to produce an informed recommendation. A lot of time was spent in the analysis stage to provide a system which used the most efficient route to an end result, without firing unnecessary (redundant) rules. This would lead to the

running of a faster, more efficient system. Speed was also considered to be an important consideration when choosing a system on which to develop the application.

6.3 Resource requirements

There are two basic requirements for the development of any expert system application: knowledge and computer resource.

6.3.1 Knowledge resource

The traditional model for building expert system applications discussed in Chapter 4 necessitates the involvement of a domain expert and a knowledge engineer. The role of the knowledge engineer would be to elicit information from the domain expert and formalise the information into a structure which could then be used to develop the expert system. However, with this current project, the system developer was defined as both the domain expert and knowledge engineer. In order to achieve this dual role, the following resources were considered for bringing together the information required to develop the application:

1. Large quantities of literature are available describing the nematode problem in sheep, methods of controlling these parasites and the drug groups available for dosing sheep. The "Compendium of data sheets for veterinary products" published every two years by NOAH (National Office for Animal Health Ltd) also provides useful information regarding all commercial licensed products currently marketed for sheep in the UK.
2. Information clarification provided by the two project advisors.
3. Additional information gained through interviews with other researchers in the field.

6.3.2 Computer resource

Due to limited background in computer programming, it was decided that due to time constraints it would be more efficient to concentrate on building the knowledge bases required for the application rather than the more technical aspects of programming from first principles. For this reason, it was decided to use an expert system shell which provides the user interface and inference engine already written. This leaves the user time to concentrate on the building of the knowledge base. The expert system shell Crystal4 (Intelligent Environments) was chosen to build the application for the following reasons:

1. It is easy to use, requiring limited programming experience to build useful applications.
2. It has a rule trace function which provides an automatic justification facility built into the system. It also provides a useful tool for setting up "help" screens which can be called up at specific points during the problem solver session. This makes it quick and easy to develop an explanation facility necessary for a useful application as defined earlier in Section 6.2.
3. It can perform a problem solving session through to providing a recommendation in a time scale the end user would find acceptable.
4. It was relatively cheap when compared with other systems.
5. It was compatible with the computer hardware available for the project.

6.4 Knowledge acquisition

The term knowledge acquisition has been defined previously in Chapter 4 as being "the transfer and transformation of problem-solving expertise from some knowledge source to a program" (Buchanan and Shortliffe, 1984; Buchanan *et al*, 1986). In the traditional mode this has involved the interaction between an expert in the domain area and a knowledge engineer. The role of the knowledge engineer is to elicit information from the domain expert in a way which can later be transformed into a succession of rules which are incorporated into the expert system.

However, this approach is disadvantageous for a number of reasons:

1. Availability of the domain expert for interview may be limited. This can lead to a bottleneck in the development time needed to build a new system.

2. The domain expert is not necessarily aware of all relationships he uses when making a decision. He is also not aware of the impact that not mentioning one piece of vital information may have to the correctness of the system produced.

3. The knowledge engineer has little experience of the domain area he is working with or the jargon which may be used. This can lead to misunderstandings during the knowledge elicitation process which can impact on the accuracy being built into the system.

4. Using knowledge from only one expert may lead to the development of a biased system. However, utilization of several experts can cause additional problems:

a. Organising the availability of multiple experts may cause additional problems to the knowledge engineer resulting in an increased bottleneck to the time needed for system development.

b. Controversial points may prove hard to resolve, with different experts having different opinions. This makes it very difficult for the knowledge engineer to elicit information.

For this project, the traditional model was not deemed appropriate. It has been previously mentioned that the application developer would assume both roles of knowledge engineer and domain expert. Therefore, the knowledge acquisition phase used the following methodology:

1. Overview of the worm problem in sheep.

2. Knowledge elicitation process.

3. Confirmation of correctness.

6.4.1 Overview of the worm problem in sheep

An initial meeting was held between the application developer and the two project advisors (Dr Allan Probert and Dr Dewi Rowlands) for the following reasons:

1. To specify the aims and objectives for the study. These have been discussed earlier in Section 6.2.

2. To discuss the best method to reach these objectives.

3. To provide an overview of worm problems in sheep.

The role of the application developer was defined as both knowledge engineer and domain expert. Because the developer had limited experience in both roles a training requirement was highlighted, therefore the project was divided into two parts:

1. Training - the first year would be devoted to assuming the role of the domain expert, incorporating the knowledge elicitation process. The first half of the second year would involve training in how to program an expert system and how to assume the role of the knowledge engineer.

2. Application development - the second half of the second year would be devoted to knowledge formalization, thereby bringing together the two roles. This would also involve the first part of the confirmation of correctness process. In the third year, the prototype problem solving system would be developed. Once the prototype application was available, the system would be validated. The validation methods used are described in Chapter 7.

Subsequent meetings were held to build up a broad overview of worm problems in sheep and varying methods used to control them. The results of these preliminary discussions were:

1. That they developed a background understanding of parasitic gastroenteritis in sheep.

2. The names of key research workers in the field were provided with the ultimate aim to make contact and elicit information from these domain experts with many years of experience in the field.

3. A list of key references to use in order to gain a deeper understanding of the domain area.

6.4.2 Knowledge elicitation process

The following methods were used to obtain the necessary information about the domain area needed to build an expert system:

1. A wide range of literature available concerning the individual nematode parasites causing parasitic gastroenteritis in sheep was reviewed. This incorporated information regarding their morphology, pathological effects, life cycle and epidemiological patterns on pasture (see Chapter 2).

2. A database was developed using information obtained from "Compendium of data sheets for veterinary products" published by NOAH. A review of the anthelmintic groups, range of administration methods and methods to utilise these drugs effectively was performed (see Chapter 3). Anthelmintic resistance was also researched, which resulted in the publication of a review article (Hazelby *et al*, 1994).

3. Personal contact with a number of domain experts in the field led to the opportunity for interview. The benefits gained using these personal interviews were:

a. Clarification of the information gained by literature review.

b. Advice on how to proceed with the application. It became obvious through these interviews that the most suitable strategy to adopt would be to keep the system as generalised and simple as possible. If the questions became too specific eg climate information at the farm level, there would be no appreciable benefit and there is a greater risk of reduced accuracy. It would also prove very time consuming building a system to utilise this information and the resulting system would only be usable on an insignificant minority of farms.

c. Additional information was obtained regarding current research being undertaken and as yet unpublished.

6.4.3 Confirmation of correctness

There were two periods considered when it would be appropriate to test the correctness of the information:

1. At the end of the first year when all domain specific knowledge had been accumulated.
2. During the validation process of the prototype expert system (see Chapter 7).

At the end of the first year, a comprehensive review was produced covering nematode lifecycle, pathology and epidemiology, anthelmintics available for use in sheep and the development of anthelmintic resistance over recent years. This information, together with the anthelmintic database was reviewed by Dr Dewi Rowlands and representatives from the three sponsoring pharmaceutical companies: Syntex Animal Health, Hoescht Animal Health and SmithKline Beecham Animal Health (Steve Dean, Dr Liz Abbott and David Hallas respectively). Following modifications to the information in response to comments and amendments suggested by all parties, the domain knowledge was considered ready for knowledge formalization discussed in the next section.

6.5 Knowledge formalization

Knowledge formalization is the most important task undertaken during the building of an expert system application. It involves "the mapping of key concepts and relationships in an appropriate formal knowledge representation" (Buchanan *et al*, 1986). The different methods used to formalize data have been discussed previously in Chapter 4.

Crystal4 is specifically designed for developing applications using production rule notation. It has already been reported that formalizing the data using decision trees can be easily converted into rules. Therefore it was decided to use this method of initially designing the application on paper by means of decision tree notation and then converting this information via production rules within Crystal4. It was ultimately decided to use a modified decision tree structure called the decision table. This format works on the same principles as the decision tree, but formalizes the data in a tabular form. The main advantage of using this method of knowledge formalization is that all possible combinations are automatically considered. This means all possible combinations of the conditions obtained through a problem solving session will lead to a conclusion.

There are two independent sources of information required in order to achieve the ultimate aim of providing qualified advice on prophylactic control of gastrointestinal nematode parasites:

1. Husbandry practices carried out on the farm.
2. Historical information about past wormer usage combined with preferred method of administration of the drug on the individual farm.

In order to combine all this information into one advisory system, it was thought more appropriate to treat each section separately and build two independent knowledge bases. These could then be linked together to create a single system.

6.5.1 Husbandry practices on the farm

This section of the advisory system estimates how safe the pasture is at important times in the calendar year. This information combined with the husbandry practices carried out at farm level are used to speculate potential problems with gastrointestinal nematodes. The recommended policy for control is then calculated within the limitations of the individual farm situation. The knowledge base became too large to run on standard hardware, therefore it was split into two sections and hence two knowledge bases:

1. Lowland situation.

2. Hill situation.

6.5.1.1 Lowland situation

Lowland farming, whatever the farm type, must be highly productive in order to compensate for the higher land prices when compared with the hill farm situation. Because of this factor and also because of the competition for high productivity which can be achieved on arable farms, lowland sheep farming is much more intensive than hill sheep farming. This means the stocking rates are much higher and a higher percentage lambing rate is required. Also, unless the sheep production system is integrated within a mixed farming model, there is a significant reduction in the proportion of alternative grazing on the farm. The farmer cannot afford to leave a significant proportion of his land empty (thus non-productive) for extended periods during the season. Furthermore, since the climate on lowland situations tends to be more temperate than that of the hill situation it favours nematode development. The combination of these factors mean that sheep on lowland farms are often at greater risk from the development of parasitic gastrointestinal worms compared with upland animals.

Lowland farms generally specialise in fat lamb production because of the higher rates of return, therefore the economic effects of nematode parasitism can be catastrophic. Any factor which adversely affects mortality, the growth rate of the lamb or reduces the quality of the carcass can significantly reduce the profitability of the lamb crop in a given season. Therefore, worm control plays a major role in the sheep calendar.

In Chapter 3 it was pointed out that using dosing as the only means of worm control is not advisable. If anthelmintics are over-used, it has been shown that this can lead to the development of anthelmintic resistance by the parasites. Therefore, the WORMS system has been designed to use pasture management combined with the most appropriate wormer(s) to provide a recommendation of integrated nematode control. It is recognised that the advice needs to be tailored to the individual needs of a given farmer. For example, there is no point in advising a farmer to move his flock onto new pasture at weaning if there is no pasture available on his farm at this time.

The discussion below describes the line of questioning used by the system in differing situations and explains why the information is required by an advisory system such as this.

(1) "Is alternative grazing ever available on your farm" [Yes] [No]

In the sheep-only model which is being used for the prototype system, it is quite feasible that there will be no alternative grazing available on the farm. As described earlier, economic constraints could force the farmer into using all available land for grazing at any one time as he cannot afford to have a percentage of the land lying fallow and thus non-productive. This is the worst case scenario when developing parasite control strategies for sheep in the lowland situation. This question is an important one as it directs the future line of questioning to reduce the risk of rule redundancy in the questions being asked.

IF "Yes" THEN goto (2)

IF "No" THEN goto (4)

(2) "During which of the following periods is enough alternative grazing available to carry the total lamb population?"

[March-May] [June-July] [Aug-Sept]

The periods included in this question were chosen for their importance during the development of the new lamb crop in terms of the epidemiology of important gastrointestinal nematode parasites (see Chapter 2).

If safe alternative pasture is available in the spring (March-May), moving the flock to this new pasture can significantly reduce the effects of the peri-parturient rise in faecal egg output by the ewe. The peak period for faecal contamination by the ewe is during the period six weeks prior to lambing until six weeks post-lambing. Following this peri-parturient period, the mothers' natural immunity to nematode parasitism is regained (resulting in reduced egg output), therefore from this point forwards the ewe plays a very minor (or much reduced) role in maintaining the levels of infective larvae on pasture. A move onto new pasture during March to May is likely to occur before the lamb crop has started significant grazing of the heavily contaminated pasture. Dosing the stock just before the move helps to prevent carry-over infection which should result in low pasture infection levels being maintained for the whole of the season. Because the lambs have been moved away from the major sources of pasture contamination, there is the additional benefit of reduced frequency of dosing. This significantly reduces the cost of worm control and reduces the risk of promoting development of resistant nematode strains to a particular group of wormers, unless resistant strains already exist to that wormer group.

If alternative pasture is available mid-summer (i.e. June-July) and lambing is late (i.e.

April), moving to this new pasture will have the same benefits as discussed above. However, if lambing occurs earlier in the season, moving at this time will coincide with weaning. The lambs are likely to have picked up significant infection levels because they will have been grazing heavily contaminated pasture for 1-2 months, therefore dosing is essential before the move. Therefore, little carry-over of infection should occur and the new pasture should remain reasonably safe for the rest of the season, unless nematode strains resistant to the wormer used exist in the host animal.

Alternative pasture available at the end of summer (Aug-Sept) may prove useful for finishing off store lambs or for the preparation of ewe lambs prior to mating. If alternative pasture is not available earlier in the season, there is a large risk of a second peak of pasture contamination at the end of July to mid-August. Leaving lambs on pasture at this time could result in a significant set back to the finishing off of store lambs. Therefore alternative pasture available at this time can prove very useful. Any setback at this time could be considered expensive to the farmer for two reasons:

1. The longer the lambs remain on the farm, the greater the profit margin is reduced. Lambs which are finished at this time of year rely on additional nutritional resources in order to achieve an acceptable liveweight and carcass conformation for the meat market. If nematode infections reach such levels that growth is checked, the period of finishing off will significantly increase. Therefore, the cost of supplementary feeding will increase which reduces the overall profitability.
2. The price of meat can fluctuate on a weekly basis therefore, the potential exists to make a substantial loss if the lambs cannot be sent to market during the preferred period.

An assumption has been made by the system that any alternative pasture available outside the time periods listed, has little importance in the development of a control strategy. Therefore:

IF "None of the above" THEN assume no alternative pasture is available.

(3) "What was the alternative pasture previously used for?"

[reseeded pasture] [arable cropping] [hay/silage aftermaths] [ewes during autumn/winter] [lambs after weaning] [lambing paddock last year]

This question is designed to estimate how safe from nematode contamination the alternative pasture will be this season. The following rules of thumb have been used to define whether alternative pasture in the coming season is safe or not:

1. If the pasture has not been used by lambs in the previous season it is considered clean.

2. Pasture is also classified as being clean if used by ewes during the autumn and winter, provided they were dosed before moving onto this pasture.

If the pasture has been reseeded, an assumption has been made that this pasture would not have been used for lambing. Also, the effect of preparing the land prior to reseeding would have affected the survival of infective larvae overwintering on this pasture. Therefore, reseeded pasture can be considered reasonably safe alternative grazing. Care does need to be taken, however, if the pasture is used during March-May because of the danger from infection by *Nematodirus* spp. It has been shown in Chapter 2 that *N.battus* can survive ploughing in significant numbers.

If the land was used to grow a cereal crop in the previous season, then the following assumptions can be made:

1. The pasture will not have been used by ewes during the critical peri-parturient period (six weeks before lambing to six weeks post-lambing) last year.

2. It will not have been grazed by lambs at all in the previous season. Therefore, using the rule of thumb defined earlier, this pasture can be considered clean.

Hay/silage aftermaths provide a useful source of relatively safe pasture at a time when it is important to move lambs i.e. at weaning. This is particularly true if the flock was housed during winter because it can be assumed that there will have been no sheep on the pasture used for hay/silage for almost a year. By May/June time therefore it would be expected that overwintered infective larvae numbers would have reduced significantly.

If the pasture was used for lambs after weaning it is possible that a significant level of contamination could have been laid down by the susceptible lamb crop by autumn. Therefore the system considers this pasture to be significantly contaminated. If the pasture was used as the lambing paddock previously it is likely that the pasture could still remain heavily contaminated in the coming season. It is also highly likely that *N.battus* larvae will be present in significant number which could have implications if the pasture was required March-May time.

6.5.1.1.1 No Alternative pasture

In this situation, there are only three possible management decisions which could possibly influence the outcome recommendation.

(4) "Do you house your sheep during winter?" [Yes] [No]

(5) "In what month do you expect most lambing to occur?"

[Dec-Jan] [Feb-March] [April]

The system automatically assumes that if lambing occurs Dec-Jan and the ewes are housed in winter then lambing occurs inside. It also assumes that if lambing is carried out in April, the flock will have already been turned out onto pasture. However, for ewes lambing in Feb-March, the position is not clear cut. This leads to the additional question for those sheep housed in winter and lambing Feb-March:

(6) "Is the lambing carried out indoors?" [Yes] [No]

The eight possible combinations of these three questions can lead to six different strategies for control in the ewe. However, it is interesting that whichever management system is chosen, there is only one possible control strategy available for the lamb situation.

6.5.1.1.2 Alternative pasture available

(4) "Do you house your sheep during winter" [Yes] [No]

This question has a much higher level of importance when considered in the case where alternative grazing is available for the following reasons:

1. In terms of the system, it drives the direction in which the questioning proceeds from this point forward.

2. In order to fully understand the potential effects of the "spring rise" throughout the lambing season, a large emphasis is put on the overwintering strategy and how this affects pasture management in the spring. For example, it is widely recognised that the danger period for faecal contamination of the pasture by the ewe is at its peak six weeks prior to lambing until six weeks post lambing. If the flock remains housed for the majority of this period, there is a significant reduction in the level of contamination laid down by the ewe in spring. Thus, the risk of heavy infestation in the new lamb crop is reduced, which ultimately leads to a reduction in the amount of anthelmintic required in the lamb crop. On the otherhand, if the flock is not housed in winter, there are other implications such as will the ewes be moved to a new paddock for lambing or after lambing and if so, what was this pasture used for previously?

(4) "In what month do you expect lambing to occur?"

[Dec-Jan] [Feb-March] [April]

Timing of lambing can play a significant role in the development cycle of nematode parasites and hence the control method adopted. If lambing occurs Dec/Jan, the peri-parturient period occurs earlier in the ewe. Therefore it is quite likely that arrested larvae will recommence development earlier. If alternative pasture is limited (which it could well be for flocks lambing Dec-Jan), this could have implications for an extra nematode generation within the season. This could lead to potential symptomatic gastroenteritis in the ewe lambs during the autumn. On the other hand, there is a reduced risk of *N.battus* infection. *N.battus* requires a period of chill followed by a mean day temperature of 10 °C in order to stimulate the mass hatch of infective larvae on pasture. Therefore the restricted season for nematodiriasis generally occurs between April and May. At this time in the season, Dec-Jan born lambs are much less likely to be susceptible to the effects of nematodiriasis as host immunity generally develops around three months of age.

If lambing occurs in Feb-March, there is a greater potential of alternative pasture being available from hay/silage aftermaths at a time when lambs are increasingly at risk from contaminated pasture generated during the peri-parturient period. However, care also needs to be taken when choosing the lambing paddock for the coming season. If the same lambing paddock is chosen as last year, the risk of nematodiriasis is high. Lambs are likely to be susceptible to infection and grazing hard during the peak period of the mass hatch of *N.battus* in spring. It has been reported in Chapter 2 that this is a lamb to lamb disease, with the ewe playing an insignificant role. Therefore, the system automatically recommends alternation of the lambing paddock on an annual basis for these lambs.

If lambing occurs in April, availability for alternative pasture increases again with hay/silage aftermaths. This would introduce the possibility of moving the new lamb crop away from the pasture heavily contaminated during the peri-parturient period at a time before the lambs start grazing hard. April born lambs are also less likely to suffer the effects of nematodiriasis. This is because they generally do not start grazing until after the danger period of mass hatch of larvae in spring.

IF "Feb-March" AND "Housed in winter" THEN goto (5)

IF "Dec-Jan" AND "Housed in winter" THEN goto (7)

6.5.1.1.2.1 Sheep housed in winter

(5) "Does lambing occur indoors?" [Yes] [No]

IF "Yes" THEN goto (7) ELSE goto (8)

(7) "How soon after lambing is turnout?"

[within 24 hours] [1 to 7 days] [1 to 5 weeks] [longer]

If the flock is not turned out until the main risk period from the peri-parturient rise has passed, the main risk to the new lamb crop on the pasture at turnout will be from over-wintered larvae. If the flock is turned out soon after lambing, the ewe will play a major role in the build up of infective larvae on pasture in spring.

(8) Was the pasture to be used for turnout used by lambs last year?"

[Yes] [No]

This question is designed to test how safe the pasture assigned for use at turnout is likely to be. If the pasture was not used for lambs in the previous season, it is assumed to be clean. Therefore: IF turnout < 6 weeks after lambing AND pasture used by lambs last year then assume high risk of infection to the new lamb crop.

IF turnout < 6 weeks after lambing AND pasture not used by lambs last year OR turnout > 5 weeks after lambing and pasture used for lambs last year THEN assume medium risk of infection to the new lamb crop.

IF turnout > 6 weeks after lambing AND pasture not used by lambs in the previous season THEN assume low risk of infection to the new lamb crop.

6.5.1.1.2.2 Sheep not housed in winter

(9) "Are the ewes moved to clean pasture before lambing?" [Yes] [No]

This question is asked in order to provide a more detailed picture of the husbandry practices that are used on a particular farm rather than for the benefits achieved by moving ewes at this time. The main implication which comes about through the resulting answer is the determination of whether the ewe requires dosing pre-lambing. It is standard practice to prevent carryover from one pasture to another to dose the ewe before the move to the lambing paddock. If the anthelmintic used has an effect on arrested larvae, this dose can also significantly decrease the level of contamination laid down during the lambing period.

(10) "Is the flock moved to new pasture after lambing?" [Yes] [No]

IF "Yes" THEN goto (11)

(11) "When is the flock moved to new pasture after lambing?"

[within 24 hours] [2 to 7 days] [within 4 weeks] [longer]

The combination of questions (10) and (11) gives an overall picture of the infection risks likely to be encountered by the lambs in spring.

If the flock is moved to new pasture soon after lambing, it is assumed that there will be a high risk of infection to the new lamb crop caused by the peri-paturient rise in faecal output by the ewe.

If the flock is moved to new pasture after lambing, but within 6 weeks from lambing, then one can assume a moderate level of infection is laid down. The level of pasture contamination will be reduced compared with that experienced in the first situation due to the ewe being dosed before the move to new pasture. However, if an anthelmintic is chosen which has only minimal effect against arrested larvae, then substantial pasture contamination will occur once the larvae resume development.

If the flock is moved to new pasture after 6 weeks, the system assumes that there will be only a low risk of infection to the new lamb crop.

6.5.1.2 Hill situation

The hill farm scenario is much more dependent on husbandry practices when developing a worm control program. This is because the flock is not accessible on a day to day basis due to the more extensive nature of the hill farm. The procedure for rounding up the flock tends to be time consuming, which can create an additional cost to the dosing program. For this reason, parasite control is generally worked into the general husbandry practices adopted on the farm. For example, the flock will be rounded up at tupping and for shearing. Therefore, dosing the flock would generally be considered while the flock is off the hill for one of these reasons. Wherever possible, these practical considerations have been built into the control recommendations.

(1) "What type of hill system do you operate?"

[Open mountain] [Mountain paddock]

There are two distinct types of hill farm system adopted by sheep farmers i.e. open mountain and upland. Open mountain is the traditional hill farm situation where grazing is extensive and grass quality tends to be poor. Lambs are generally grown on as replacements or as store lambs which are subsequently finished off for the meat industry on lowland farms. The climate is more severe than in lowland areas and sheep generally roam the hillside at a much lower density. Both these factors prove unfavourable for the development and establishment of the majority of gastrointestinal nematodes. Upland farms, on the other hand, consist of improved hill land which has been defined into a number of large paddocks. Because the grass quality tends to be of much higher quality than that found on the open mountain, a more intensive farming regime is possible, more characteristic of the lowland situation. However, climate conditions again affect the development of the worm parasites which should be considered during the development of a worm control strategy. It became apparent during our own sheep farm survey carried out in 1992 that farmers appeared to confuse the terms hill and upland (see Chapter 5). Therefore, the wording of the menu choices for this question were considered carefully before deciding upon those chosen.

(2) "Is the flock brought off the hill in winter?" [Yes] [No]

It has been highlighted in Chapter 5 that a proportion of farmers lease land from lowland farmers to overwinter their hill flock. This is common practice by hill farmers within the Snowdonia National Park who in general lease land on Anglesey to overwinter their stock. The economic advantages of reduced supplemental feed requirements combined with significantly higher percentages of successful lambings off-set the transport costs incurred by moving the flock. This strategy can lead to major implications in the control strategy adopted for combatting worm problems. If the flock is moved off the hill in winter, the flock is being subjected to a more intensive farming situation even if for only a short period of time. Therefore it is recognised as being important in terms of worm problems, with the new lamb crop being most vulnerable to the effects of nematode parasitism.

IF "Yes" then goto (3) ELSE goto (4)

(3) "Is the flock housed in winter?" [Yes] [No]

This question has been discussed fully in the lowland situation where alternative grazing is available (Section 6.5.1.1.2).

(4) "Are the ewes housed for lambing?" [Yes] [No]

If the ewes are housed for lambing then the system assumes that the ewe will be housed for a large proportion of the early peri-parturient period i.e. 6 weeks prior to lambing. Therefore, in terms of worm control, there appears to be insignificant difference to the situation of the flock being housed for winter. Thus the system treats both situations in the same way.

6.5.1.2.1 Sheep housed in winter

(5) "How soon after lambing do you turnout the flock?"

[within 24 hours] [1 to 7 days] [2 to 5 weeks] [longer]

The major proportion of pasture contamination in the new season is related to the peri-parturient rise in faecal egg count. This period lasts until six weeks post lambing. Therefore, the sooner the ewes are turned out after lambing the larger the risk of heavy pasture contamination.

(6) "Was the pasture you propose using for lambs at 6 weeks to 3 months of age used for lambs in the previous season?" [Yes] [No]

Nematodiriasis provides a major hazard to lambs between the ages of six weeks to three months.

After three months, most lambs develop immunity to this parasite. It has already been shown in Chapter 2 that this nematode undergoes one complete generation in the year. The eggs lie dormant on pasture until a period of chill followed by a day mean temperature of 10 °C occurs. Most of the eggs hatch into 3rd stage infective larvae leading to a sudden massive contamination on pasture. If susceptible lambs are present, heavy mortality losses of up to 30-40% maybe encountered. The main characteristic of this disease is that it can only transmit from lamb to lamb. Therefore it is important that wherever possible, the lambing paddock is alternated on an annual basis. Where this is not practical, frequent anthelmintic dosing is required to protect the lamb crop during this time period.

(7) "When do you propose moving the flock back to the hill?"

[April] [May] [June] [July]

In terms of worm control it is advantageous to return the flock to the hill as soon as possible in spring. It was described earlier how much more likely parasite problems are to occur in a lowland situation due to the higher stocking densities and more temperate climate. However, care still needs to be taken when moving the flock back onto the hill. Because of the more severe weather conditions, worm parasites tend to develop later in the season than on lowland pasture. For example, April lambing off the hill may avoid problems with *N.battus* on lowland pasture, but if the sheep are moved back onto the hill in June, *N.battus* populations on pasture maybe at their peak.

The next question is specific to Mountain paddocks:

(8) "During the season are the lambs returned at any point to pasture grazed by sheep previously in the season?" [Yes] [No]

If sheep are moved back onto pasture used previously in the season, the system assumes this pasture is dirty (i.e. contaminated).

6.5.1.2.2 Sheep not housed in winter or for lambing

(9) "Will the flock be moved to a different paddock after lambing?"

[Yes] [No]

IF "Yes" THEN goto (10) ELSE goto (6)

(10) "How soon after lambing does the move to a new paddock occur?"

[within 24 hours] [2 to 7 days] [within 4 weeks] [longer]

The same line of reasoning is used for this farm strategy as was used in the lowland situation described earlier.

The line of questioning followed from this point forward is the same as has already been described in Section 6.5.1.2.1, starting at question (6).

6.5.2 Anthelmintics

The second part of the decision making process by WORMS involves choosing the most suitable wormer group, given the history of wormer usage on the farm. In the prototype system the history of wormer usage only extends back one season. Ideally this situation will be expanded in later versions to include a history of 2 or more seasons of wormer usage. Other important factors included in this section are:

1. Confirmed or suspected anthelmintic resistance.

2. Preferred mode of administration. Wherever possible, WORMS respects the farmer's own preference regarding the mode of administration. However, there are some situations when the farmer's preferred administration method may conflict with the optimal control methods

recommended by the system. In these cases, the situation is highlighted and the user prompted to reconsider his decision. This will be discussed in more detail later on in the chapter.

6.5.2.1 Wormer choices

The anthelmintics used for the control of parasitic gastrointestinal worms in sheep have been reviewed previously in Chapter 3. The four main groups of broad spectrum drugs are discussed in detail, together with the small number of narrow spectrum drugs, mainly marketed for adult liver flukes, but which also confer some activity against certain blood sucking nematodes. The advisory system developed is based on a prophylactic method of control. For this reason, the narrow spectrum drugs were discounted as possible alternative drugs. This is because their level of activity against the targeted parasites is limited and therefore unsuitable for a generalised prophylactic approach. If the system had been developed as a therapeutic control system, these additional drugs could have been included for situations where the major parasite causing parasitic gastroenteritis could be identified.

6.5.2.2 Anthelmintic resistance

With the increased prevalence of benzimidazole resistance since first being reported in the UK 1981 (Britt,1982) and the prospect of levamisole and ivermectin resistance occurring, anthelmintic resistance is becoming a major issue when choosing a wormer. There are two main issues which need addressing for any potential control system:

1. If anthelmintic resistance has not occurred on an individual farm, control should be tailored around preventing the possibility of introducing resistant nematodes onto the farm. At the same time, the control strategy should try to prevent resistant genes within the nematode population found on the farm being advantaged to such a point that anthelmintic resistance is expressed.

2. If anthelmintic resistance has occurred on an individual farm, the level of resistance needs to be managed. This can be achieved by encouraging the survival of susceptible nematodes in order to dilute the proportion of resistant nematodes on pasture.

The most efficient way to meet all of these objectives is to rotate on an annual basis the four main groups of wormer available.

6.5.2.3 Mode of Administration

There are four possible modes of administration available in order to administer the drug to the animal:

1. Oral dosing - this is the most popular means of administering anthelmintic drugs to sheep. The drenching gun administers a pre-defined dose when the trigger is pulled into the mouth of the animal. This method is considered both quick and easy to administer a reasonably accurate dose to each individual animal. At the current time all four groups of wormer can be purchased in this form.

2. Injection - injectable formulations are available for levamisole and ivermectin only. It is not easy to administer the dose to an individual animal due to the fleece and thick skin, although it is a very accurate method. It would be inefficient, however, to use this method of administration on a large farm.

3. In-feed - these usually consist of cubes or pellets which are incorporated into the normal feed. At the present time, this method of dosing is only available for benzimidazole drugs. It is not a recommended method for administering anthelmintic because it is not guaranteed that each individual animal will consume enough feed to ensure that the correct dose has been administered. In recent years it has become accepted that the administration of the correct dose

rate of anthelmintic is critical to reducing the risk of resistance problems developing.

4. Controlled-release devices - this method for administering anthelmintics to cattle has been available for a number of years. However, in 1992, albendazole became the first anthelmintic drug for sheep to become available in this form (Hallas, Personal communication). The bolus is inserted into the rumen by a veterinary surgeon, where it releases a set dosage of albendazole on a daily basis for 100 days. The bolus remains within the rumen for approximately a year after which time it is excreted. The main advantage of using this method of administration is that only one dose per season is required for the ewe which reduces the stress caused by handling, especially during the lambing season. However, because the dose has to be administered by a veterinary surgeon, this increases the cost for dosing the flock. Also, there is the restriction that this mode of administration can only be used at present in sheep within the weight range of 35 to 65 kg. At the present time, albendazole is the only drug marketed in the UK for sheep in this form.

6.5.2.4 Design of the anthelmintic knowledge base

(1) "Was a wormer used on this farm for sheep last year? [yes] [no]

It cannot be automatically assumed that we are dealing with an established sheep farm. This question was introduced to reduce the risk of a redundant line of enquiry.

IF "yes" THEN goto (2) ELSE goto (3)

(2) "What anthelmintic group(s) did you use last year?"

All possible combinations of the four groups of broad spectrum anthelmintics currently available are listed. The system uses the recommendation of rotating the groups of wormer on an annual basis. Therefore drug groups which are defined as suitable for the coming year up to this point are calculated by a process of elimination. For example, if benzimidazole only was used last year, the system concludes that levamisole, morantel and ivermectin drugs are all eligible this year. On the other hand, if benzimidazole and ivermectin drugs were both used last year, only levamisole and morantel would be available this year. The case is more complicated for morantel and levamisole where it has been discovered that if levamisole resistance occurs, cross resistance to morantel has also been found. However, if morantel resistance develops, cross resistance to levamisole does not necessarily occur. There is also the possibility, although unlikely, that the farmer used all four drugs in the previous season. By processing the strategy mentioned above, all four groups of drug would be eliminated at this stage. In this situation alone, instead of eliminating any group of drugs, all four groups are assigned as suitable to be chosen for the coming season.

(3) "Which of the following modes of administration do you prefer?"

[Oral dosing] [Injection] [In-feed] [Controlled-release bolus]

At this point the system performs internal checks to ensure that anthelmintic groups defined as suitable for the coming season are compatible with the mode of administration chosen. Certain scenarios have been deemed unsuitable for use in any recommendation and if the situation should arise the user is alerted to the situation and advised to reconsider his choice. The following situations fall into this category:

1. Levamisole was used on the farm last year and the user has chosen injection as the preferred mode of administration. As mentioned previously, the only group of drugs currently marketed in the UK as an injectable formulation is levamisole. Because the system encourages the use of annual rotation of drugs, the situation is highlighted with the recommendation that the user chooses an alternative mode of administration.

2. A benzimidazole drug was used last year and in-feed formulation is chosen as the preferred mode of administration. As mentioned previously, the only group of wormers currently marketed in the UK as in-feed preparations are the benzimidazoles. Therefore, for the same reason as levamisole and injection, the user is alerted to the situation and advised to change the mode of administration.

3. If a non-benzimidazole drug was used last year and in-feed was chosen as the mode of administration, the system would still highlight a potential problem. It has been mentioned earlier that it is difficult to ensure an individual animal receives the total recommended dose of the drug. In light of the implications caused by underdosing the flock (see Chapter 3), this mode of administration is not recommended at all by the system. Therefore, a warning appears to alert the user to the potential problems encountered using the in-feed strategy and he is prompted to reconsider an alternative mode of administration i.e. oral dosing, injection or controlled-release bolus.

4. A benzimidazole drug was used last year and the controlled-release bolus is the chosen mode of administration. At the current time only the benzimidazole drug albendazole is marketed in the UK in this form. Therefore, the user is advised to choose a different administration method i.e. oral or injection.

The following question is only asked if the mode of administration is controlled-release bolus:

(4) "Are the majority of your ewes less than or more than 65 kg?

[less than 35 kg] [35-65 kg] [more than 65 kg]

The reason for asking this question is that the albendazole bolus available at the present time is only suitable for sheep in the weight range 35-65 kg. If the user chooses the menu options one or three, a warning appears to alert the user that this administration method is not suitable for the situation. He is then asked to reconsider his preferred dosing method.

(5) "Has anthelmintic resistance to any group of wormer been identified on your farm?"

[Yes] [No]

This question is designed to identify whether official testing has been carried out on the farm which came back with a positive result.

IF "Yes" THEN goto (6)

otherwise (ELSE) goto (7)

(6) "To which of the following drug group(s) was resistance identified on your farm?" All possible combinations of the four groups of broad spectrum anthelmintics currently available are listed.

IF "No drug failure" THEN goto (7)

If any other option than "No drug failure" is chosen, those drug groups selected are ruled out of any recommendation on the grounds of definite resistant nematode populations present on this farm.

(7) "Have any of the following drug groups failed to control worms on your farm?" Again, all possible combinations of the four groups of broad spectrum anthelmintics currently available are displayed. The aim of this question is to highlight potential resistance problems by asking the user if he has subjectively noticed any decrease in wormer efficiency on his farm.

IF [No drug failure] then assume no resistance problems exist on this farm.

ELSE goto (8)

(8) "Common reasons for drug failure are:

1. Inaccurate weighing of stock

2. Poor administration of the dose

3. Inefficient rounding up of the flock

Could any of these points be a reason why the drug may have failed to perform?"

[Yes] [No]

This question was designed to speculate whether possible drug failure on the farm could be caused by management practices or whether there is the possibility of resistance developing on the farm.

IF "Yes" then assume no resistance problems exist on the farm.

IF "No" then possible resistant nematodes could be present therefore treat as though resistance confirmed. An additional information screen is supplied to highlight that a possible resistance problem exists which requires further investigation.

Once again, the system makes some internal checks to ensure the integrity of the information supplied up to this point. The following situations are highlighted if they occur and the user is advised to reconsider his preferred method of drug administration:

1. Benzimidazole resistance on the farm and In-feed is the preferred mode of administration.

2. Benzimidazole resistance on the farm and controlled-release bolus is the chosen method of dosing.

3. Levamisole resistance on the farm and injectable formulation is the preferred mechanism of dosing by the farmer.

At this point, the system has obtained enough information about a particular farm situation to provide a qualified recommendation about the most appropriate group or groups of wormer to be used in the coming season. This information is combined with the most appropriate husbandry strategy for both ewes and lambs to produce a complete management plan for the new year. Examples of possible recommendations made by WORMS to defined farm situations are discussed in Chapter 8.

6.6 Discussion

The primary aim for developing WORMS was to produce a computerised system capable of giving advice on the most appropriate method to control parasitic gastrointestinal worms in sheep in the coming season. It can be seen through the design of the three knowledge bases - hill situation, lowland situation and anthelmintics that this objective is possible. An analysis was made to consider the appropriateness of using expert system technology to develop WORMS. It was reported in Chapter 4 that if one or more of the criteria listed were met, that a proposed application is suitable for developing in this manner. The analysis showed that all but one of these criteria were met, therefore is was concluded that it was appropriate to use an expert system approach to develop WORMS.

The move away from the traditional model of using a domain expert and knowledge engineer proved very successful. Combining the two roles necessary to build an expert system application has only become possible in recent years with the advent of the expert system shell. Also, with a large number of shell packages, the developer can incorporate the rules into the knowledge base using natural language. These two factors have made it possible for less computer literate individuals to program useful expert system applications. The main advantages which came out of the WORMS project for the domain expert developing the application are as follows:

1. In order to program the expert system shell, the developer will have a better understanding of how the information will be stored in the knowledge base(s). This information will be extremely useful at the knowledge formalization stage when it is important to encode the knowledge in a way suitable for translation within the expert system.

2. The domain expert has a good working knowledge of the subject area which should lead to a greater level of correctness during prototype development. In the traditional model, when the knowledge engineer attempts to elicit data from a domain expert, he will not automatically understand key concepts or relationships. Rectifying these initial mistakes in the prototype system can lead to a longer period of prototype development than with the one man approach.

3. Because the domain expert has a good working knowledge of the subject area, the time period for knowledge acquisition is minimalised. In the traditional model, it has been previously discussed that this period can be a rate limiting step within the development cycle of a new application.

In the knowledge formalization stage (see Section 6.5), it can be seen how complex a seemingly simple scenario can appear when all necessary relationships are linked together. For example the anthelmintic knowledge base on the surface appeared a relatively simple problem to solve. However, as the picture evolved of wormer usage and preferred mode of administration, it becomes obvious that the situation was not as straight forward as first envisaged. There are a number of answer combinations which cannot be recommended by the system because of the importance placed on annual alternation of chemical groups. The situation was complicated even further when the question of resistance was entered into the equation. It can also be seen that the ordering of questions is an important consideration in order to prevent any unsuitable lines of questioning being followed (i.e. to reduce redundancy). For example:

(1) "Is alternative grazing ever available on your farm?" [Yes] [No]

(2) "What type of alternative grazing is available on your farm?"

(3) "Do you move the flock to alternative grazing after lambing?"

If the answer to (1) is "no", then there is no point in asking questions (2) and (3).

The husbandry knowledge base became too large to be considered usable for the following reasons: Firstly, intermittent memory problems caused the system to crash and secondly, the time taken to load up the knowledge base was considered unacceptable.Therefore, the knowledge base was split into two: hill situation and lowland situation. One of the main benefits of expert system technology is that separate modules (knowledge bases) can be set up independently of each other which can later be linked together to form a single application. For large applications this has the increased advantage of speeding up the processing time.

The method of using decision tables proved to be an efficient and manageable method of encapsulating the information required for the knowledge bases. It is probably the first time that every single possible situation has been considered in terms of developing integrated control strategies.

It was decided that due to time constraints allowed for this project, that the prototype would be developed for the sheep-only farming system. The benefits of providing a system with a high level of accuracy outweighed those benefits of developing WORMS further for mixed farm situations. This leaves plenty of scope for developing WORMS further in the future. This subject will be discussed more fully in Chapter 9. At this point in the lifecycle of the WORMS application, the analysis of the situation has been completed together with the design for programming the expert system shell. In the next chapter, the prototype development cycle will be discussed together with the validation methods used to test the accuracy of the system.

Chapter 6 - References

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Contents - Chapter 7

Chapter 7 - Developing WORMS using Crystal4

7.1 Introduction

In Chapter 6, a comprehensive account of the first four phases of the expert system lifecycle has been given:

1. Aims and objectives.
2. Identification of resource requirements.
3. Knowledge acquisition.
4. Knowledge formalization.

The questions thought appropriate for a problem solving session were recorded in a tabular decision tree format and all possible combinations for each possible line of questioning were mapped. The next phase within the expert system lifecycle is the implementation of this knowledge into a suitable computer format. This process will be carried out using the expert system shell Crystal4. This is then followed by the prototyping method used to improve the advice being produced by the system. The human interface plays an important part in defining how practical the application is in terms of the end user. A section therefore follows which describes factors which were considered necessary in order to make the application more user-friendly. Finally, there is a section on the methods used to validate the system.

7.2 Development of WORMS using Crystal4

It has been previously mentioned that Crystal4, the expert system shell used to develop WORMS, utilizes knowledge bases using a production rule structure. The initial development of WORMS, translating the decision tree mappings into production rule notation, caused very few problems. However, there are several criteria which need to be considered during the application development phase. These are discussed below.

7.2.1 Data driven versus goal driven systems

It is very important during the design stage to consider which strategy would suit the proposed applications most efficiently. In Chapter 4, the concepts of forward and backward chaining were introduced. Backward chaining (goal driven) systems are used in situations where the conclusion is available and the rules are used to test if the conclusion is correct. For example, the conclusion could be "it is suspected that an animal is suffering from gastrointestinal nematode parasitism." The system analyses all the test data available before proving whether or not the initial diagnosis (conclusion) is correct. In the case of a forward chaining (data driven) system, all the questions are asked at the start of the program and all possible conclusions are tested before specifying which of the conclusions meet all the criteria.

When building large applications, a mixture of forward and backward chaining may be used in order to improve the structure and performance of the system. This strategy was used for the development of WORMS. Three distinct operations were built into the system:

7.2.1.1 Data collection

All questions which were required to produce a recommendation were asked during this phase using both forward and backward chaining strategies. Questions concerning stock management and anthelmintic treatment strategies used on the farm were handled separately under two rules:

1. Husbandry information.
2. Anthelmintic information.

Each set of questions is then asked in turn with certain questions defining the subsequent line of questioning. For example:

(1) "Do you house your sheep during winter?" [Yes] [No]

IF "Yes" THEN goto (2) and THEN (3)

IF "No" THEN goto (4) and THEN (5)

(2) "How soon after lambing is turnout?"

(3) "Was the pasture to be used for turnout used by lambs last year?"

(4) "Are the ewes moved to clean pasture after lambing?"

(5) "Is the flock moved to new pasture after lambing?"

This directional approach to the line of questioning is being driven by the data entered by the user and is therefore forward chaining. On the other hand, once all husbandry questions have been answered, the "Husbandry information" rule is considered TRUE, i.e. all criteria have been met, therefore the system moves onto the next rule "Anthelmintic information". The aim is to prove whether the "Husbandry information" rule is TRUE or FALSE, given the criteria specified at a lower level, therefore a backward chaining approach is also being used.

7.2.1.2 Assessment of the Anthelmintic data

Once all questions regarding the history of anthelmintic usage have been established, the system is in a position to process the data and provide a recommendation. There are four possible wormer types which are assessed for their suitability for use in the coming season. Therefore each wormer group is tested in turn against the criteria thought necessary to define a group as suitable for the coming season. In Figure 7.1, the rule is shown for assessing whether the benzimidazole group of wormers should be recommended. If all the criteria are met, the rule "Benzimidazole" is considered TRUE by WORMS. Testing whether an individual group of wormers is suitable

Figure 7.1 WORMS rule "Benzimidazole"

```
Benzimidazole

IF              NOT  Benzimidazole chosen
        AND     Oral formulation
        AND     NOT bdz resistance
        AND     Assign drugfound$:="Benzimidazole"


OR              NOT  Benzimidazole chosen
        AND     In-feed formulation
        AND     NOT bdz resistance
        AND     Assign drugfound$:="Benzimidazole"
```

Rule translation

Benzimidazole chosen	- **benzimidazole drug used last year**
Oral formulation	- **oral dosing preferred by the user**
In-feed formulation	- **In-feed dosing preferred by the user**
bdz resistance	- **benzimidazole resistance been reported on the farm or considered possible by WORMS**

therefore uses a backward chaining approach. However, it is necessary that all four groups of wormer are assessed, even if "Benzimidazole" rule is shown to be TRUE. More than one group of wormers could be considered suitable in any given season. Therefore a forward chaining approach is used to test all possible outcomes. All wormer groups considered suitable for the coming season are stored within a character variable DRUGFOUND, which is displayed within the conclusion form at the end of the problem solving session.

7.2.1.3 Assessment of the husbandry data

Once the anthelmintic data has been assessed, the information regarding stock management on the farm is also assessed. The decision tables created during the knowledge formalization phase were used to create all possible unique ewe and lamb treatments to be used by WORMS. These treatment recommendations were built into the system as conclusion screens, together with a set of rules linking the criteria defined to the relevant conclusion screens (see Figure 7.2). Only one possible ewe treatment and lamb treatment is possible, therefore once a set of criteria has been satisfied, the appropriate conclusion screens appear. This section of the program uses a purely goal driven (backward chaining) approach.

7.2.2 Loops

Loops are used in WORMS to repeat a question which the user has already answered. There are two situations which were highlighted when this would be useful:

7.2.2.1 Question re-run

This situation arises when the answer to a combination of questions leads to a conclusion not advocated by the system. For example:

(1) "What anthelmintic group(s) did you use last year?"

Figure 7.2 A section of the WORMS rule "Ewe treatments assessed 1A

```
                                          ┌── IF    Indoors for lambing
IF    Ewe treatment 31 chosen             │     AND turnout within 5 weeks
  AND Assign ewetreatment:=31  ───────────┤
                                          └── OR    NOT Indoors for lambing

IF    Ewe treatment 32 chosen  ────────────── IF    Indoors for lambing
  AND Assign ewetreatment:=32                   AND turnout after 5 weeks
```

Answer="Benzimidazole"

(2) "Which of the following modes of action do you prefer?"

Answer="Controlled release bolus"

The line of reasoning used by the system states that because a benzimidazole drug was used last year, it should not be recommended for the coming season. At the present time, only the benzimidazole drug albendazole is marketed for sheep in the UK as a controlled release bolus. At this point, therefore, the user is enlightened about this fact and asked to reconsider his chosen mode of administration. The original answer to this question is cleared from the memory and the rule, to ask the question, is re-run.

One situation was considered, however, which could not be processed in the way described above:

"Which of the following modes of action do you prefer?"

Answer="In-Feed"

At the present time, benzimidazole drugs are the only group of anthelmintics marketed in the UK as in-feed preparations. Therefore, if a benzimidazole drug had been used last year, the same scenario would be encountered as described above. The mode of administration rule would be re-run. However, the system considers that in-feed dosing is disadvantageous in any situation and that the user should be given the opportunity to reconsider his decision. Unlike the previous example though, if benzimidazoles are recommended in the coming season, in-feed dosing could be used. This means re-running the original rule would not be appropriate. Choosing in-feed would always call up the warning display form. In this situation, the warning is placed on a menu screen which prompts the user to reconsider his chosen mode of administration. If the user chooses in-feed again, the system proceeds with the next question. If a different mode of administration is chosen, the value recorded in the mode of administration variable is re-assigned.

7.2.2.2 What-If

Once a problem solving session has been completed advice is given on the most appropriate control strategy for the coming season. An additional feature was added where all questions and answers are displayed on screen. The user is then prompted to modify one of the answers. For example:

"In what month do you expect lambing to occur?"

The user may have chosen "Dec/Jan" lambing initially, but wishes to change that decision to "Feb/March". Once this question has been chosen for modification, the original answer is cleared from memory. A global restart then operates which re-runs all rules, using the information stored in memory from the problem solving session. When it comes across a rule where information is required for the system to proceed, the user is prompted to supply the missing information. In this case, the lambing date will be requested. Once this piece of missing information has been obtained, a new set of advice screens is presented to the user.

If the question prompted for change affects the line of reasoning, the system automatically adjusts and attempts to obtain the missing information. For example:

"Do you house your sheep during winter?"

If the question was answered "yes" initially, but then the user decides to change the answer to "NO", the whole line of questioning requires modification:

"Are the ewes moved to clean pasture before lambing?"

"Is the flock moved to new pasture after lambing?"

These two questions were not asked during the initial problem solving session because they were considered inappropriate to the particular situation. Because of the change in emphasis of the situation, answers to these questions are now required. Therefore, the user will be prompted to answer these two questions as well as the housing question initially chosen for modification.

The advantages of this facility are twofold:

1. If the user accidently chooses the wrong option to one of the questions during the initial problem solving session, this can be resolved without the user having to restart a new problem solving session.

2. It allows the user to understand the reasoning used by the system by creating a "WHAT-IF" facility. The user can see the effects that modifying a single answer can have on the advice being given.

7.2.3 Rule processing by Crystal4

A basic understanding of how Crystal4 processes rules is required in order to produce a completely functional system. In general, Crystal processes the rules in the order in which they appear within the knowledge base. In Figure 7.3, Crystal would look first at Rule 1. If Criteria 1 and 2 were both found to be TRUE then Rule 1 would succeed and the system would stop. If Criterion 1 was TRUE, but criterion 2 was FALSE, then Rule 1 would fail. Rule 2 would likewise fail, without consideration being given to Criterion 3. The system would move to Rule 3 and process Criteria 3 and 4. If both Criteria 3 and 4 are then found to be TRUE, Rule 3 would succeed and the system would stop. This method of rule processing can be used where all possible alternatives within a rule are mutually exclusive i.e. goal driven (backward chaining) systems.

Figure 7.3 An example rule structure

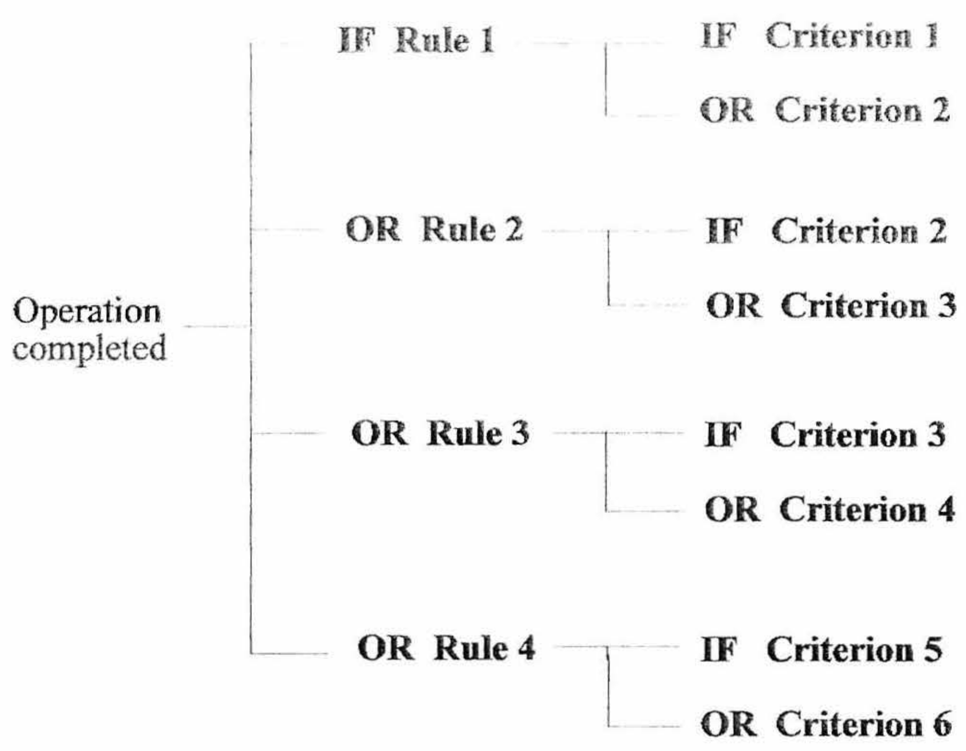

Figure 7.4 WORMS rule "Type of alternative pasture"

Type of alternative grazing

```
IF         : Menu     alttypemenu
    AND    : Test alttypemenu=1
    AND    : Assign alttype$="reseeded pasture"

OR         : Test alttypemenu=2
    AND    : Assign alttype$="arable cropping"

OR         : Test alttypemenu=3
    AND    : Assign alttype$="hay/silage aftermaths"

OR         : Test alttypemenu=4
    AND    : Assign alttype$="ewes during autumn/winter"

OR         : Test alttypemenu=5
    AND    : Assign alttype$="lambs after weaning"

OR         : Test alttypemenu=6
    AND    : Assign alttype$="lambing paddock last year"
```

```
What was the alternative pasture
previously used as?

  reseeded pasture
  arable cropping
  hay/silage aftermaths
  ewes during autumn/winter
  lambs after weaning
  lambing paddock last year
```

In Figure 7.4, a menu question is used to assign a value to the variable alttype$. If the user chose "hay/silage aftermaths":

alttypemenu=1 - FALSE

alttypemenu=2 - FALSE

alttypemenu=3 - TRUE

Rules 4, 5 and 6 would be ignored because the rule "Type of alternative grazing" had already succeeded.

This method of processing is not suitable, however, when a number of different possibilities could be chosen. For example, in Figure 7.5 an assessment is made about which anthelmintic groups can be recommended for the coming season. If a benzimidazole drug was used last year, oral dosing is the preferred dosing method and no resistance has been found on the farm, then morantel, levamisole and ivermectin are all recommended for the coming season. However, using the rule processing method described above the following analysis would result:

Benzimidazole	Benzimidazole not used last year	FALSE
Morantel	Morantel not used last year	TRUE
	Oral formulation	TRUE
	No morantel resistance	TRUE

Therefore, the rule Morantel would succeed because all the criteria are TRUE. At this point, the system would stop looking for alternative drugs, therefore levamisole and ivermectin would not be considered. In order to force the system to process all possibilities, each condition within the rule "Anthelmintic products assessed" is forced to fail even if TRUE (see Figure 7.6). In order to let the overall rule succeed once all possibilities have been considered, a succeed statement

Figure 7.5 WORMS rule "Anthelmintic products assessed"

```
IF   Benzimidazole ------------> IF      NOT benzimidazole chosen
                                   AND Oral formulation
                                   AND NOT bdz resistance
                                   AND Assign drugfound$:="Benzimidazole"

                                 OR      NOT benzimidazole chosen
                                   AND In-feed formulation
                                   AND NOT bdz resistance
                                   AND Assign drugfound$:="Benzimidazole"


OR   Morantel -----------------> IF      NOT morantel chosen
                                   AND Oral formulation
                                   AND NOT mor resistance
                                   AND Assign drugfound$:="Morantel"


OR   Levamisole ---------------> IF      NOT levamisole chosen
                                   AND NOT In-feed
                                   AND NOT CRD
                                   AND NOT lev resistance
                                   AND Assign drugfound$:="Levamisole"


OR   Ivermectin ---------------> IF      NOT ivermectin chosen
                                   AND NOT In-feed
                                   AND NOT CRD
                                   AND NOT Iver resistance
                                   AND Assign drugfound$:="Ivermectin"
```

Figure 7.6 Improved WORMS rule "Anthelmintic products assessed"

```
IF    Benzimidazole       ──────▶ IF    NOT benzimidazole chosen
  AND Drug list updated             AND Oral formulation
  AND Fail                          AND NOT bdz resistance
                                    AND Assign drugfound$:="Benzimidazole"

                                  OR    NOT benzimidazole chosen
                                    AND In-feed formulation
                                    AND NOT bdz resistance
                                    AND Assign drugfound$:="Benzimidazole"


OR      Morantel          ──────▶ IF    NOT morantel chosen
    AND Drug list updated           AND Oral formulation
    AND Fail                        AND NOT mor resistance
                                    AND Assign drugfound$:="Morantel"


OR      Levamisole        ──────▶ IF    NOT levamisole chosen
    AND Drug list updated           AND NOT In-feed
    AND Fail                        AND NOT CRD
                                    AND NOT lev resistance
                                    AND Assign drugfound$:="Levamisole"


OR      Ivermectin        ──────▶ IF    NOT ivermectin chosen
    AND Drug list updated           AND NOT In-feed
    AND Fail                        AND NOT CRD
                                    AND NOT Iver resistance
                                    AND Assign drugfound$:="Ivermectin"


OR      Succeed
```

is required at the end.

7.2.4 Rule dictionary

Each knowledge base developed using Crystal4 contains its own unique rule dictionary. Every rule which has ever been written into the knowledge base is recorded here. This has two main advantages:

1. A rule remains consistent throughout the system. Every time a rule is modified, all other occurrences of the rule are also updated.

2. If a rule which has been previously developed is required at another point within the system, the rule dictionary can be called using the F7 key and the appropriate rule chosen. This can significantly speed up the development time of an application.

One disadvantage of using a rule dictionary is that even if a rule no longer appears within the knowledge base, it still appears in the rule dictionary. However, a facility is available for removing all unused rules from the rule dictionary. This operation needs to be carried out regularly to prevent computer memory being used up on redundant information.

7.2.5 Use of negation

In Crystal4, conditions of a rule are either TRUE or FALSE. There are many situations when two opposing conditions may be required within the knowledge base. For example, in Figure 7.7 it is seen that the rule called "Benzimidazole resistance" can be used in two ways within the anthelmintic knowledge base:

1. During the assessment of possible resistance, a number of questions are asked in order to ascertain whether benzimidazole resistance is present on the farm. If the rule succeeds, benzimidazole resistance is considered by WORMS to occur on the farm and the variable

Figure 7.7 Use of negation within the anthelmintic knowledge base

(partial rules "Drug failure occured" and "Benzimidazole" used for demonstration purposes)

Rule 1:

Drug failure occurred

```
IF    Benzimidazole resistance
AND   Reslist updated
AND   Fail
```

Rule 2:

Benzimidazole

```
IF    NOT Benzimidazole chosen
AND   Oral formulation
AND   NOT Benzimidazole resistance
AND   Assign drugfound$:="Benzimidazole"
```

RESLIST is assigned the value "Benzimidazole".

2. When assessing all possible drugs to be recommended for use in the coming season, a rule is required that NO benzimidazole resistance has been reported. This is the negative of situation (1). Negating the rule built for situation (1) by using the F9 key to assign NOT to the rule "Benzimidazole resistance" has the following advantages:

1. Utilization of the same rule increases the level of consistency achieved by the system.

2. It reduces the need to produce another rule with multiple criteria, which in turn reduces development time of the application.

However, negation must be used with caution because what may appear on the surface to be the total opposite of a pre-existing rule in reality is not. For example:

(1) BDZ resistance confirmed

(2) BDZ resistance not confirmed.

On the surface these two rules would appear to be opposites, but this is not the case. The opposite of the rule BDZ resistance confirmed actually contains a possible two further rules:

(2) BDZ resistance not confirmed - i.e. no official testing has proved benzimidazole resistance exists on the farm, but the system has identified there may be a possible resistance problem developing.

(3) No benzimidazole resistance problem exists.

7.3 Prototype development

In the traditional model where the knowledge engineer works together with the domain expert, prototype development means enhancement in the light of new information. The domain expert will discuss several test cases with the knowledge engineer from which a set of rules are defined and the initial expert system is developed. Additional test cases are then used to modify and refine the knowledge base. Another approach to prototyping is to build a small system quickly in order to understand key concepts and then throw away this initial prototype and develop the full application using a more traditional programming approach.

The approach to prototyping used in this study was completely different to the two methods described above. The majority of the time was spent at the knowledge formalization stage, creating the decision tables described previously. Once a complete section of the knowledge base had been fully analysed on paper, it was programmed into the expert system shell Crystal4. Each section was then reviewed in turn by one of the project advisor's Dr Dewi Rowlands who would provide feedback on the correctness of the advice being produced by the system to the farm situation given. Even though the prototyping cycle is different, the requirements which need addressing at the prototype stage are still the same:

1. An expert system should adequately represent the domain knowledge. As mentioned previously, Dr Dewi Rowlands reviewed the prototype application in the role of domain expert testing the advice being given by the system.

2. The knowledge should be applied by the system in a way which is both efficient and intelligible to the user. Section 7.2 has already described how the programming of WORMS in Crystal4 developed in order to produce an efficient system.

3. It should have a good human interface in order to remain in day to day use. A great deal of consideration was given to the user interface of the system in order to make it feel as user-friendly as possible (see Section 7.4 for details).

4. It should integrate wherever possible with existing sources of information and other software.

This could not be accomplished by WORMS because suitable software is not currently available which could provide any of the information requested by the system. However, with the increasing adoption of computer technology on farms, if the farmer was to database his overall stock management and dosing schedule, it would be possible in the future that this could be used by WORMS to provide the historical background to the problem needed by the application.

Once the prototype system was available, a demonstration was set up with the project supervisors, three representatives from the Pharmaceutical Companies sponsoring the project and a representative from the farming journal "Farmer's Weekly". A hands-on session using WORMS took place, after which each person was asked to complete a questionnaire to provide initial feedback from independent users. A copy of the questionnaire form, results and modifications made in response to this feedback can be found in Appendix B.

7.4 The human interface

One important consideration when designing any computer system is to make it as user-friendly as possible for the end user. If a system appears complicated, it will not be used. WORMS was designed with this point in mind. Thus, the following steps were taken to improve the user-interface.

7.4.1 Overall appearance

Screen design can significantly affect the way the user views a new system. The rules described below were followed in an attempt to improve the appearance of the system.

1. Providing too much information on a single screen was avoided wherever possible. This can lead to an impression of a cluttered and unnecessarily complicated system.

2. Colour was used wherever possible to break up large blocks of text and to make the screen

more readable. The basic design of screens used in the questionnaire was kept as uniform as possible. Different colours were used to define different types of text. For example, question text appears in black, answer text red and on-screen help/instructions yellow.

7.4.2 Question type

The accuracy of the recommendation produced by the system is clearly dependent on the accuracy of the information being entered. In order to increase this accuracy, several areas of question design used for developing the questionnaire for the sheep farm survey in 1992 were considered (see Chapter 5):

1. The questions were kept as simple as possible and designed in the multiple choice format. This reduces the amount of possible misinterpretation by the end-user and also makes the analysis of the information easier.

2. The questions were designed to prevent the possibility of bias i.e. by not leading the user towards one particular answer.

3. Negative questions were not used since they can lead to misinterpretation both by the user and by the system.

4. The problem solver was kept as short as possible. If a questionnaire appears unacceptably long, it will alienate the user and therefore not be used.

5. In certain cases, a question required two alternatives in order to reach a decision. However, it was considered advantageous to expand the number of alternative replies to improve the design and flow of the question. For example:

"How soon after lambing is turnout?"

[within 24 hours] [1 to 7 days] [1 to 6 weeks] [longer]

The decision regarding this question revolves around whether turnout is within 6 weeks or longer than 6 weeks after lambing. However, expanding the options available improves the structure of the question and influences the accuracy of the reply obtained.

6. The type of end-user was also considered carefully as this has implications concerning the question and answer style. The prototype system was designed primarily for the farmers, therefore the use of complex scientific terminology was considered to be inappropriate and likely to alienate the end user.

7.4.3 Explanation facility

There are three types of explanation facility built into the system:

1. Crystal4 automatically produces a rule trace which provides a complete history of a problem solving session. This proved valuable both for testing purposes and also for the end user to follow the line of questioning used.
2. Help screens have been built behind every question asked during a problem solving session. At any time, the user can access these screens in order to find out why a particular question has been asked.
3. Auxiliary programs have been incorporated within the application to provide background information in all the key areas described above. This area will be discussed in detail in Chapter 8.

7.4.4 Provision of help for the user

There are three levels of help provided to the user:

1. On-screen information tries to lead the user through the system, telling him what key strokes are required to proceed.

2. The help screens have been designed to incorporate any information a user might require in order to answer a question.

3. A comprehensive user's manual accompanies the application. This manual is provided in Chapter 8.

7.5 Validation

Validation testing is an important phase within the development cycle of any new application. However, developing validation procedures for an expert system is not easy because of the judgemental nature of the information assessment. How do you validate an expert's opinion? There are two main areas in which a system can be tested:

1. System testing to validate to test the information is correctly handled by the application, that the data is processed in a consistent manner and that suitable program de-bugging has been performed.

2. Field testing to check how the application performs in the real world. Unfortunately, due to the time constraints on this study, no field testing was carried out using WORMS.

7.5.1 System testing

In Chapter 4, the system testing techniques required for validating an expert system application are discussed. There are four sections of testing which were considered necessary for validating WORMS:

1. Consistency.

2. Completeness.

3. Soundness.

4. Usability.

The following discussion looks at each of these sections in turn, describing the methods used to validate WORMS.

7.5.1.1 Consistency

Validating the system for consistency means testing that the knowledge is used in a consistent way throughout all knowledge bases incorporated into the application. The three areas tested for during validation were:

1. Conflict - this situation occurs when two rules are capable of succeeding in the same situation but with conflicting results.
2. Redundancy - there are two possible types of redundant rule:

(i) When two rules are capable of succeeding in the same situation leading to the same result.

(ii) When a rule is fired which is irrelevant to the problem solving activity being undertaken and which has no influence on the final outcome.

3. Subsumption - this occurs when two rules have the same end result, but one contains an additional condition before it can succeed. This additional condition is a special type of redundant rule.

There are several features found in Crystal4 which reduce the risk of inconsistencies being introduced into the application. These include:

1. The rule dictionary which allows the use of any rule to be called again for use in a different area of the knowledge base. It also means that if a rule is modified in one place, the system will automatically update all occurrences of that rule found throughout the knowledge base.
2. Negation rule - this allows the opposite conditions of a previously defined rule to be used. This prevents the risk of overlap between the two sets of opposing conditions and also the risk of

overlooking important conditions.

However, although these features improve the overall confidence concerning system consistency, it is recognised that a more formal testing approach was required. The method used to test for consistency was firstly to map out the rule structure built into the system. The following general procedures were then followed to eliminate the risk of inconsistencies occurring:

1. Ensure there is only one rule present within the knowledge base for a defined group of conditions. This can be achieved by defining the conditions within each named rule on the knowledge base and checking for duplicates. Because WORMS is an integrated system combining three different knowledge bases, it is appropriate to carry out checks, between, as well as within, the knowledge bases.
2. If rules with opposing conditions are found, look into the possibility of removing one of these rules and using the negative of the other rule instead.

Further testing was then carried out using the rule trace facility of Crystal4 to test the path used during a problem solving session. All possible combinations were tested to check for the following:

1. That all rules fired within each problem solving session were appropriate i.e. testing for redundancy.
2. To test that the system was utilizing each rule in the predicted manner.

7.5.1.2 Completeness

Testing for completeness means ensuring that enough information is available to the system in order to make it usable. There are two main types of completeness which require checking: semantic completeness and formal completeness.

7.5.1.2.1 Semantic completeness

This area tests whether the domain area incorporated into the system is large enough to be useful, but small enough to be usable:

1. Does the system include enough problem areas? It was decided that in the first instance WORMS could be developed for sheep only situations. This could be used to understand the fundamentals involved in developing such a system which could then be used to expand the system to incorporate mixed farming strategies. This aim has been achieved and a useful system has been produced.
2. Is there enough information available to produce a recommendation? Yes.

7.5.1.2.2 Formal completeness

This area tests whether the rule structure built into the system is complete and that all possible outcomes have been considered. There are three procedures required to test for formal completeness:

1. Check that all the conclusions within the system can be produced from the rules i.e. testing for redundant conclusions.
2. Check that the conditions within the rule structure are sufficient to differentiate between the different conclusions available.
3. Check that all possible conditions within the knowledge base will ultimately lead to a conclusion i.e. testing for missing conclusions.

Test 2 has already been achieved during the rule trace testing carried out during consistency validation described in Section 7.5.1.1 above. Tests 1 and 3 can be combined into one test procedure which is described below.

There are three possible reasons why situations 1 and 3 might occur:

1. Paper formalization of the data is incorrect. This is highly unlikely because as mentioned in the previous chapter, using decision tables eliminates the risk of missing/redundant information.
2. Translation of the information into the system.
3. Modifications of the rules could lead to conclusions no longer being required and therefore redundant, or new rule structures requiring new conclusions which have been overlooked.

Each conclusion consists of two separately derived sections: ewe treatment and lamb treatment. Each treatment used within the system is coded eg. ewe 1, ewe 23, lamb 14 etc.. This same coding methodology was also used on the decision tables. Each unique combination of rules is processed in turn using WORMS to see if the ewe and lamb treatment recommendation produced match those recorded on the decision tables. Any situations which failed to produce a match were investigated using the rule trace facility and then modifications made to the code. The rule would then be re-run until satisfactory.

7.5.1.3 Soundness

Testing for soundness means testing whether the expertise is correct - does the information agree with expert opinion? This validation process was carried out during the prototyping phase where a domain expert (Dr Dewi Rowlands) reviewed the advice being generated by the system. See Section 7.3 for details.

7.5.1.4 Usability

It is essential that any system is capable of collecting information consistently through a number of users or even the same user on a variety of occasions. The questions must be readily understandable and any ambiguities eliminated. Initial user testing was carried out during the prototyping stage (see Section 7.4 for details), however it was decided that further testing was required to ensure the usability of the system. Unfortunately, time constraints on the project were such that this testing could not be carried out. However, a methodology of how the testing could proceed is provided below.

There are two areas where testing usability can be directed:

1. Does the user fully understand the demands being made on him during a problem solving session? A system cannot be considered usable if a given user answers the questions in a different way for the same situation on different occasions.

A group of ten users is required who have not previously used WORMS. Three differing farm situations are provided and the users are instructed to obtain advice from WORMS on what control strategy to recommend for the given situations. The users are requested to record the answers to the questions that they chose and to print out the resulting recommendations. This test should be repeated a week later with the same users and the same farm situations. The results could then be databased and comparisons made:

(i) between single individuals on different occasions.

(ii) Between the ten individuals on the same occasion.

2. What is the user's overall impression of the system? This is very important - if the user does not like the system or finds it difficult to use, the system will not be used.

The same set of ten users should be used and given three hours training on how to use WORMS and how WORMS works. The users are then asked to repeat the previous exercise and then fill in a questionnaire on what they thought of the system and any areas they feel improvements could be made.

7.5.1.5 Anthelmintic knowledge base testing

The validation procedures described above are suitable for the two husbandry knowledge bases - lowland and hill. In both of these cases a recommendation is made in the form of conclusion screens providing the most appropriate ewe and lamb treatment for the coming season. However, in the case of the anthelmintic knowledge base, the recommended anthelmintics for the coming season are recorded in a character variable which is then displayed within the conclusion screens of the husbandry knowledge base. Given a small number of standard rules, the wormer groups being proposed are either suitable or unsuitable for use in the coming season. Therefore, a separate process of validation was developed for the anthelmintic knowledge base.

7.5.1.5.1 Method

A table was created with a column specified for each possible question asked within WORMS (see appendix C which shows an example form). Each possible question answer combination was reviewed in turn and a check made that the wormer group(s) chosen was as expected. The final column on the form was used to record the correctness of the response by WORMS. If a problem was encountered where the system did not respond as expected, the situation was repeated using the rule trace facility to test for possible programming errors. Once the problem was resolved, the test would be repeated for the problem situation and if no error was encountered the testing procedure would continue until all possible combinations had been checked.

7.5.1.5.2 No drug suitable

During the validation process a significant minority of situations were found when no broad spectrum wormer would be suitable using facts about the anthelmintics and the rules of thumb employed by the system. Most of these situations are unlikely to occur in real-life in the UK, but for system completeness they could not be ignored. Therefore, a display screen was provided to highlight the problem to the user and the problem solving session halted on the ground that a suitable recommendation could not be provided.

7.6 Discussion

In this chapter, the second half of the lifecycle for building the application WORMS has been discussed. It is shown that the characteristics of and utilities provided by the expert system shell program can have a major impact on the way that the application is developed. It has also been shown that the features built into the shell program can enhance the facilities provided by the application being developed. For example, the rule dictionary has led to a standardization of the rules built into the system. This in turn resulted in a reduction of the number of errors being written into the code and also significantly reduced the time span needed to "debug" the system. Any modifications made to a particular rule were carried out for every occurrence of that rule within the knowledge base. The use of negation also decreased the possible risk of alternative scenarios being overlooked which could occur if two opposing rules had been built independently of each other. In situations where a group of criteria occur or do not exist, the use of negation was always considered. However, it is also seen that negation may not always be appropriate and should therefore be used with caution.

A prototyping approach was then used in order to enhance the level of expertise provided by the system. It was highlighted that the project did not use the more traditional prototyping approach where a knowledge engineer would sit down on a number of occasions with a domain expert. At this stage the system was reviewed by the application developer, project supervisor, three representatives from Pharmaceutical Companies and representative from the farming press. In light of the comments made by the various reviewers, modifications were made to the system and these have been documented in Appendix B.

It was recognised following the sheep farm survey carried out in 1992 that questionnaire design can play an important role when considering the usability of a system. This area was given high priority when designing the layout of the WORMS application. Areas given particular attention were overall appearance of the system, question type and provision of an explanation facility and help for the user. Using Crystal4 made it easy to develop a system which was pleasing to look at and also which provided suitable help when required.

Validation of any computer program is always an important part of its development lifecycle. In the case of WORMS, it is recognised that not only should the system be tested to check for programming errors, but that it also requires testing in the field situation. Unfortunately due to the time constraints of the project, field testing the system was not possible. There are four main areas of system validation discussed in this chapter: consistency, completeness, soundness and usability. Because the data built into an expert system tends to be judgemental in nature, any validation methods need to be tailored to the needs of the application under development. There are no standard procedures for testing these programs. A full methodology is thus provided describing procedures used to test the consistency, completeness and soundness of WORMS. Unfortunately, due to the time constraints on the study, usability could not be validated, however, a proposed methodology has been provided.

Therefore, it can be seen that WORMS has completed all stages of the development lifecycle and been tested as far as was feasible, given the time constraints. Further testing is required before the system could be considered ready for a real-time situation. This will be discussed further in Chapter 9. In the next chapter, a user guide is provided designed to help the end user to operate WORMS, together with a number of test cases to demonstrate how WORMS problem solves to generate an appropriate recommendation.

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Chapter 8 - WORMS: User Guide and Demonstration

8.1 WORMS user guide

8.1.1 Introduction

WORMS is a computer program specifically designed to provide advice to the user on the best method of control for preventing PGE nematode disease of sheep in the coming season. The package also includes two auxiliary learning tools developed to improve the users understanding of nematode parasitism in sheep.

8.1.1.1 Technical Requirements

WORMS can be run on a 286 or higher machine which contains a 3.5 inch floppy disk drive and 4 megabyte of RAM. MS DOS 5.0 or higher is required. There must be at least 3 megabyte of RAM available as extended memory, therefore a modification may be required to the configuration file config.sys, usually located in the c:\ directory. To edit config.sys, move to the c:\ directory then type:

EDIT CONFIG.SYS <enter>

Ensure the following line exists within the file and if not edit as appropriate.

device=c:\windows\EMM386.EXE RAM 3072

Press ALT-F to choose file from the top menu then choose exit <enter>. Press <enter> again to save the modified file. The PC will need to be rebooted to ensure the modifications to memory configuration are implemented.

8.1.1.2 To Load the System

To enter the system, put disk 1 into the disk drive and type a: <return>

Type worms <return>

After an initial start-up screen, an introduction screen is displayed which provides a brief description of the three sections incorporated into the WORMS package (see Figure 8.1):

1. Problem solver.

2. Drug information.

3. Additional information.

8.1.2 Problem solver

In this section the user is asked a number of questions regarding husbandry practices used on the farm and historical drug usage. Each question contains a list of possible choices from which the user can select an answer using the up and down arrow keys and then pressing enter. On-screen help is provided to help the user. There are also help screens available by pressing F1. Once sufficient information is available for the system to provide a recommendation, advice screens appear with both ewe treatment and lamb treatment recommendations. The user can print the advice screen by following the instructions provided on screen. A display screen then follows showing the user all answers to the questions he has just given.He is then asked if he would like to change one of his responses. By choosing one of the question boxes, the previous answer is deleted and the question is re-asked. A new recommendation is then presented to the user.

An additional two knowledge bases have been added to the WORMS application as reference guides to the worm problem in sheep. The aim of these programs is to provide the user with a more in depth understanding of the worm parasites themselves and the drugs used to control them.

8.1.3 Anthelmintic Information

The anthelmintic information program covers all aspects of drug control of worms: what

Figure 8.1 WORMS introduction screen

```
                        INTRODUCTION

     Welcome to WORMS, a sheep management system designed to advise
     on the most suitable methods for controlling stomach and
     intestinal worms of sheep.

     There are three sections incorporated into the package:

  1. Problem solving - by answering a series of questions related to
     past worm control and management practices, advice can be given
     on how to tackle the problem in the coming season.
  2. Drug information - this gives a listing of the anthelmintics
     currently marketed in the UK and their various advantages and
     disadvantages.
  3 Additional information - this section provides information about
     the different worm parasites found in this country, the general
     lifecycle and symptoms of worm parasitism.

              ***** Press any key to continue *****
```

drugs are currently marketed in the UK, how to use them effectively and the prevalence of anthelmintic resistance in specific countries around the world. There are four sections included within the program:

1. Query

2. Information

3. Resistance

4 Drug usage

8.1.3.1 Query

The query tool provides a look-up facility between the generic drug name eg benzimidazole, albendazole, ivermectin etc and the better known trade names. The user is prompted to choose a wormer group eg. levamisole (see Figure 8.2). WORMS then provides a display screen with all trade names currently marketed in the UK for that group of wormer (see Figure 8.3).

8.1.3.2 Information

The information section provides more detailed information about all groups of broad spectrum wormers for sheep and all products currently marketed in the UK. The program is divided into four parts, one for each wormer type i.e. benzimidazole, levamisole, morantel and the avermectins. Each of these sections is then subdivided further into general information and product information.

8.1.3.2.1 General information

General information provides an overview of the group of wormer concerned (see Figure 8.4). A brief description is given about the level of activity conferred by the drug on the worm

Figure 8.2 Drug information program, query section

```
                         DRUG QUERY

    This program is a product search to convert the drug
groups commonly used in literature and in the problem
solving section into the more commonly known product name.


               benzimidazole
               levamisole
               Morantel
               avermectin
               Leave this section
               Leave the system


Use the up and down arrow keys to choose an option then press ENTER
```

Figure 8.3 Query section, levamisole chosen

```
                         LEVAMISOLE

     The following listing is of those products containing
     levamisole:

            Armadose              Nilzan
            Bionem                Ridaverm
            Chanaverm             Ripercol
            Levacide              Sure
            Levacur               Vermisole
            Levadin               Vermofas
            Levafas               Wormaway
            Nilverm

          ***** Press any key to continue *****
```

Figure 8.4 Benzimidazole chosen. general information

```
                         BENZIMIDAZOLES

     This group includes the compounds thiabendazole, parbendazole,
oxibendazole, mebendazole, fenbendazole, albendazole, oxfendazole
and ricobendazole (albendazole oxide).
     Febantel, thiophanate and netobimin are also included within
this group as pro-benzimidazoles because they are metabolised to
benzimidazole products and it is these products which confer
activity against the worm parasites.
Activity: Good against adult, immature and egg stages of worm
          parasites. The newer drugs also show good efficacies
          against arrested larval stages.
          Good efficacy is also found against lungworms and
          tapeworms, variable activity against adult liver fluke.
Resistance: resistance has been found in some parts of the UK to
            benzimidazole products by the parasites. If resistance
            is found on a farm benzimidazole compounds cannot be
            used reducing the choice of wormer which can be used to
            levamisole, morantel and ivermectin.
     If you want definitions of the highlighted terms press F1
             ***** Press any key to continue *****
```

parasites and a summary of drug resistance by worms to the drug reported to date. Any technical terms which the user may have difficulty understanding are also explained through help screens (see Figure 8.5).

8.1.3.2.2 Product information

The product information sections provide detailed information concerning the wormers currently marketed in the UK. When product information is chosen from the menu, a sub-menu appears where all drugs currently marketed for that particular group of wormers are listed (see Figure 8.6). When a particular drug is chosen, the following details are provided: all formulations of the product available, manufacturer, active ingredient, mode of administration, dose rate for sheep and pack sizes available (see Figure 8.7). The user is then asked if he wishes to view the contra-indications for that particular product. The source data used for the product information sections was the NOAH "Compendium of Veterinary Products 1995/1996".

8.1.3.3 Resistance

With anthelmintic resistance being reported on a regular basis in the lay press over recent years, the anthelmintic program could not have been considered complete without covering this important topic. What resistance is, the extent of the problem on a worldwide scale and how to reduce the spread of resistance are all discussed in this section. When the user chooses resistance from the main menu, a sub-menu is displayed with the following choices:

1. Definitions of terms associated with resistance. The four terms resistance, resistance factor, side resistance and multiple resistance are defined.

2. Prevalence of resistance in different areas of the world. A summary of any resistance problems reported in recent years is provided by individual country. Countries included are the UK,

Figure 8.5 Help screen for benzimidazole chosen, general information

```
HELP
                              Terminology

     ACTIVITY:    This refers to the effectiveness of the wormer against
                  different lifestages of the parasite. If a wormer has
                  good efficacy against a parasite, this usually means
                  by using the drug at the recommended dose rate over
                  90% of the parasites within the animal at the time of
                  dosing will be killed.

     RESISTANCE:  Anthelmintic resistance has come to the fore in recent
                  times (it has been recorded since 1981 in this country).
                  A parasite population is said to show resistance if a
                  significantly larger number of parasites survive the
                  worming treatment than that of a normal population of
                  the parasite.

              ***** Press any key to leave the help screen *****
```

Figure 8.6 Benzimidazole chosen, product information

Benzimidazole Products

The following is a list of benzimidazole products currently marketed in the UK. To choose an option use the arrow keys to highlight the option and then press ENTER.

Allverm	Panacur
Bayverm	Parafend
Bental	Proftril
Bovex	Supaverm
Chanazole	Synanthic
Fendazole	Systamex
Hapadex	Valbazen
Nemafax	Zerofen
Ovitelmin	Leave this section
	Leave the system

Figure 8.7 Product information, Allverm chosen

```
                    ALLVERM

Manufacturer: Crown Veterinary Pharmaceuticals

Compound:     Ricobendazole

ALLVERM 4% (includes cobalt and selenium)

Administration: Oral

Dose Rate:      1 ml per 8 kg bodyweight (worm dose)
                1.5 ml per 8 kg bodyweight (worm and fluke dose)

Pack Sizes:     1 litre and 2.5 litres


           **** Press any key to continue ****
```

Denmark, France, Germany, Switzerland, the Netherlands, Australia, New Zealand and South Africa.

3. Recommended policies to reduce resistance development. The following areas have been documented as areas which should be considered when devising a control strategy to prevent anthelmintic resistance problems developing at the farm level:

(i) Dose rate.

(ii) Alternation of chemicals.

(iii) Frequency of dosing.

(iv) Dosing of bought-in stock.

(v) Influence of goats.

Advice is given on each of these subjects with the aim of educating the user on how to achieve the best results from a wormer and reduce the risk of developing a resistance problem. It is also hoped that the user will understand better why a particular recommendation was made by the problem solver.

8.1.3.4 Drug usage

The aim of this section is to provide information on how to achieve the best results from a particular wormer. The following areas are considered in this section:

(i) Different modes of administration available. There are four different methods to administer the wormer to sheep: oral drench, injection, in-feed and controlled release bolus. A description is provided for each administration method, together with wormer types currently marketed in that particular formulation.

(ii) Importance of correct drug dosage. Problems which may be encountered if underdosing and overdosing occur are discussed in this section.

(iii) Estimation of dose rate. A description is given of the most accurate method for calculating the dose rate of the flock is provided.

(iv) Maintenance of dosing equipment. Advice is provided on how to maintain the drenching/injection equipment in order to ensure an accurate dose is given to an individual animal.

8.1.4 Additional Information Program

This knowledge base has been designed to provide the user with background information concerning the worm parasites responsible for PGE symptoms in sheep. There are four sections included within this program:

1. The lifecycle.
2. Worm species.
3. Epidemiology.
4. Dictionary.

8.1.4.1 The lifecycle

It has been previously shown in Chapter 2 that there are two different general lifecycle patterns demonstrated by PGE nematodes of sheep. Firstly there is the generalised lifecycle shown by the majority of worm parasites of economic importance in sheep. Secondly there is the atypical lifecycle demonstrated by *Nematodirus battus*. A graphical presentation is provided of each lifecycle pattern together with a textual summary describing the different stages within the lifecycle.

8.1.4.2 Worm species

This section of the program is designed to provide an overview of the individual species of worm parasite. After choosing the option, an initial summary screen indicates the characteristic location within the host of the adult worm of different species (see Figure 8.8). A menu is then provided listing most of the genera of important PGE nematodes of sheep. The user is prompted to choose a species. Information provided about each genera includes individual species which are found in the UK which parasitise sheep, a brief description of their morphology and a summary of their pathological characteristics (see Figure 8.9). The information has been presented in a way which will, hopefully, prove user friendly to the end user. For example, colour has been used to break up large quantities of text. Also,the majority of screens have been broken down into smaller blocks. The first paragraph is shown, the user then presses <enter> and the second paragraph appears. To distinguish the new text, the first paragraph is coloured grey so that it still readable, but less dominant than the second paragraph.

8.1.4.3 Epidemiology

This section provides the user with basic infection patterns which may be seen during the course of a season. When this section is chosen a brief introductory screen is displayed. This is then followed by a menu screen where the user can choose to review three different types of infection pattern which may occur:

1. Generalised infection pattern when the flock is grazed on contaminated pasture.
2. Generalised infection pattern when the flock is grazed on clean/safe pasture.
3. *Nematodirus battus* infection pattern.

When one of these options is chosen, a graph is displayed showing infection levels at

Figure 8.8 Additional information program, worm species

```
Worm species causing parasitic gastroenteritis in sheep

    Abomasum:      Ostertagia circumcincta, O.trifurcata
                   Haemonchus contortus
                   Trichostrongylus axei

    Small
    intestine:     Trichostrongylus colubriformis, T.vitrinus
                   Cooperia curticei
                   Nematodirus battus, N.filicollis, N.spathiger
                   Bunostomum trigonocephalum
                   Strongyloides papillosus

    Large
    intestine:     Oesophagostomum venulosum, O.columbianum
                   Chabertia ovina
                   Trichuris ovis

        ***** Press any key to continue *****
```

Figure 8.9 Worm species section, *Nematodirus* spp chosen

NEMATODIRUS

There are three species found in sheep: N.battus, N.filicollis and N.spathiger. N.battus is generally regarded as the dominant species in the UK followed by N.filicollis. N.spathiger is rare in the UK, although higher levels have been recorded in the Channel Islands.

The adult worms are slender and approximately 2 cm long. The intertwining of worms gives an appearance similar to that of cotton wool. All species are mainly found within the mucosa of the ileum.

Symptoms

N.filicollis generally produces chronic disease with symptoms similar to that of Ostertagia and Trichostrongylus spp. N.battus, however tends to produce acute disease as the majority of infective larvae hatch at the same time causing sudden large levels of infection. Symptoms include inappetance and dehydration, with lambs congregating around drinking places.

Age immunity occurs faster than in other species: 3-6 months.

***** Press any key to continue *****

different times of the year during a typical season. Explanatory text is also provided to give a summary of nematode epidemiology on pasture and within the host animal.

8.1.4.4 Dictionary

The dictionary provides a reference manual of the terms used within the system and the whole area of PGE parasitism of sheep. The user is prompted to provide the first letter of the term he wishes to view (see Figure 8.10). A list of terms available within the dictionary beginning with that letter is then displayed (see Figure 8.11). If a term is then chosen, a definition for that term is displayed (see Figure 8.12).

Figure 8.10 Dicionary introduction screen

DICTIONARY

Welcome to the WORMS Dictionary

What is the first letter of the
term you wish to define?

a

***** Enter the appropriate letter then press ENTER *****

Figure 8.11 Dictionary section, letter 'A' chosen

A

Those terms listed below are defined in this program.

Abomasum
Acute disease
Anaemia
Anthelmintic
Arrested larvae
Avermectin
Leave 'a' terms
Leave the dictionary
Leave the system

To choose an option use the up and down arrow keys then press ENTER

Figure 8.12 Dictionary section, abomasum chosen

```
                    Abomasum

*********************************************************
*                                                       *
* This is also known as the 'true' or 'rennet' stomach. *
* It is the 4th stomach in ruminants.                   *
* The abomasum is where digestion takes place in        *
* ruminating animals.                                   *
*                                                       *
*********************************************************

       ***** Press any key to continue *****
```

8.2 Demonstration of the problem solver

The following farm situations are used to demonstrate a problem solving session using WORMS. Each farm situation is described which is then followed by the line of reasoning used by WORMS in order to produce a recommendation of treatment for the coming season. The advice produced by WORMS is described and explanation given as to why WORMS produced the recommendation. In each case this is then followed by documentation of the screens used by WORMS for each problem solving exercise.

8.2.1 Case history 1

Farm 1 occupies a lowland situation. There is no alternative grazing available at any time of year. Lambing occurs early, around Christmas time and the flock is not housed over winter. Panacur was used this season and oral dosing is the preferred mode of administration. The farmer has not noticed any reduced efficacy with the wormers used in previous years and no anthelmintic resistance testing has been carried out on the farm.

8.2.1.1 WORMS Problem solving

"Is alternative grazing ever available on your farm?

Answer="No"

"Do you house your sheep over winter?"

Answer="No"

"In what month do you expect most lambing to occur?"

Answer="Dec/Jan"

"Was a wormer used on this farm for sheep last year?"

Answer="Yes"

"What anthelmintic group(s) did you use last year to treat lambs?"

The user knows that Panacur was used last year, but is unsure as to which drug group Panacur belongs to. He therefore presses F1 for help.

Answer="Benzimidazole"

"Which of the following modes of administration do you prefer?"

Answer="Oral dosing"

"Has anthelmintic resistance to any group of wormer been identified on your farm?"

Answer="No"

"Have any of the following drug groups failed to control worms on your farm?"

Answer="No drug failure"

8.2.1.2 WORMS recommendation

8.2.1.2.1 Ewe Treatment

"Dose ewes at tupping with one of the following drugs"

As autumn approaches, the majority of PGE nematodes undergo arrested development within the host animal. This can lead to the appearance of clinical symptoms during December and January eg type II ostertagiasis and trichostrongylosis ("black scour"). Therefore, it is recommended to dose the ewes at tupping with an anthelmintic drug capable of killing arrested larvae. It has also been found that dosing the ewes at this time can enhance the condition of the ewe at mating.

"Dose ewes 4-6 weeks prior and/or 6 weeks after lambing"

For most of the year the ewe shows strong immunity to worm parasites. However, during the period 6 weeks prior to 6 weeks after lambing, the immunity status of the ewe is greatly reduced. Therefore, unless treated, the ewe will significantly increase the level of contamination laid down on already contaminated pasture. Therefore, it is recommended that the ewe should be treated before or after lambing, but preferably twice during the peri-parturient period.

8.2.1.2.2 Lamb Treatment

In this situation, the pasture grazed by the new lamb crop is contaminated and no alternative pasture is available. Therefore pasture management cannot be built into a possible control strategy. The only way to minimalise the effects of nematode parasitism in the new lamb crop is to dose every 4 weeks until weaning.

8.2.1.2.3 Anthelmintic Treatment

In the previous season the benzimidazole drug Panacur was used on this farm. Because of the increased prevalence of anthelmintic resistance reported over recent years, WORMS advocates the use of a three year rotation of the main groups of anthelmintic wormer. An oral wormer type is preferred and there is no suspected or reported anthelmintic resistance present. Levamisole, morantel and ivermectin are all non-benzimidazole drugs which are available as oral formulations.

8.2.1.3 WORMS screens used for case history 1

WORMS

Is alternative grazing ever available on your farm?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Do you house your sheep during the winter?

yes
No

Use the up and down arrow keys to highlight the option then press ENTER

WORMS

In what month do you expect most lambing to occur?

Dec-Jan
Feb-March
April

Press the up or down arrow keys to highlight the option then press ENTER

WORMS

Was a wormer used on this farm for sheep last year?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

WORMS

What anthelmintic group(s) did you use last year to treat the lambs?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, Morantel and Lev
Ivermectin	Bdz, Morantel and Iver
Bdz and Morantel	Bdz, Lev and Iver
Bdz and Levamisole	Morantel, Lev and Iver
Bdz and Ivermectin	All four types
Morantel and Lev	

Use the up and down arrow keys to highlight the option and press ENTER
To convert these anthelmintic groups into better known trade names press F1

WORMS

Which of the following modes of administration do you prefer?

Oral Dosing
Injection
In-Feed
Controlled release bolus

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Has anthelmintic resistance to any group of wormer been identified on you farm?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

Press F1 for help

WORMS

Have any of the following drug groups failed to control worms on your farm?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, Morantel, Lev
Ivermectin	Bdz, Morantel, Iver
Bdz and Morantel	Bdz, Lev, Iver
Bdz and levamisole	Morantel, Lev, Iver
Bdz and ivermectin	No drug failure
Morantel and Lev	

Use the up and down arrow keys to choose an option then press ENTER
To convert these anthelmintic groups into better known trade names press F1

WORMS

Proposed control strategy for the coming season

EWE TREATMENT

Dose ewes at tupping with one of the following drugs:
Benzimidazole

Dose ewes 4-6 weeks prior and/or 6 weeks after lambing with one of the following group(s) of drugs:

Morantel
Levamisole
Ivermectin

For further information about the drugs/groups of drugs see the:
drug information section
******** Press any key to continue ********

WORMS

Proposed control strategy continued ...

Lambs grown on for meat market

Dose every four weeks from 6 weeks of age until approximately 3 months of age. A further dose may be necessary towards the end of August, beginning of September. The most recommended group(s) of drugs for this season is/are:

Morantel
Levamisole
Ivermectin

For further information about the drugs/group of drugs see the
drug information section

******** Press any key to continue ********

8.2.2 Case history 2

Farm 2 is situated in a lowland location where alternate grazing becomes available after the second silage cut. Lambing occurs mainly during February. The flock is housed over winter. Bayverm and Levadin were used last year and oral dosing is the preferred mode of administration. No anthelmintic resistance testing has been performed on the farm, but the farmer has noticed Bayverm used last year did not prevent symptoms of PGE parasitism occurring in lambs less than three months old. The farmer did admit, though, that his policy for calculating the correct dosage of wormer required improvement.

8.2.2.1 WORMS problem solving

"Is alternative grazing ever available on your farm?"

Answer="Yes"

"During which of the following periods is enough alternative grazing available to carry the total lamb population?"

Answer="June/July"

"What was the alternative pasture previously used as?"

Answer="Hay/silage aftermaths".

"Do you house your sheep during winter?"

Answer="Yes"

"In what month do you expect most lambing to occur?"

Answer="Feb-March"

"Does lambing occur indoors?"

Answer="Yes"

"How soon after lambing is turnout?"

Answer="1-7 days"

"Was the pasture to be used at turnout used by sheep after June last year?"

Answer="Yes"

"Was a wormer used on the farm last year?"

Answer="Yes"

"What anthelmintic group(s) did you use last year to treat the lambs?"

Answer="Bdz and Levamisole"

"Which of the following modes of administration do you prefer?"

Answer="Oral dosing"

"Has anthelmintic resistance to any group of wormer been identified on your farm?"

Answer="No"

"Have any of the following drug groups failed to control worms on your farms?"

Answer="Benzimidazole"

"The following three points are common reasons for drug failure at the farm level:

Inaccurate weighing of stock

Administration of the dose

Rounding up of the flock

Could any of these points be a reason why the drug you identified could have failed to perform on your farm?"

Answer="Yes"

8.2.2.2 WORMS recommendation

8.2.2.2.1 Ewe treatment

"Dose ewes at housing with one of the following drugs: Bdz and Levamisole"

As autumn approaches a large proportion of PGE nematodes undergo arrested development within the host animal. These arrested larvae then recommence development as the host immunity of the ewe wanes prior to lambing. This can lead to problems such as "black scour" (trichostrongylosis) or type II ostertagiasis occurring December/January time. To prevent this situation occurring, ewes should be dosed immediately before housing with a drug capable of killing arrested larvae. Because the dose is being given this season rather than next, the recommended drugs are those which were used earlier in the season. If no drug was used this season, the recommendation would be to use an anthelmintic recommended for next season.

"Dose again 4-6 weeks after turnout"

Because the turnout pasture was used for sheep after June last year, it cannot be regarded as safe. Therefore a dose is required after turnout to prevent the ewe contributing significantly to the amount of contamination laid down on pasture for the new lamb crop.

8.2.2.2.2 Lamb treatment

"Dose lambs at 4-6 weeks of age"

By 4-6 weeks of age, lambs will have started grazing and therefore started to develop a worm burden.

"As the lambing paddock cannot be considered clean of worms, lambs require dosing at 4 weekly intervals from the initial dose until weaning"

Because the turnout paddock cannot be considered safe, lambs require a regular dosing regime until alternative pasture becomes available.

"Alternative grazing is available June/July, therefore dose and yard for 24 hours before moving all lambs onto this pasture"

Even with dosing at regular intervals, the lambs will have picked up a significant worm burden from the contaminated pasture. In order to prevent the carry over of infection from one paddock to another, WORMS recommends that the lambs should be dosed immediately before the move. However, it generally takes the drug 24 hours to pass through the whole of the gastrointestinal tract, therefore if lambs are placed on the new pasture within this period, carry over of infection will occur. Therefore it is recommended that the lambs should be yarded for 24 hours between the dose being given and the lambs being moved to the new paddock. Because the alternative pasture was used for silage making, it can be considered clean. Therefore lambs should not require any further dosing for the rest of the season.

8.2.2.2.3 Anthelmintic treatment

The pro-benzimidazole drug febantel (Bayverm) and the levamisole product Levadin were used in the previous season. Therefore ivermectin is the only drug suitable for the coming season. Morantel has been shown to use a different mode of action to levamisole and is therefore generally accepted to belong to its own group (see Chapter 4). However, side resistance can be seen - if levamisole resistance occurs, morantel resistance might be also found. Therefore for the purposes of this program levamisole and morantel are treated as the same group. Levamisole was used last year, therefore levamisole and morantel should not be used this year. A reduction in the efficacy of Bayverm was highlighted, however after further investigation this has been put down to improper drug usage rather than a potential resistance problem developing. Therefore, no anthelmintic resistance has been found and oral formulation is required therefore ivermectin is recommended by WORMS for this situation.

8.2.2.3 WORMS screens for case history 2

WORMS

Is alternative grazing ever available on your farm?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

WORMS

During which of the following periods is enough alternative grazing available to carry the total lamb population?

March-May
June/July
Aug/Sept
None of the above

Use the up and down arrow keys to choose an option then press ENTER

WORMS

What was the alternative pasture previously used as?

- reseeded pasture
- arable cropping
- hay/silage aftermaths
- ewes during autumn/winter
- lambs after weaning
- lambing paddock last year

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Do you house your sheep during the winter?

- yes
- No

Use the up and down arrow keys to highlight the option then press ENTER

WORMS

In what month do you expect most lambing to occur?

Dec-Jan
Feb-March
April

Press the up or down arrow keys to highlight the option then press ENTER

WORMS

Does lambing occur indoors?

yes
no

Use the up and down arrow keys to choose an option then press ENTER

WORMS

How soon after lambing is turnout?

within 24 hours
1 to 7 days
1 to 5 weeks
longer

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Was the pasture to be used at turnout
used by sheep after June last year?

yes
no

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Was a wormer used on this farm for sheep last year?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

WORMS

What anthelmintic group(s) did you use last year to treat the lambs?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, Morantel and Lev
Ivermectin	Bdz, Morantel and Iver
Bdz and Morantel	Bdz, Lev and Iver
Bdz and Levamisole	Morantel, Lev and Iver
Bdz and Ivermectin	All four types
Morantel and Lev	

Use the up and down arrow keys to highlight the option and press ENTER
To convert these anthelmintic groups into better known trade names press F1

WORMS

Which of the following modes of administration do you prefer?

Oral Dosing
Injection
In-Feed
Controlled release bolus

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Has anthelmintic resistance to any group of wormer been identified on you farm?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

Press F1 for help

WORMS

Have any of the following drug groups
failed to control worms on your farm?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, Morantel, Lev
Ivermectin	Bdz, Morantel, Iver
Bdz and Morantel	Bdz, Lev, Iver
Bdz and levamisole	Morantel, Lev, Iver
Bdz and ivermectin	No drug failure
Morantel and Lev	

Use the up and down arrow keys to choose an option then press ENTER
To convert these anthelmintic groups into better known trade names press F1

WORMS

The following three points are common reasons for drug failure at the farm level:

Inaccurate weighing of stock
Administration of the dose
Rounding up of the flock

Could any of these points be a reason why the drug you have identified could have failed to perform on your farm?

Yes
No

For information about each of the cases highlighted above, use the up and down arrow keys and press ENTER.

To answer the question, use the arrow keys to highlight the option and press ENTER.

WORMS

Proposed control strategy for the coming season

EWE TREATMENT

Dose ewes at housing with one of the following drugs:
Bdz and Levamisole
Dose again 6 weeks after turnout. The most suitable group(s) of drugs is/are:

Ivermectin

For further information about these drugs see the:
drug information section

******** Press any key to continue ********

WORMS

LAMB TREATMENT

Dose lambs at 6 weeks of age.
As the lambing pasture cannot be considered clean of worms, lambs require dosing at 4 weekly intervals from the initial dose until weaning.
Dose again at weaning.
Alternate pasture is available June/July, therefore dose and yard for 24 hours before moving all lambs onto this pasture.

The most recommended group(s) of drugs is/are:
Ivermectin

For further information about these drugs see the
Drug Information Program
***** Press any key to continue *****

8.2.3 Case history 3

Farm 3 is a Welsh mountain farm where the sheep roam the hill freely during the summer months. The flock is brought off the hill in winter and moved to a lowland area on Anglesey. A benzimidazole drug was used last year, and the farmer has shown an interest in using a controlled release bolus to dose his flock in the coming season. A couple of seasons ago the farmer reported to his veterinary surgeon that levamisole did not seem to be working as he had suffered nematodiriasis during June of that year. Tests were carried out, but after further consultation it was discovered that the farmer had been underdosing his flock by approximately 25%.

8.2.3.1 WORMS problem solving

"What type of hill system do you operate?"

Answer="Open mountain"

"Is the flock brought off the hill in winter?"

Answer="Yes"

"Is the flock housed in winter?"

Answer="No"

"Will the flock be moved to a different paddock after lambing?"

Answer="No"

"Was the pasture you propose using for the lambs at 6 weeks to 3 months of age used for lambs in the previous season?"

Answer="Yes"

"When do you propose moving the flock back to the hill?"

Answer="June"

"Was an anthelmintic drug used on this farm last year?"

Answer="Yes"

"What anthelmintic group(s) did you use last year to treat sheep?"

Answer="Benzimidazole"

"What mode of administration do you prefer?"

Answer="Controlled release bolus"

Warning screen

WORMS has recognised that a benzimidazole drug was used last year and that the farmer wants to use a controlled release method of administration in the coming season. It has been previously mentioned that the system has been programmed to recommend a three year drug rotation between the three main groups of broad spectrum wormer. The only group of wormers marketed in the UK for sheep is controlled release form are the benzimidazoles. Therefore, the user is advised of this fact and then is asked to consider an alternative mode of administration.

"What mode of administration do you prefer?"

Answer="Oral"

"Has any anthelmintic resistance to any group of wormer been identified on your farm?" The user was unsure on how to answer this question therefore pressed F1 for help.

"Answer="No"

"Have any of the following drug groups to your knowledge failed to control worms on your farm?"

Answer="Levamisole"

"The following three points are common reasons for drug failure at the farm level:

Inaccurate weighing of stock

Administration of the dose

Rounding up of the flock

Could any of these points be a reason why the drug you identified could have failed to perform on your farm?"

The user requested further information about the category "Inaccurate weighing of stock"

Answer="Yes"

8.2.3.2 WORMS recommendation

8.2.3.2.1 Ewe Treatment

"Dose with one of the following drugs when the flock is moved off the hill for winter:

Benzimidazole"

In the ewe treatment recommendation for Case 2 (Section 8.2.2.2.1), the problems associated with larvae undergoing arrested development in autumn were discussed. In Case 3, the flock is moved to a lowland location for the winter period. It can be assumed that the lowland pasture will be more densely populated and that the arrested larvae within the ewe will commence development as the ewe's natural immunity wanes during the periparturient period. This can lead to outbreaks of disease during Dec/Jan and can also result in significant pasture contamination being laid down by the ewe. Therefore, for all of these reasons, the ewe should be dosed with a suitable wormer before being moved to the lowland pasture. It has already been stated that the farmer used a benzimidazole drug earlier in the season, therefore it is recommended that a benzimidazole drug would be most suitable at this time.

"Dose with a suitable drug pre-lambing and/or 6 weeks post lambing"

The pasture being used overwinter was also used for susceptible lambs last year, therefore it cannot be regarded as being "safe". At this time the immunity of the ewe is low therefore the ewe could significantly contribute to the level of contamination on pasture for the new lamb crop. In order to prevent this additional source of contamination, therefore, it is recommended that the ewe should be dosed pre-lambing or 6 weeks post lambing, but preferably both.

8.2.3.2.2 Lamb treatment

Two alternative treatments have been suggested for the coming season:

1. "Dose the lambs with a suitable wormer and move to new pasture not used by lambs during the previous season. Dose lambs again before moving the whole flock back onto the hill"

In this case, it is suggested that if lambs are moved out of the contaminated pasture and onto alternative pasture, the frequency of dosing can be reduced. Because it is likely that the lambs will have taken up a certain amount of infective larvae, the lambs will require a second dose immediately before the move back onto the hill. This is to prevent cross contamination of worms from the lowland situation to the hill.

2. "Dose the lambs with a suitable drug at four weekly intervals from 6 weeks of age until the flock is moved back onto the hill"

If alternative pasture is not available, a frequent dosing schedule is required to protect the lamb crop from nematodiriasis and reduce the build-up of a sizable worm burden within the lamb. If a large worm burden was allowed to develop at this time, subclinical infection could significantly affect lamb development at an important period in their growth cycle.

8.2.3.2.3 Anthelmintic treatment

The farmer stated that he had used a benzimidazole drug last season and preferred to use a controlled release device for the coming season. Because the only drug currently marketed as a controlled release bolus for sheep in the UK is a benzimidazole drug, the user was prompted to reconsider his choice. Oral dosing was chosen at this point. Resistance testing had been carried out on the farm, but no anthelmintic resistance was reported and the conclusion was that lack of efficacy had resulted from improper drug use. Therefore, WORMS concluded that there was no resistance problems to date for this farm situation. Therefore, morantel, levamisole and ivermectin are all recommended for the coming season.

8.2.3.3 WORMS screens used for case history 3

WORMS

What type of hill system do you operate?

open mountain
mountain paddocks

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Is the flock brought off the hill in winter?

yes
no

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Is the flock housed in winter?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Will the flock be moved to a different paddock after lambing?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

Was the pasture you propose using for the lambs at 6 weeks to 3 months of age used for lambs in the previous season?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

When do you propose moving the flock back to the hill?

April
May
June
July

Press the up and down arrow key to choose an option then press ENTER

WORMS

Was an anthelmintic drug use on this farm last year?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

What anthelmintic group(s) did you use last year to treat the sheep?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, morantel and lev
Ivermectin	Bdz, morantel and iver
Bdz and Morantel	Bdz, lev and iver
Bdz and Levamisole	Morantel, lev and iver
Bdz and Ivermectin	All four types
Morantel and Lev	

Press the up and down arrow keys to choose an option then press ENTER

To covert these anthelmintic groups into better known trade names press F1

WORMS

Which mode of administration do you prefer?

- oral
- injection
- in-feed
- Controlled release bolus

Press the up and down arrow keys to choose an option then press ENTER

WARNING

Benzimidazole used last year + Controlled release

The only group of wormers currently marketed in the uk as a controlled release bolus are the benzimidazoles. This system recommends the use of rotation of wormers on an annual basis.

In this situation, a benzimidazole product was used last year and controlled-release is you preferred method of administration. Therefore this choice of dosing method is not suitable for your situation in the coming season.

***** Press any key to continue *****

WORMS

Which mode of administration do you prefer?

- oral
- injection
- in-feed
- Controlled release bolus

Press the up and down arrow keys to choose an option then press ENTER

WORMS

Has any anthelmintic resistance to any group of wormer been identified on your farm?

- Yes
- No

Use the up and down arrow keys to choose an option then press ENTER

Press F1 for help

Help

Has anthelmintic resistance been identified on your farm

The aim of this question is to find out whether there has been any formal testing carried out by a veterinary surgeon, pharmaceutical representative or other official body on your farm.

If such tests were carried out and the results came back positive then answer this question YES

If such tests were carried out but the results came back negative then answer this question NO

If no formal testing has been carried out on your farm then answer this question NO

***** Press any key to continue *****

WORMS

Have any of the following drug groups to your knowledge failed to control worms on your farm?

Benzimidazole	Morantel and iver
Morantel	Lev and iver
Levamisole	Bdz, morantel, lev
Ivermectin	Bdz, morantel, iver
Bdz and morantel	Bdz, lev, iver
Bdz and levamisole	Morantel, lev, iver
Bdz and ivermectin	No drug failure
Morantel and lev	

Press the up and down arrow keys to choose an option then press ENTER

To convert these anthelmintic groups into better known trade names press F1

WORMS

The following three points are common reasons for drug failure at the farm level:

Inaccurate weighing of stock
Administration of the dose
Rounding up of the flock

Could any of these points be a reason why the drug you have identified could have failed to perform on your farm?

Yes
No

For information about each of the cases highlighted above, use the up and down arrow keys to chose the option and press ENTER.

To answer the question, us the arrow keys to highlight the option and press ENTER

Accurate weighing of stock

In order to achieve accurate weight of the stock it is essential to divide the flock into the different age/sex groups and weigh a sample of animals from each group. For the best results, it is recommended to weigh the heaviest animals in each age sex class.

It has been shown experimentally that weighing by sight and/or touch is not accurate enough for dose rate calculations, leading primarily to a reduced efficacy or failure of the drug to control a parasite problem and ultimately to an increased probability of developing a drug resistance problem onto the farm. From experiments which have been carried out to date, the chances of reversing a resistance problem once it has occurred is very unlikely, therefore prevention is the only answer.

If the recommended procedure above was not implemented when drug failure occurred then answer "yes" that there are drug administration problems on the farm. This is not applicable if drug screening was then carried out and resistance was found to have occurred on your farm.

***** Press any key to continue *****

WORMS

Proposed strategy for the coming season

EWE TREATMENT

Dose with one of the following drugs when the flock is moved off the hill for winter.

Dose with a suitable drug pre lambing and/or 6 weeks post lambing.

The most recommended group(s) of drugs is/are:
Morantel
Levamisole
Ivermectin

For further information about these compounds see the drug information section of this program

***** Press any key to continue *****

WORMS

Proposed strategy for the coming season

LAMB TREATMENT

There are two alternatives for overcoming this problem:

1. dose the lambs with a suitable drug and move to a pasture not used for lambs during the previous lambing season. Dose lambs again before moving the whole flock back onto the hill.
2. dose the lambs with a suitable drug at 4 weekly intervals from 6 weeks of age until the flock is moved back onto the hill.

The most recommended drug(s) is/are: Morantel
Levamisole
Ivermectin

***** Press any key to continue *****

8.2.4 Case history 4

Farm 4 occupies a hill situation where the hill pasture has been improved and divided into large paddocks. The sheep remain on the hill all year, but are brought off temporarily and housed for lambing. Once the lambs are six weeks old, the flock is moved back into the hill paddocks. The farmer used levamisole during the lambing period last year and ivermectin in the autumn. The farmer prefers using an injectable preparation. No resistance testing has been carried out on the farm and the farmer has not noticed any reduction in efficacy with the wormers he has used over recent years.

8.2.4.1 WORMS problem solving

"What type of hill system do you operate?"

Answer="Mountain paddock"

"Is the flock brought off the hill in winter?"

Answer="No"

"Are the ewes housed for lambing?"

Answer="Yes"

"How soon after lambing do you turnout the flock?"

Answer="Longer"

"Was the pasture you propose using for the lambs at 6 weeks to 3 months of age used for lambs in the previous season?"

Answer="No"

"When do you propose moving the flock back to the hill?"

Answer="May"

"During the season are the lambs returned at any point to pasture grazed by sheep previously in the season?"

Answer="No"

"Was an anthelmintic drug used on this farm last year?"

Answer="Yes"

"What anthelmintic group(s) did you use last year to treat the sheep?"

Answer="Lev and Iver"

"Which mode of administration do you prefer?"

Answer="Injection"

Warning screen

In the UK, the only group of wormers which are marketed as injectable formulations are levamisole and ivermectin. Because these two groups of wormer were used by the farmer in the previous season, WORMS does not recommend their use in the coming season. Therefore, the user is highlighted to this problem and asked to reconsider his/her choice.

"Which mode of administration do you prefer?"

Answer="Oral"

"Has any anthelmintic resistance to any group of wormer been identified on your farm?"

Answer="No"

"Have any of the following drug groups to your knowledge failed to control worms on your farm?"

"No drug failure"

8.2.4.2 WORMS recommendation

8.2.4.2.1 Ewe treatment

"Dose ewes when the flock is brought down off the hill for lambing"

The reasoning for this ewe dose is the same as has already been fully discussed in test Case 2 (Section 8.2.2.2.1).

"Dose again when the flock is moved back onto the hill in spring"

Dosing the ewe before moving back onto the hill will hopefully prevent the possibility of carryover infection between the lowland pasture and the mountain paddocks.

8.2.4.2.2 Lamb treatment

"There is no need to dose the lambs in spring"

The lambs will not be exposed to any kind of pasture before being moved back onto the hill, therefore will not be exposed to infective nematode larvae. Therefore, there is no need to dose lambs at this time.

"Once moved back onto the hill, try to move lambs to pasture not grazed during the previous autumn/winter. As the season progresses, try to prevent moving lambs back to pasture grazed previously in the season. If this cannot be achieved, dose the lambs with a suitable drug 4-6 weeks after the move"

The second half of the recommendation highlights situations which should be avoided wherever possible. If neither situation can be avoided the lambs require dosing 4-6 weeks after the move. There is no point dosing the lambs at the time of the move because they should be worm free. However, 4-6 weeks after the move, a significant worm burden may have developed within the lamb, therefore dosing at this time would seem appropriate.

8.2.4.2.3 Anthelmintic treatment

Levamisole and ivermectin were used last year and the farmer prefers to use an injectable formulation. At the current time, only levamisole and ivermectin drug groups are marketed as injectable formulations. Therefore, this mode of administration was not considered suitable by WORMS for the coming season. The user was asked to reconsider his chosen method of administering the wormer and oral dosing was chosen. No anthelmintic resistance was highlighted by WORMS to occur in this farm situation. Because morantel is classified within WORMS to belong to the same group of wormers as levamisole, benzimidazoles are the only group of wormers recommended by the system for the coming season.

8.2.4.3 WORMS screens used for case history 4

WORMS

What type of hill system do you operate?

open mountain
mountain paddocks

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Is the flock brought off the hill in winter?

yes
no

Use the up and down arrow keys to choose an option then press ENTER

WORMS

Are the ewes housed for lambing?

yes
no

Use the up and down arrow keys to choose an option then press ENTER

WORMS

How soon after lambing do you turnout the flock?

within 24 hours
1-7 days
2-5 weeks
longer

Use the up and down arrow keys to choose an option and then press ENTER

WORMS

Was the pasture you propose using for the lambs at 6 weeks to 3 months of age used for lambs in the previous season?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

When do you propose moving the flock back to the hill?

April
May
June
July

Press the up and down arrow key to choose an option then press ENTER

WORMS

During the season are the lambs returned at any point to pasture grazed by sheep previously in the season?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

Was an anthelmintic drug use on this farm last year?

yes
no

Press the up and down arrow keys to choose an option then press ENTER

WORMS

What anthelmintic group(s) did you use last year to treat the sheep?

Benzimidazole	Morantel and Iver
Morantel	Lev and Iver
Levamisole	Bdz, morantel and lev
Ivermectin	Bdz, morantel and iver
Bdz and Morantel	Bdz, lev and iver
Bdz and Levamisole	Morantel, lev and iver
Bdz and Ivermectin	All four types
Morantel and Lev	

Press the up and down arrow keys to choose an option then press ENTER

To covert these anthelmintic groups into better known trade names press F1

WORMS

Which mode of administration do you prefer?

- oral
- injection
- in-feed
- Controlled release bolus

Press the up and down arrow keys to choose an option then press ENTER

WARNING

Administration: Injection

With the increased importance over the last few years in the UK of anthelmintic resistance, annual rotation of the three anthelmintic groups is recommended.

In the situation you have given, levamisole/morantel and ivermectin were used last year and this year you would prefer to use an injectable preparation. Unfortunately, only levamisole and ivermectin are available in the injectable form, therefore this method of drug administration is not suitable for your situation in the coming season.

***** Press any key to continue *****

WORMS

Which mode of administration do you prefer?

- oral
- injection
- in-feed
- Controlled release bolus

Press the up and down arrow keys to choose an option then press ENTER

WORMS

Has any anthelmintic resistance to any group of wormer been identified on your farm?

Yes
No

Use the up and down arrow keys to choose an option then press ENTER

Press F1 for help

WORMS

Have any of the following drug groups to your knowledge failed to control worms on your farm?

Benzimidazole
Morantel
Levamisole
Ivermectin
Bdz and morantel
Bdz and levamisole
Bdz and ivermectin
Morantel and lev
Morantel and iver
Lev and iver
Bdz, morantel, lev
Bdz, morantel, iver
Bdz, lev, iver
Morantel, lev, iver
No drug failure

Press the up and down arrow keys to choose an option then press ENTER

To convert these anthelmintic groups into better known trade names press F1

WORMS

Proposed control for the coming season

EWE TREATMENT

Dose ewes when the flock is brought down off the hill for lambing.
Dose again when the flock is move back onto the hill in spring.
The most recommended group(s) of drugs is/are:

[druglist$[0]   ]
[druglist$[1]   ]
[druglist$[2]   ]
[druglist$[3]   ]

***** Press any key to continue *****

WORMS

Proposed control strategy for the coming season

LAMB TREATMENT

There is no need to dose the lambs in spring unless they reach 6 weeks before being returned to the hill. In this case, dose just before the move with one of the following drugs.

The most recommended group(s) of drugs is/are:

[druglist$[0]   ]
[druglist$[1]   ]
[druglist$[2]   ]
[druglist$[3]   ]

Once moved back onto the hill, try to move to pasture not grazed in the previous autumn. As the season progresses try to prevent moving lambs back to pasture grazed previously in the season. If this cannot be achieved, dose flock with a drug recommended above 4-6 weeks after the move.

For further information about the drugs see the drug information section of this program

***** Press any key to continue *****

Chapter 9 - Discussion and Conclusions

In Chapter 2, the nematode species responsible for causing parasitic gastroenteritis (PGE) in sheep were discussed. It was shown that if the susceptible lamb crop is moved out of the lambing paddock at weaning onto clean alternative pasture, the potential for a significant build up of contamination on pasture during the second half of the season is greatly reduced. It has also been shown that the success of the worm burden within the host animal affects the level of pasture contamination laid down. Therefore, if the worm burden was removed at the time of the move eg by dosing with a suitable anthelmintic, the amount of carryover infection maintained by susceptible animals would be negligible. Availability of susceptible animals at a certain point in the season is of particular importance in the case of *Nematodirus battus*, which undergoes a mass hatch on pasture in spring lasting 6-8 weeks. If there are no susceptible lambs on this pasture during this period, the potential for infectivity in this season is lost. Therefore, it can be seen that pasture management can play an important part in worm control of sheep.

In Chapter 3, the anthelmintic drugs used for worm control in sheep were introduced. With the increased intensity of sheep farming over recent years, more illness problems have come to light. Therefore, drugs are used more frequently which has in turn led to the development of anthelmintic resistance. At the present time there are only four groups of broad spectrum wormer available, with the possibility of perhaps one more new group being discovered in the next ten years. Therefore a balance is required in order to dose the flock effectively while at the same time sustaining the longevity of the wormer groups available.

In Chapter 4, it has been shown that one branch of artificial intelligence i.e. Expert Systems has grown into an important area of computer science. This is probably due to the fact that prototype systems can be developed quickly in comparison with conventional programming methods. They also provide a reliable and efficient method for widening the audience for what had been considered "expert knowledge". However, the main advantage expert system technology has over conventional programming methods is the justification facility. Expert system applications can justify their conclusions, a facility which increases user confidence in the advice being given. It has also been shown that since the advent of expert system shell programs, the number of new applications being developed has increased significantly. This has probably come about because the domain expert is now capable of developing the expert system application himself, rather than requiring the help of a computer programmer.

In Chapter 5, the sheep farm survey carried out in 1992 was discussed. It was shown that the basic trends followed the same pattern as those found in similar surveys carried out in other areas of the UK in recent years. It was found that even with the high profile publicity aimed at providing effective control strategy recommendations over recent years, the majority of farms use inefficient control procedures which have the potential to encourage the development of anthelmintic resistance. There also appeared to be a confusion regarding different wormer products and different wormer groups. This survey highlighted the need for a new approach to educating the farmer on effective worm control. It was anticipated that the WORMS application may be capable of fulfilling that role.

In Chapters 6 and 7, the development process of the WORMS advisory system was described. The system was developed by incorporating the roles of domain expert and knowledge engineer into one person. This approach proved very successful, partly due to the use of the expert system shell, which reduced the level of computer expertise required to develop the application. The problem solving section of WORMS needed to be divided into three sections due to the large number of rules required to produce a functional system. However, this in turn showed the ease with which module knowledge bases can be incorporated into a single application. The information considered necessary for building WORMS was formalised using decision tables which proved an effective method for acquiring the knowledge needed to build an expert system application. The system underwent modification once complete to improve the accuracy of the advice being given and then through system validation checking for consistency, completeness, soundness and usability. WORMS was built in the first instance for use on a sheep-only enterprise.

The main aim of this project was to produce a computerised parasite control advisory system. It can be seen through Chapters 6-8 that this aim has been achieved. The four case histories discussed in Chapter 8 demonstrate how, by answering a few questions tailored to the particular farm situation being investigated, a suitable recommendation of control procedures for the coming season can be produced by WORMS. Thus, the system helps the farmer to select an efficient method of control for his particular situation and also helps him to choose a suitable group of wormers for the coming season. In Chapter 8, two auxiliary programs are described (drug information program and additional information program) which have been developed as educational tools. The drug information program can help teach the farmer the difference between wormer product and wormer group, whilst at the same time providing advice on efficient dosing practices. The additional information program provides the farmer with a better understanding of the worm parasites responsible for PGE in sheep. Therefore, it can be seen that WORMS has the potential for alternative uses eg as a training tool for veterinary students, farm advisers or sales representatives for pharmaceutical companies.

WORMS has been validated for consistency, completeness and soundness. Preliminary testing for usability has proved positive. However, further testing is required before the system could be considered ready for field testing. Once system validation and full field trials have been completed, WORMS could be considered suitable for release. WORMS has been developed in the first instance for sheep-only farms, however the potential exists to expand the application to cover mixed farming situations. The modular nature of the system make it suitable for marketing either as a complete package or divided into a number of unit programs which could be sold separately. The information contained within the system is likely to date very quickly, particularly the drug database, where the information will require updating on an annual basis. There are a number of different ways in which the package could be made available to the end user:

1. Provide the user with a set of "floppy disks" containing the application. The user would need to be sent regular updates on disk.
2. Arrange for the information to be stored on a bulletin board which the user can access, providing he/she has a modem and the required level of access to the bulletin board.

The advantage of the second strategy is that the information contained on the bulletin board can be kept completely up to date. Updates can be applied during the night, when no user would be expected to use the system.

Computer technology has become a part of our every day life over the last two decades. WORMS has only covered a very small area of that which could benefit from the building of advisory programs. However, WORMS has shown the potential for using expert system technology to build applications for the livestock industry.

Appendix A - Questionnaire design used for the Sheep Farm Survey carried out in 1992

CONTROL METHODS USED FOR WORM PARASITES OF SHEEP BY NORTH WALES FARMERS

by: Carol Hazelby
Research Assistant,
Bangor University

This survey is being conducted by myself: Carol Hazelby, a postgraduate student of the University of North Wales, Bangor. My project is to review the control methods currently available, and with the help of computer technology, produce a system to assess the sheep worm problems of particular farm situations and give control options most suitable for that situation, which maximise the resources available (eg. manpower, equipment and facilities) and prove economically beneficial to the farmer.

The aims of this survey are:
1. to look at the control methods used on a variety of different farm situations and why they are used,
2. look at how worm control fits into the other management practices of the farm, and
3. look at how you the farmer view the success of the control practices you use and how you feel they could be improved.

By answering these fundamental questions, the control practices built into the proposed system will be designed to embrace both the best interests of the farmer (i.e. ease of administration within the overall management regime and economic benefit) and the welfare of the livestock.

If you have any questions you would like to ask me about the project please do not hesitate to ring me during office hours at the number listed below, or write to me at the above address.

Tel No. 0248 351151 extension 2332

Thank you for your cooperation,

Carol Hazelby

Please answer ALL of the following questions.

Please use block capitals:

Name: ____________________

Address: ____________________

____

Tel No. ____________

NB. The above information will be kept in the strictest confidence and will only be used for the purposes of this survey.

****

Unless otherwise indicated, please circle the answer of your choice.

Example: you farm mainly hill sheep, but bring them down to upland pastures during winter. The answer to the question:

What kind of land do you farm? is:

hill	(1)	hill	1 ✓
upland	(2)	upland	2 ✓
lowland	3	lowland	3
correct answer		incorrect answer	

1a.	what kind of land do you farm? (if more than 1 type, circle all appropriate answers)	Hill	1
		Upland	2
		Lowland	3

1b.	IF you farm hill land do you farm it:	All year	1
		Summer only	2
		Winter only	3
		Not applicable	4

1c.	IF you farm upland do you farm it:	All year	1
		Summer only	2
		Winter only	3
		Not applicable	4

1d.	IF you farm lowland do you farm it:	All year	1
		Summer only	2
		Winter only	3
		Not applicable	4

2a.	How many hectares is this farm?	< 20 ha	1
		20-49 ha	2
		50-99 ha	3
		100+ ha	4

2b.	How many hectares do you farm altogether?	< 20 ha	1
		20-49 ha	2
		50-99 ha	3
		100+ ha	4

3	What is the flock size of this farm?	less than 50	1
		50-99	2
		100-199	3
		200-299	4
		300-499	5
		500-1,000	6
		> than 1,000	7

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4. What stocking rate is used on this farm ____ ewes/ha.

5.	How many full-time workers(including members of your own family) work on this farm?	you alone	1
		you + 1 other	2
		you + 2 others	3
		you + >2 others	4

6.	What type of farming do you practice?	Sheep only	1
		Sheep + arable	2
		Sheep + cattle	3
		Other	4

7a.	What type of grazing system do you use? If you answer (1), go to 7b. If you answer (2), go to 8a.	Set stocking Rotational grazing	1 2
7b.	Is there any alternative grazing at any time of year? If you answer "yes" go to 7c.	Yes No	1 2
7c.	When is alternative grazing available? If alternative grazing available during several periods, ring all appropriate answers.	Jan-March April-May June-July Aug-Sept Oct-Dec	1 2 3 4 5
8a.	Do you house your sheep over winter?	Yes No	1 2
8b.	Does most lambing occur inside?	Yes No	1 2
9.	Over which period does most lambing occur?	Dec-Jan Feb-March April Other	1 2 3 4
10a.	Are wormers used on this farm for sheep?	Yes No	1 2
10b.	What type of wormer has been/will be used this year (refer to anthelmintics list on page 6) (If more than 1 will be used ring all appropriate answers).	White drench Levamisole Ivermectin	1 2 3

10c.	Which of the following do you consider important when choosing a wormer? (ring all appropriate answers)	Economical	1
		Efficient	2
		Easy to use	3
		Recommended	4
		Other	5
10d.	How many different wormer products do you use in any one year?	One	1
		Two	2
		More than 2	3
10e.	Are different wormers used from year to year?	Yes	1
		No	2
10f.	If Yes, why is this?	Anthelmintic resistance	1
		Recommended by an advisor	2
		Other	3
10g.	Where do you buy your wormer?	Farm suppliers	1
		Wholesaler	2
		Company representative	3
		Other	4
11.	Is treatment followed by a movement to safe pasture?	Yes	1
		No	2
12.	Which mode of wormer administration do you prefer?	Drench	1
		Injection	2
		In-feed	3

13.	If drenching equipment is employed, how often is the drenching gun maintained and calibrated?	After every treatment	1
		Annually	2
		once in 2 years	3
		less frequently	4
		Never	5

14.	How do you estimate the liveweight of each age sex/class for dosing?	By Sight	1
		Touch/lifting	2
		Weigh random sample from each class	3
		Weigh heaviest animals in each class	4
		Other	5

15.	Which do you think should be avoided most?	Overdosing	1
		Underdosing	2

16.	When are EWE treatments carried out? (ring all appropriate answers)	Autumn, pre-tupping	1
		Autumn, post-tupping	2
		Spring, Pre-lambing	3
		Spring, post-lambing	4
		No treatment	5
		Other	6

17.	How often are LAMB treatments carried out?	Every 2-3 weeks	1
		Weekly	2
		Monthly	3
		When necessary	4
		Other	5

18a.	How often do your sheep scour between April and Sept	Never	1
		Occasionally	2
		Frequently	3

18b.	How often do your sheep scour over winter?	Never	1
		Occasionally	2
		Frequently	3

18c.	How often do your sheep scour during other periods of the year?	Never	1
		Occasionally	2
		Frequently	3

19a.	Do you consider your worm control programme to be efficient?	Yes	1
		No	2

19b.	In what area(s) do you think you could improve your worm control programme?	Use a different drug	1
		Less frequent dosing of lambs	2
		More frequent dosing of lambs	3
		Better use of alternative grazing	4
		More accurate weighing of stock	5
		Better maintenance of dosing equipment	6
		Other	7

19c.	Do you think these improvements could easily be put into practise on the farm?	Yes	1
		No	2

19d.	If NO, what are your reasons?	Economics	1
		Lack of alternative grazing on the farm	2
		Not enough labour	3
		Too time consuming	4
		Other	5

20a.	How do you introduce bought-in stock to the main flock?	Worm and introduce	1
		Worm then quarantine	2
		Introduce to flock	3
		Other	4

20b.	If you quarantine bought-in stock, how long do you yard the new stock?	Few hours	1
		One day	2
		2-3 days	3
		One week	4
		Other	5

Thank you for your participation in this survey. The answers you have given will prove a valuable source of information for the project.

21.	Would you be interested in a copy of the full results of this survey when available?	Yes	1
		No	2
22.	Would you like your name putting in for the the prize draw (winner receiving £40 voucher from Farmer Supplies.	Yes	1
		No	2

If you want your name putting in for the prize draw, the closing date for returning the questionnaire is June 30th 1992 (post-mark).

Appendix B - Questionnaire developed to provide preliminary feedback about WORMS from representatives of three pharmaceutical companies

The following questions are grouped into four categories corresponding to different aspects of the WORMS program. All the questions are of a multiple choice design, requiring a single tick in the most appropriate box.

GENERAL

1. How user friendly did you find the system?

A. Very easy to follow ____
B. A few minor difficulties but on the whole understandable ____
C. Quite difficult to understand ____
D. Impossible ____

2. Are the instructions given on each screen:

A. Comprehensive ____
B. Adequate, but could be improved upon ____
C. Misleading ____
D. Not informative enough ____

PROBLEM SOLVER

3. Are the questions understandable?

A. Yes ____
B. On the whole yes, but some are ambiguous ____
C. Most are ambiguous ____
D. No ____

4. Do you feel the questions are asked in a neutral manner, or is the user likely to feel pre-judged?

A. Neutral ____
B. Pre-judged ____

5. Do you feel the advice being given is reasonable, in terms of the farm situation given?

A. Yes ____
B. Sometimes inaccurate ____
C. Often inaccurate ____
D. Advice way out ____

6. Do you feel the advice is comprehensive enough?

A. Yes ____
B. No ____

7. Do you feel the advice would be practicable in a field situation?

A. Yes ____
B. No ____

DRUG INFORMATION PROGRAM

8. Do you feel this program is useful?

A. Yes ____
B. No ____

9. Do you feel the information contained is comprehensive?

A. Yes ____
B. Yes, but there are areas not covered which should be ____
C. Yes, but there are areas not covered which could be ____
D. No ____

10. Are the explanations given understandable?

A. Yes ____
B. Most of the time ____
C. Some of the time ____
D. Never ____

ADDITIONAL INFORMATION PROGRAM

11. Do you feel this program is useful?

A. Yes ____
B. No ____

12. Do you feel the information contained is comprehensive?

A. Yes ____
B. Yes, but there are areas not covered which should be ____
C. Yes, but there are areas not covered which could be ____
D. No ____

13. Are the explanations given understandable?

A. Yes ____
B. Most of the time ____
C. Some of the time ____
D. Never ____

14. If there are any areas which you feel need improvement, please list below:

Important issues raised

Issue 1

Resistance questions need to be more comprehensive i.e. on what information is the farmer basing his answer - subjective or on the basis of a FECR test?

Response

The anthelmintic resistance section of the problem solver has since been modified. There are now two lines of questioning used to establish whether anthelmintic resistance occurs on the farm:

1. Has anthelminic resistance been officially reported and if so to which groups of wormer?

2. Have any of the drugs failed to control worms on your farm, and if so could anthelmintic

resistance be a possibility?

The full details of the questions asked by WORMS are documented in Chapter 6.

Issue 2

The drug information program should cover selenium and cobalt supplementation.

Response

The main aim of the drug information program was to educate the farmer on what products he could use in the following season, given the advice produced by the problem solver. The additional information included within this section is secondary to this primary aim. However, developing a section addressing selenium and cobalt supplementation could be considered for the future.

Issue 3

Can regional weather/temperature factors be included eg for the fluke and *Nematodirus* season?

Response

The main aim of the problem solver was to provide a method by which a farmer could achieve advice from WORMS on how to control gastro-intestinal nematode parasites in sheep in the coming season. The emphasis, therefore, was placed on pasture management and dosing strategies. There is a problem that if the line of questioning requires highly specific information, such as climatic data, there is a high potential that the information provided to the system could be inaccurate and hence the recommendation could be less appropriate. It is also likely that if the line of questioning requires data from sources other than the farmer, the system will not be used because it appears too difficult to obtain a recommendation. The original WORMS problem solver did require information from the *Nematodirus* forecasting system, however during the course of this project, the annual forecast was withdrawn. Control of liver flukes is not within the scope of this project.

Issue 4

More cross referencing between the different programs would be useful.

Response

This point has been noted and applied wherever it was considered appropriate. For example, when a recommendation is produced by the problem solver, the drug group is provided in the advice. At the bottom of the screen a message informs the user that if he/she needs more information about the anthelmintic products suitable for the coming season, then reference should be made to the drug information program.

Issue 5

The product information contained within the drug information program needs updating.

Response

All drugs represented in the drug information program have been revised using the "Compendium of data sheets for veterinary products 1995-1996".

Issue 6

When a technical term is used, there needs to be a reference to the dictionary where this term is defined.

Response

This point has been noted and applied wherever it is thought appropriate.

Appendix C Form used for validation of the anthelmintic knowledge base

Wormer type used	admin	resist yes/no	which group(s)	drug failure	resistance possible	correct response