AN EPIDEMIOLOGICAL INVESTIGATION OF RUMINANT HELMINTHOSES IN SMALLHOLDER FARMS IN CENTRAL KENYA.

By

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This thesis is dedicated to my parents, my wife and children.

ABSTRACT

The aim of this study was to investigate the pattern of infection with gastrointestinal nematodes and liver flukes (*Fasciola gigantica*) in ruminants on smallholder farms in central Kenya and, based on the information gained, design and test strategic anthelmintic control strategies against current control practices in order to make recommendations for future helminth control in this and other similar areas of Kenya.

The objective of the first part of the study was to gather together the available information from local farmers, veterinary extension staff and the local veterinary investigation laboratory. This was followed by a detailed epidemiological investigation of helminth infections in ruminants in Mathira division, Nyeri district. All ruminant livestock in 58 randomly selected smallholder farms were faecal sampled every month for nematode and trematode egg counts and pasture samples were collected from 8 communal grazing sites in the study area to assess pasture levels of nematode larvae. Six tracer lambs were introduced in the area and four local permanently grazed sheep were purchased every month for *post mortem* worm burden estimations. A strategic treatment programme was designed on the basis of this investigation and was compared with current helminth control practices in 80 smallholder farms for both small ruminants and cattle. During this period monitoring of the patterns of infections with nematodes and liver flukes continued.

Interrogation of laboratory records over a 10 year period showed that infection with parasitic gastrointestinal nematodes was more often diagnosed in small ruminants whereas *F. gigantica* infection was more common in cattle. The majority of ruminants were at pasture permanently with a high proportion grazing on communal pastures. Local farmers relied on the use of anthelmintics alone for helminth control, treating small ruminants 1-4 times (mean 3.3) and cattle 1-8 times (mean 3.5) a year. Sheep and goats on smallholder farms had the highest level of infection with gastrointestinal nematodes during the two rainy seasons, especially in March, April and October. *Haemonchus contortus* was the most predominant nematode species found in the tracer lambs, but in the permanently grazed sheep *Trichostrongylus* spp. were more abundant. Based on these results, two strategic treatments annually, one in January and one in October, were suggested for the control of gastrointestinal nematodes in small ruminants. The mean prevalence of *F. gigantica* infections in sheep and cattle was 5.6(±3.2)% and 13.0(±6.2)% respectively and most infections were recorded during the rainy seasons. Periods of peak pasture infectivity with *F. gigantica* metacercariae were recorded during the dry season and early in the wet season. A single treatment in October with triclabendazole or three annual treatments in April, June and October using other fasciolicides were suggested for the control of fasciolosis in cattle.

The strategic treatment for gastrointestinal nematodes in sheep and goats resulted in lower mean faecal egg counts in treated animals for most of the study period but overall, there was no significant effect of strategic treatment over existing treatments on FEC, birth weight and growth rate in lambs and kids. With regard to fluke treatments there were no significant variations in the proportions of cattle infected with liver fluke or in the daily weight gains in calves attributable to the strategic treatment over the study period.

This study succeeded in generating valuable and new epidemiological information on helminth infections of ruminants in smallholder farms in the high potential areas of central Kenya. However, it failed to demonstrate significant advantages of the strategic treatments over the existing helminth control practices. The performance of these treatments, assuming a high adoption rate in specific localities, needs to be evaluated over a longer period of time. Results from such trials would form the basis for recommendations of the strategic treatments to many other areas of Kenya.

LIST OF CONTENTS

LIST OF APPENDICES PAGE

LIST OF TABLES

LIST OF FIGURES

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AUTHOR'S DECLARATION

The work described in this thesis was performed by the author except where the assistance of others has been acknowledged. It has not been submitted for any another degree or professional qualification.

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LIST OF ACRONYMS

AHA	Animal Health Assistant
DFID	Department for International Development
EPG	Eggs per gram
FAO	Food and Agriculture Organisation
FEC	Faecal egg count
GIS	Geographical Information System
GLM	General Linear Models
GPS	Global positioning sensor
IGAD	Intergovernmental Authority on Development
KARI	Kenya Agricultural Research Institute
NARP	National Agricultural Research Project
NVRC	National Veterinary Research Centre
PGE	Parasitic gastroenteritis
UK	United Kingdom
USA	United States of America
VIL	Veterinary Investigation Laboratory

CHAPTER ONE

GENERAL INTRODUCTION

1. Ruminant helminthoses

1. 1 General introduction

Internal parasites cause some of the most important disease problems of livestock, hampering global efforts to meet the growing food requirements of a rapidly increasing human population. This is particularly true in view of the fact that most major epizootic contagious diseases are more or less under control in many parts of the world (Hörchner, 1990). From the wealth of information now available on many parasitic diseases, especially in the developed world, it can be seen that outbreaks of parasitism causing widespread mortality amongst domestic animals are generally rare. However, infections with parasitic helminths are still common in cattle, sheep and goats and cause varying degrees of morbidity and mortality.

Parasitic gastroenteritis (PGE) of ruminants, caused by infection with various species of gastrointestinal nematodes affects mainly young animals and is a world-wide problem which can result in substantial economic losses from mortality and sub-optimal production in animals infected with even moderate burdens of parasites (Allonby and Urquhart, 1975; Fabiyi, 1987; Carles, 1992).

Fasciolosis is another important parasitic disease caused by trematodes of the genus *Fasciola*. In temperate countries the disease is caused by *Fasciola hepatica,* whilst in the tropics *Fasciola gigantica* infection is the main problem with *Fasciola hepatica* being confined to certain highland areas. Both species are transmitted by snail intermediate hosts: *Lymnaea truncatula* being the main intermediate host for *F. hepatica* and *Lymnaea natalensis* for *F. gigantica.*

1.2 Economic impact

Over the last 30 years, various workers have considered the economic effects of

parasitism with gastrointestinal nematodes and liver flukes in both sheep and cattle. Though the costs of the drugs used to treat or prevent diseases caused by helminths are relatively easy to determine, the total cost of infection attributable to production losses, mortality and other deleterious effects are more difficult to assess. In Australia for instance, the average costs of parasites for the sheep industry per farm was estimated at US $ 7,460 annually, $ 695 of which was due to internal parasites (Beck *et al.*, 1985). Production losses (wool loss, meat loss and deaths) accounted for 82.7% of the US $ 7,460 loss, while prevention and treatment operations accounted for the remainder. In another Australian study, Gray (1987) estimated that one out of every seven bales of wool perish at point of production because of helminths. The economic losses attributable to fasciolosis of cattle in the United Kingdom have been estimated to exceed £ 50 million (Froyd and McWilliams, 1975). Earlier, Froyd (1975) had estimated that liver condemnations and poor lamb growth rates resulting from fasciolosis cost the British sheep industry more that £ 1.5 million. The Food and Agricultural Organisation (Anon, 1994) estimated that more than 300 million cattle and 250 million sheep are exposed to fasciolosis world-wide, causing economic losses amounting to US $ 3 billion per year.

A number of factors have been proposed to explain how infections with parasitic helminths can reduce returns to farmers by Barger (1982):

a) Mortality, which includes the capital cost of replacement;
b) Quantitative and qualitative reduction in live weight gain, wool growth and reproductive efficiency;
c) Increased cost of production through the requirement for anthelmintic treatments and labour involved;
d) The opportunity costs foregone by avoiding or spelling pastures known to be highly contaminated.

The two parasitic disease syndromes, PGE and fasciolosis, present major problems to livestock and their owners all over the world and different aspects of these problems, in both temperate and tropical environments, including aetiology, life cycles, pathogenesis,

epidemiology and control have been the subject of much scientific research.

1.2 PARASITIC GASTROENTERITIS OF RUMINANTS

The most important nematode genera associated with parasitic gastroenteritis in ruminants are *Haemonchus, Ostertagia, Trichostrongylus, Cooperia, Nematodirus, Trichuris* and *Oesophagostomum* (Horak and Snidjers, 1968; Hendson and Kelly, 1978; Bairden, 1991). It is generally considered that those which parasitise the abomasum (*Haemonchus, Ostertagia* and *Trichostrongylus*) are more pathogenic than those in the intestines. However, as field infections generally comprise a combination of genera, their individual, as distinct from collective, pathogenic effect on the host can be difficult to assess (Horak and Snijders, 1968). The life cycles of most genera causing PGE are similar, being direct and consisting of external and internal phases of development. The successful completion of the life cycle of the different genera of parasites is largely dependent upon climate and therefore it is not surprising that the parasite fauna in similar geographic regions are generally found to be alike. The life cycle of *H. contortus* is described as being typical of parasites causing PGE and its pathogenesis, epidemiology and control are reviewed for both temperate and tropical environments.

1.2.1 The genus *Haemonchus*

Haemonchus was first described by Karl Asmund Ruldolphi, who in 1803 recorded an abomasal parasite of sheep which he named *Strongylus contortus*. The genus *Strongylus* gradually accumulated such large numbers of different species that, towards the end of the 19th century, taxonomists created new groupings, among them being Cobb who in 1898 described the genus *Haemonchus* to accommodate Rudolphi's *S. contortus*.

More than 20 species of *Haemonchus* have been described, but only nine are now recognised as valid according to a revision of the genus by Gibbons (1979). *Haemonchus contortus* is probably the most important, parasitising sheep, goats and cattle. *Haemonchus placei*, previously regarded as a strain of *H. contortus* adapted to cattle, has recently been reported as a distinct species based on DNA analysis (Stevenson, Chilton and Gasser, 1995 and Blouin, Yowell, Courtney and Dame, 1997). Two other

species have domestic animals as their principal hosts: *H. similis* being a parasite of cattle and water buffaloes and *H. longistipes* infecting camels. The other six species have wild animals as their primary hosts.

Haemonchus contortus possesses a small buccal cavity with a slender tooth or lancet; cervical papillae are prominent and spine-like; the bursa is large especially the lateral lobes, and the dorsal lobe is small, asymmetrical and supported by a Y-shaped dorsal ray. The vulva in the female is posterior with a prominent linguiform process or vulvar flap. Males are 10-20 mm and females 18-30 mm in length. The male has an even reddish colour, while in the female, the white ovaries are spirally wound around the red intestine, producing the characteristic appearance of a barber's pole. *Haemonchus* is also commonly known as the 'Stomach-worm' or 'Wireworm' of ruminants.

1.2.1.2 **Life cycle of *Haemonchus contortus***

Haemonchus contortus females are capable of laying between 5,000 and 10,000 eggs per day and this parasite has one of the highest biotic potentials among the parasitic nematodes of ruminants (Gibbs, 1982). The eggs are passed in the faeces of the host into the environment to begin the external or pre-parasitic phase of development. The eggs, containing up to 500 cells, develop to a stage where a ventral indentation appears, before developing to the 'tadpole' and finally into the pre-hatch stage (Christie and Jackson, 1982).

After hatching, the first stage larva (L_1) emerges and undergoes a moult to give rise to the second stage larva (L_2). These first two larval stages are capable of feeding, mainly on bacteria (Gibbs, 1982), and their intestinal cells become packed with food granules. A subsequent moult results in the infective third larval stage (L_3) but, as the L_2 cuticle is retained, these L_3 are totally ensheathed. This sheath protects the larvae from harsh environmental conditions, but at the same time prevents them from feeding. The L_3 therefore rely for their survival on the stored nutrients obtained during the first and second larval periods.

The eggs require moisture, oxygen and heat for development and hatching to take place, and this phase of development has been studied by many workers. In a study of the effect of climate on the development of nematode larvae in the USA, Dinaburg (1944) found that *H. contortus* eggs failed to hatch into infective larvae when the monthly mean maximum temperature was 18.3°C regardless of the amount of rainfall. When the monthly mean maximum temperatures were 18.9°C to 28.9°C the numbers of infective larvae recovered from the field increased with the amount of rainfall. Working in the Kenyan highlands, Dinnik and Dinnik (1958) found that a diurnal fluctuation in temperature (low night temperature and high day temperature) between a mean minimum of 12.2°C and a mean maximum of 23.3°C, with at least one inch of rainfall evenly distributed over their ten day observation period, were the most favourable conditions for development of *H. contortus* from eggs to infective larvae

In laboratory experiments in Britain, Silverman and Campbell (1959) studied the effect of temperatures, representative of those in the field, on the rate of development of *H. contortus* eggs and larvae and concluded that development to the infective stage would require from two weeks in mid-summer to considerably longer than this at other times of the year. Hatching occurred at between 11°C and 14°C. These findings were confirmed by Gibson and Everett (1976) who found that climatic conditions favourable for development and hatching only occurred from July to September in Southern England. Eggs placed outdoors from January to April and October to December all failed to develop and no infective larvae were recovered from the herbage.

Factors contributing to the survival of the infective larvae of *H. contortus* have also been studied and although temperature and humidity are known to be crucial (Skinner and Todd, 1980), the micro-climate on a pasture is considered to be more important than the macro-climate (Crofton, 1952). Horak and Snijders (1968) described the 'mat' of the pasture, the part between the soil and the herbage, as being most important in supplying the larvae with a correct micro-climate which prevented desiccation and drastic alterations in temperatures. Survival of L_3 in the soil has also been reported by Al Saqur, Bairden and Armour (1982) who found that larvae of *Ostertagia* could migrate to 15 cm

below the ground surface and survive there for at least 12 months.

Infective third stage larvae show no further development until they are ingested by a suitable host and they must therefore be available on the herbage in sufficient numbers, to allow for ingestion and establishment and thus ensure continuation of the life cycle. Moisture is essential for larval migration on to the herbage (Gibbs, 1982), and in its absence the L_3 remain in the faecal pat or in the root mat until conditions are favourable. The migration of the L_3 onto the herbage, often termed 'translation,' is one of the most critical steps in allowing completion of the life cycle. From the studies of Skinner and Todd (1980) *H. contortus* infective larvae were found to be capable of migrating laterally on the ground, with over 90% moving up to a distance of 10 cm from faeces in 24 hours. Moisture and temperature were identified as the most important climatic factors associated with lateral migration with very little migration occurring during hot, dry periods.

The successful completion of the pre-parasitic phase in the life cycle of *H. contortus* is achieved best in warm and humid areas (Gibson and Everett, 1976), but because of its enormous biotic potential the parasite is capable of building up high levels of contamination as soon as favourable conditions arise in otherwise unsuitable environments.

Following ingestion by grazing animals, the L_3 exsheath in the rumen and then move to the abomasum and undergo two moults through L_4 to L_5, the early adults. This takes place in close proximity to the gastric glands. Just before the final moult the larvae develop a piercing lancet which enables them to obtain blood from the mucosal blood vessels. Adults are to be found moving freely on the mucosal surface and the prepatent period is approximately 21 days.

1.2.1.3 **Pathogenesis of haemonchosis**:

The development and effects of infection of sheep with *H. contortus* have been extensively studied. Only exsheathed larvae can mature into adults in the abomasum and

the L_3 must lose their sheath in the reticulorumen (Soulsby, 1982; Urquhart *et al.*, 1996). In a study of the kinetics of infective larval arrival into the abomasum, Dakkak, Fioramonti and Bueno (1981) found that only 40 to 60 % of ingested larvae developed into adult worms. From their work, and that of Blanchard and Wescott (1985), it appears that a considerable number of sheathed and coiled larvae, which do not develop into adult parasites, pass to the abomasum.

The arrival of exsheathed larvae in the abomasum results in a disturbance in mucosal permeability within 30 minutes and this precedes the abomasal haemorrhage observed later (Dargie, 1973). Other changes associated with the arrival of larvae include increases in abomasal pH, plasma gastrin concentration (Blanchard and Wescott, 1985; Nicholls, Lee, Adrian, Bloom and Care, 1988) and plasma pepsinogen concentration (Dargie, 1973). Gastrin concentration starts to increase two to three days after ingestion, reaching a peak between 20 and 38 days post-infection. Plasma pepsinogen concentration increases within the first week of infection. In a study of the development of *H. contortus* in goats, Rahman and Collins (1990) found that more worms established in the fundic than in the middle or pyloric region of the abomasum. By the fourth day after infection, all larvae had completed the third moult to the L_4 and by day 17 the majority were adults, females having eggs in their uteri by day 21 post infection.

The principal pathological feature of infection with *H. contortus* is anaemia. Both adults and fourth stage larvae are blood suckers (Allonby and Urquhart, 1975), and as they move they leave wounds which bleed into the abomasum. The average blood loss associated with one worm has been calculated at 0.05 ml per day (Dargie, 1973). Using radio-isotopic techniques, Dargie and Allonby (1975) investigated the development of anaemia in sheep heavily infected with *H. contortus* and demonstrated that it developed in three stages. Following initial infection, a progressive and fairly dramatic fall in packed cell volume (PCV), accompanied by a negative or low faecal egg count, was attributed directly to the blood sucking activities of the fourth stage larvae and young adults as well as a delay in the host haemopoietic response. This first stage lasted from 7 to 25 days after infection. The second stage, which lasted for 6 to 14 weeks, developed in

association with significant faecal egg counts and normal or slightly reduced serum iron concentrations and in some cases involved further reductions in PCV. Latent iron deficiency developed with the enhanced rate of red cell synthesis which now equalled the rate of breakdown and loss. The final stage was characterised by a dramatic reduction in PCV and very low serum iron concentrations and signalled the exhaustion of the host synthetic machinery due to deficiencies of iron and protein.

Albumin loss in haemonchosis has been investigated by Dargie and Allonby (1975) who found that the rate of loss in infected sheep was more than twice that of uninfected sheep. The albumin loss and the subsequent hypoalbuminaemia largely reflected blood loss into the abomasum.

The various clinical manifestations of haemonchosis are dependent upon a complex relationship involving age and nutritional status of the host and the rate and size of challenge (Allonby and Urquhart, 1975; Abbott, Parkins and Holmes, 1985). The clinical effects of haemonchosis are categorised into three syndromes, namely, acute, hyperacute and chronic and the majority of clinical cases can be grouped under these headings.

The hyperacute form is the least common but may be seen when young susceptible sheep are exposed to sudden massive infection. This results in a rapidly developing severe anaemia with dark coloured faeces due to a severe haemorrhagic gastritis; this may prove fatal during the prepatent period.

Acute haemonchosis is seen when young susceptible animals become heavily infected. The anaemia develops rapidly, leading to an increased erythropoietic response of the bone marrow, and is accompanied by hypoproteinemia and oedema followed by death. Faecal egg counts are usually high, up to 100,000 eggs per gram of faeces (epg) (Allonby and Dargie, 1973). Carcasses show generalised oedema and anaemia and 1,000 to 10,000 parasites may be present (Holmes, 1987). Although this syndrome is not commonly observed in cattle, Waruiru *et al.*, (1993a) reported an outbreak of acute haemonchosis in dairy calves in Kenya.

Chronic haemonchosis is a common syndrome which is of great economic importance. It is caused by infection with low numbers of parasites, usually 100 to 1,000 (Allonby and Urquhart, 1975). Affected animals are weak, unthrifty and emaciated. Anaemia and hypoproteinemia may or may not be severe depending on erythropoietic capacity, iron reserves and nutritional status of the host. Faecal egg counts may often be less than 2000 epg and *post mortem* findings include hyperplastic gastritis and chronic expansion of the bone marrow.

A unique observation, the self-cure phenomenon, is seen in sheep harbouring *H. contortus* where ingestion of fresh larvae, usually in the rainy season, is associated with the expulsion of the resident adult worm population. This expulsion of the adult population is considered to be due to an immediate type hypersensitivity reaction to antigens derived from the developing larvae. The hypersensitivity reaction is responsible for the observed transient increase in histamine concentration and intense mucosal oedema (Gibbs, 1982). The mechanism is, however, not generally protective although Allonby and Urquhart (1976) showed that Merino sheep having haemoglobin type A (HbAA) underwent self-cure more frequently and effectively than the more susceptible animals with haemoglobin type B (HbBB). Similar observations were made by Preston and Alloby (1979) in another flock of Merino sheep.

1.2.2 **Epidemiology of parasitic gastroenteritis**

1.2.2.1 **Epidemiology of parasitic gastroenteritis in temperate regions**

In the temperate climate of many areas of the Northern hemisphere, a mild moist spring is followed by a warmer, drier summer period, with a wet autumn which precedes the onset of the coldest part of the annual cycle, the winter. The normal grazing period for cattle is from late April to October i.e. spring through autumn. Cattle are housed during the winter.

The epidemiology of disease due to infections with gastrointestinal helminths is related to seasonal factors, especially to their effects on the ecology of the pre-parasitic stages in

the environment. During unfavourable conditions larval development may not take place, can be delayed or the larvae which develop have a poor survival rate. During favourable conditions on the other hand, development can be rapid and survival of larvae for many months is possible. Levine and Anderson (1973) have shown that when lower temperatures prevail egg development may cease though the survival of larvae already on the herbage or in the faecal pats may be enhanced. Earlier studies in the West of Scotland by Anderson *et al.* (1969) showed that, over a two year period the population of *O. ostertagi* and *C. oncophora* in calves grazed from May to October increased markedly in August, September and October. Rose (1962) and Mitchell (1969) working in England, found that eggs of *O. ostertagi* and *C. oncophora* deposited on the herbage in April, May and June appeared as infective larvae from mid-July. Thereafter the period taken for the eggs to develop to infective larvae lengthened and by September little or no development of freshly excreted eggs occurred. These studies led to the conclusion that in Britain there is only one generation of *O. ostertagi* per year with a second generation possibly occurring in some of the warmer areas. From more recent work on larval populations from grazed and ungrazed cattle pastures in South West Scotland (Bairden, Armour and McWilliam, 1985), considerable numbers of *O. ostertagi* and *C. oncophora* survived for at least 18 months on ungrazed pasture. This indicated that cattle pastures, at least in this part of Britain, are not helminthologically safe even after two grazing seasons during which cycling of the parasite has not occurred.

Studies with *O. circumcincta* in sheep (Gibson and Everett, 1971; Thomas and Boag, 1972), *T. colubriformis* (Gibson and Everett, 1967) and *H. contortus* (Connan, 1971) were conducted to investigate the epidemiology of PGE in Britain. The periparturient rise (PPR) or spring rise in faecal egg output was found to be most marked in sheep. The phenomenon is associated with the relaxation of host immunity around the time of parturition, thought to be due to changes in the lactogenic hormone prolactin. The PPR in faecal egg count has been extensively studied (Barger, 1993) and it has considerable epidemiological importance in that the high egg output of lactating ewes is the most important source of nematode infection for the susceptible spring-born lambs.

In Australia and New Zealand the studies of Anderson (1972, 1973) and those of Donald and Waller (1973) also demonstrated the seasonal nature of nematode infections in parts of these countries with a temperate climate. Work by Southcott, Major and Barger (1976) in Australia showed that for *H. contortus*, larval availability from egg deposition was rapid in summer and slow in autumn, maximum inhibition within the host occurring in larvae ingested in the winter months due to low temperatures. *Ostertagia* spp. presented a marked contrast, with curtailed development in summer and contamination in autumn producing high levels of contamination on pasture in late winter.

Field studies have shown that although grazing animals are infected by a combination of many genera of nematodes, *O. ostertagi* is the most pathogenic and economically important parasite in the temperate countries of the world (Anderson *et al.*, 1965a; Ross, 1965; Armour, 1970). Outbreaks of parasitic gastritis due to *O. ostertagi* have therefore been studied in considerable detail, especially in Britain. In cattle, outbreaks appear to be most common in young dairy calves and are usually associated with grazing on permanent calf paddocks and high stocking rates. Studies by Mitchell (1968) and Anderson *et al.* (1969) indicated that *O. ostertagi* infective larvae can successfully overwinter and these are ingested by calves grazing in the following spring.

The phenomenon of hypobiosis, where ingested larvae become inhibited in development at the fourth larval stage in late autumn, was first described by Anderson *et al.* (1965a), although it had previously been associated with the acquisition of immunity by the host during the grazing season (Urquhart *et al.*, 1962). The critical work on hypobiosis by Anderson *et al.*, (1965a) was carried out from spring through autumn on farms in the West of Scotland. In this study, it was found that a high proportion of the *O. ostertagi* ingested during autumn (September to October) became arrested at the early fourth stage, both in permanently grazed calves from May through October and in young susceptible tracer calves which were grazed for only two weeks then housed for seven to ten days to allow normally developing larvae to advance beyond the early fourth stage. It was therefore concluded that declining temperatures and not host immunity were responsible for triggering hypobiosis. In the Netherlands, hypobiosis of *H. contortus* in

sheep has been reported by Eysker (1981). In the temperate areas of New Zealand (McKenna, 1973) and Australia (Anderson, 1972) arrested *O. ostertagi* were found to accumulate in cattle and sheep in spring which corresponds climatically to autumn in the northern hemisphere.

Clearly, the accumulation of significant numbers of arrested larvae in the host often coincides with the onset of environmental conditions which are adverse to the free-living development of the nematodes (Armour, 1980). As for the actual aetiology of hypobiosis, opinion is divided: some have asserted that the effect is via the host either through its endocrine system or immunological response whilst others have suggested that hypobiosis results from a direct effect on the metabolism of the free-living stages. Experimental support for the latter theory was provided by Armour and Bruce (1974) who demonstrated the inducement of a significant degree of hypobiosis by storing infective larvae of *O. ostertagi* at 4°C for five weeks prior to infection of calves. A similar result was obtained by Eysker (1981) with *H. contortus* stored at 15°C for five weeks before being administered to sheep.

The maturation of hypobiotic larvae has an important epidemiological implication as it results in an increased contamination of the environment usually at a time when conditions are suitable for the development and survival of the free-living stages; this ensures the survival of the nematodes through to another generation but of more importance to the host is that clinical disease may ensue as a result of emergence with both *H. contortus* (Conan, 1971) and *O. ostertagi* (Anderson *et al,* 1965b; Reid and Armour, 1978). The stimuli for renewed development and maturation remains unknown.

1.2.2.2 **Epidemiology of parasitic gastroenteritis in tropical environments**

Tropical environments are characterised by periods of prolonged drought with distinct rainfall periods. Such environments exist in North Western Australia, parts of Southern USA, Africa, parts of Asia and South America. Unlike temperate regions, grazing of livestock takes place throughout the year. The prevalence of parasitic gastrointestinal nematodes in these areas is therefore largely determined by rainfall since the prevailing

temperatures are generally high enough to allow development throughout the year, although this may be temporarily curtailed under very cold or hot conditions (Roberts, O'Sullivan and Rick, 1952; Bryan, 1980). *Haemonchus* spp., *Trichostrongylus* spp., *Cooperia* spp. and *Oesophagostomum* spp. are the common genera involved in PGE in the tropics.

A study of the existing literature reveals that in many tropical countries a tremendous amount of effort has gone into identifying the species of nematodes present and much less into studying the seasonal prevalence of these infections or the ecology of the free-living larval stages. This is in contrast to the situation in temperate areas especially in Britain and Western Europe.

Studies in Australia by Roberts, O'Sullivan and Riek (1952), Forsyth (1953) and Riek, Roberts and O'Sullivan (1953) using faecal cultures, showed that *H. contortus*, *T. axei* and *O. ostertagi* were the important cattle helminths encountered in the tropical areas. Also in Australia, Winks (1968) showed that *Bunostomum phlebotomum, Cooperia punctata, Cooperia pectinata, Nematodirus* spp. and *Oesophagostomum radiatum* were also important helminths of cattle. Henderson and Kelly (1976) made similar observations in northern Australia and found *H. placei* and *Cooperia* spp. to be the most important helminths found in calves. The majority of outbreaks of clinical disease due to helminths were shown by these studies to occur during the drier and cooler months of the year (July to October). This was thought to be associated with the poor nutritive value of the pastures at this time.

In a survey based on faecal examination of calves in the North Western Cape in South Africa, Reinecke (1960) reported that *H. placei, C. pectinata, B. phlebotomum* and *Oe. radiatum* were the most common cattle nematodes while Hobbs (1961) found the same helminths plus *Trichostrongylus* spp. in the Natal Coast. Other studies, in the Transvaal Highveld, were conducted by Horak and Louw (1978) who found, using tracer calves, that *Haemonchus* spp. and *Cooperia* spp. were the most prevalent parasites with peak infections occurring between May and August. Horak (1981) used the 12 climatological

regions in South Africa to build up a checklist of the helminths of sheep and cattle present in different regions of the country.

In Nigeria the studies of Lee, Armour and Ross (1960) on seasonal availability of infective larvae to cattle in the savannah grasslands, demonstrated that the highest levels of infection with *Haemonchus* spp., *Cooperia* spp., *Oesophagostomum* spp. and *B. phlebotomum* occurred during the wet season which extended from May to September. These results were based on periodic slaughter of calves and differentiation of their worm burdens. Later, Fabiyi, Oluyede and Negedu (1979) reported an outbreak of parasitic gastroenteritis in calves four months after the onset of the dry season, *H. placei, C. punctata* and *C. pectinata* being the predominant species involved. This outbreak was associated with the maturation of inhibited larvae since infective larvae were absent from pasture during the dry season.

While the onset of arrested larval development in the temperate zones is clearly linked with the advent of cold and falling temperatures, such conditions do not prevail in tropical areas. In these areas arrested larvae can accumulate following the onset of arid conditions, and in Northern Nigeria Hart (1964) showed that arrested fourth stage larvae of *H. contortus* accumulated in cattle at the onset of dry conditions. A later study by El-Azazy (1990) in the Sharkia Province of Egypt concluded that hypobiosis did not take place in abomasal nematodes of sheep and goats in that region. In Kenya, where two wet seasons occur with a comparatively short arid period intervening, the population of arrested larvae is low (Gibbs, 1982) but evidence from recent work by Gatongi *et al.* (1998), where arrested larval development was observed in sheep in a semi-arid area in Naivasha, indicates that this phenomenon may play an important role in the epidemiology of haemonchosis in arid and semi-arid areas.

Most studies on parasitic gastroenteritis in Kenya have concentrated on the description of the helminth species involved in different parts of the country rather than on their seasonality. The most detailed work was that by Round (1962) that listed all the helminth parasites that had been recorded in different parts of Kenya, citing the references to their

first descriptions. Mango *et al.*, (1974), in a survey of slaughter houses in different parts of the country, found that *Haemonchus* and *Cooperia* were the most commonly encountered genera of nematodes in cattle. In subsequent studies by Gatongi, Gathuma and Munyua (1987, 1988) it was found that *Cooperia, Trichostrongylus, Haemonchus* and *Strongyloides* were the most common cattle nematodes in Nyeri district in central Kenya; similar results were obtained by Waruiru, Mbuthia and Kimoro (1993b) in the same area. Peak infections were found to follow the onset of the rains in March to May and September to October. From the earlier work of Preston and Allonby (1979) and subsequent studies by Maingi, Gichanga and Gichohi (1993) there is no doubt that *H. contortus* is the most important nematode of sheep and goats in Kenya.

1.2.3 **Control of parasitic gastroenteritis**

The control of PGE in ruminants is generally aimed at ensuring that the parasite populations in the host do not exceed a level compatible with economic production (Corwin, 1997). Control is usually approached in three ways: by the use of anthelmintics, grazing management and utilising host immunity. Potentially, the most efficient control may require the integration of two or all three of these approaches (Bairden, Armour and Duncan, 1991). Control strategies should also be based on the application of a knowledge of parasite life cycles, larval ecology, epidemiology and husbandry practices in an area (Brunsdon, 1980; Schroder, 1981).

Control by anthelmintic administration was not very widely practised until 1962 when the first effective broad spectrum anthelmintic, thiabendazole (Thibenzole, MSD) was introduced. Afterwards, other new benzimidazoles with a wider spectrum of activity including fenbendazole, oxfendazole and albendazole and the non-benzimidazole, levamisole became available. More recently avermectins such as ivermectin and the milbemycins have been developed and marketed.

The traditional administration of anthelmintics in order to control parasitic disease when clinical signs become obvious can require many treatments to suppress the infection (White and Fisher, 1994). In warm, humid areas where sheep are reared intensively,

frequent drenching during the peak transmission season is relied upon to control helminth disease (Craig and Miller, 1990). In Australia for example, Dash (1986) reported drenching frequencies ranging from 2 to over 12 times per year. Production losses are still possible under these circumstances where clinical disease becomes apparent before treatment is started.

In Britain and other European countries, a knowledge of the epidemiology of parasitic gastroenteritis has led to the development of systems for convenient and effective control based on the administration of anthelmintics (McKellar, 1988). For dairy calves a system of 'Dose and Move' (Michel, 1968) was developed. This method is a good example of a combination of anthelmintic treatment and grazing management for the control of helminth disease. The system involves administration of a single anthelmintic treatment in the middle of the grazing season to remove parasites already established within the host animals. Treated animals are then transferred to 'clean' pastures, either aftermath or fields not grazed by the same host species in the previous season. When clean grazing is not available an alternative strategy is to give two or three anthelmintic treatments in the early part of the grazing season in order to prevent the build-up of large numbers of infective larvae on the pasture during the grazing season and thus to prevent clinical disease (Armour, 1980).

Based on the same epidemiological knowledge that led to the development of the 'Dose and Move' system, sustained and pulse release rumen bolus systems for the administration of anthelmintics to cattle have now been developed (Jones, 1981). These techniques of continuous anthelmintic medication or pulse dosing over vital periods of contamination, such as the early part of the grazing season, offer a simple and effective method of controlling bovine parasitic gastroenteritis (Anderson and Laby 1979; Armour, Bairden and Preston, 1980; Bairden, 1991). The first commercial anthelmintic bolus was made available in 1981 (Paratect®, Pfizer Ltd.). This was a sustained release device containing 11.8g of morantel tartrate which was dispensed over 90 days, thus preventing establishment of patent infections and a build-up of infective L_3 on pasture later in the season (Armour *et al.*, 1980). Later on another delivery system (Paratect-

Flex®, Pfizer Ltd.) has been developed (Bairden, 1991) which is effective in the control of PGE. The new device is administered as a rolled up cylinder whose outer covering dissolves on contact with the rumenal fluid. It is then retained in the rumen because of its flat shape, unlike the old device which was retained because of its weight. There are now several other sustained release boluses containing ivermectin (Ivomec bolus®, Merial Animal Health Ltd.) and fenbendazole (Panacur bolus®, Hoechst Roussel Vet. Ltd.) which release drug continually over a period of approximately 135 days from the time of administration (White and Fisher, 1994).

Another preparation to be introduced was the pulse release bolus system (Autoworm bolus® system, Schering Plough Animal Health). There are three types of this bolus for cattle of different sizes but they all rely on the release of a therapeutic dose of oxfendazole at a time interval of approximately 21 days. This gives protection for a period of at least 100 days (Bogan, Armour, Bairden and Galbraith, 1987).

Although much pioneering work on intrarumenal devices was carried out in sheep, it was only much later that a controlled-release device against gastro-intestinal parasites in sheep was developed (Bell and Thomas, 1992). The work by these two authors showed that the administration of a sustained-release intrarumenal device containing albendazole (Proftril®) to ewes, suppressed the peripaturient egg rise and was thus effective for seasonal parasite control in lambs.

Criticisms of the use of intrarumenal devices have focused on the potential for the development of anthelmintic resistance due to continued exposure to the same anthelmintic, difficulties encountered in the processing of offal in abattoirs as a result of the steel remnants from boluses and long meat withdrawal periods of up to 180 days (White and Fisher, 1994).

The frequent and often indiscriminate use of anthelmintic drugs has led to the development of anthelmintic resistance (McKellar, 1988). Anthelmintic resistance to all of the major drugs has occurred, though this has been mainly in warmer and humid areas

where *H. contortus* predominates (Craig and Miller, 1990) because of multiple annual cycles of infection and frequent anthelmintic treatments. Since the early reports on resistance of *H. contortus* to thiabendazole in America by Conway (1964) and by Smeal, Gough, Jackson and Hotson (1968) in Australia, many more reports have emerged from other parts of the world (Prichard *et al.*, 1980; Van Wyk, 1990; Jackson, Coop, Jackson, Scott and Russel, 1992; Wanyangu *et al.*, 1996a; Waller, 1997). Recent studies indicate that anthelmintic resistance, involving all of the available anthelmintic groups is increasing, especially in sheep producing areas of the southern hemisphere (Edwards, Wroth, Chaneet, Besier, Kalsson, Morcombe, Morgan and Roberts, 1986; Webb and Ottaway, 1986; Njanja, 1987; Van Wyk and Malan 1988; Maingi, 1991, Maingi, Gichanga and Gichohi, 1993; Mwamanchi, Audho, Magadi, Reynod, and Baker, 1995; Wanyangu *et al.*, 1996a). Different measures, including the design of rational control programmes with limited and strategic anthelmintic treatments are being recommended in areas where resistance has developed (Waller, 1987; Maingi, *et al.*, 1993). In Australia for instance, a programme for the control of haemonchosis involving regular strategic drenching with the drug closantel, before lambing in August, after lambing in November and at weaning in February was recommended by Dash (1986). This method relied on the high efficacy and persistence of closantel against blood-feeding parasites such as *Fasciola* spp. and *H. contortus*. Closantel binds strongly to plasma proteins thereby producing residual activity. Two other roundworm control programmes for sheep, called 'Drenchplan' and 'Wormkill' were introduced in New South Wales (Waller, 1987). These involved fewer drug treatments, including the use of closantel against *H. contortus*, and were aimed at slowing down the development of anthelmintic resistance.

Grazing management systems, often referred to as integrated or clean grazing systems, include mixed grazing, alternate grazing and rotational grazing (Bairden, 1991). Although grazing management systems have been reported to have beneficial effects in reducing worm burdens (Southcott and Barger, 1975), Bairden (1991) and Bairden *et al.* (1991), in experiments involving the alternation of cattle and sheep over a four year period, indicated that this system did not prevent the acquisition of high burdens of gastrointestinal nematodes by calves grazed on the alternated pastures in the final years

of the study. Similar results were reported by Taylor, Hunt and Wilson (1991) who found that under UK conditions integrated control strategies were not completely effective in controlling *H. contortus*. They attributed the failure of these strategies to the high biotic potential of *H. contortus*. It is clear from these findings that the value of integrated systems lies in their use in combination with anthelmintic treatment as in the 'Dose and Move' system already discussed.

One application of host immunity in the control of parasitic gastroenteritis is based on the findings that some breeds of animals are more resistant to helminth infections than others (Urquhart, 1990). The resistance is manifested by a failure of the parasites to become established, the inhibition of larval stages, reduced fecundity of adult females and elimination of existing infections (Rifkin and Dobson, 1979). It may also result in stunting of worms (Smith and Christie, 1979). These manifestations arise from rapidly acquired resistance in some breeds of animals. There are many reports of differences between breeds of sheep in their abilities to resist gastrointestinal nematodes. For example, the Scottish Blackface was more resistant to re-infection than the Dorset (Altaif and Dargie, 1978) and the St. Cruix more resistant than the Florida Native, Barbados Blackbelly and Dorset (Gamble and Zajac, 1992). In Kenya, the Red Maasai was found to be more resistant to *H. contortus* than the Blackhead Somali, Dorper, Merino, Corriedale and Hampshire Down (Preston and Allonby, 1978 and 1979). In a comparison of resistance to *H. contortus* between four breeds of sheep, Mugambi *et al.* (1997) found the Red Maasai to be more resistant to both natural and challenge infection than the Dorper, Blackheaded Somali and the Romney Marsh. The Small East African goats were similarly found to be more resistant to *H. contortus* than the Galla goats (Baker, Mwamachi, Audho, Aduda and Thorpe, 1998). The current state of knowledge and the potential for exploitation of genetic variation in resistance to nematodes has recently been extensively reviewed (Woolaston and Baker, 1996; Gray, 1997). These reports indicate that there are immediate prospects for application of this technology to increase the resistance of sheep populations to parasitic nematodes. This would be an extremely valuable contribution to combat loss of production due to widespread and heavy parasite infections (Urquhart, 1990).

1.3 FASCIOLOSIS OF RUMINANTS

1.3.1 The life cycle of *Fasciola* spp.

1.3.1.1 Life cycle of *Fasciola hepatica*

The final work that led to the elucidation of the life cycle of *F. hepatica* was carried out independently by Thomas (1882) working in Britain and by Leuckart (1882) in Germany. These two workers completed an extremely long process extending over 100 years, for the full revelation of the life cycle by identifying the snail, *Lymnaea truncatula,* as the intermediate host of *F. hepatica.* The fascinating story of how this complex life cycle was elucidated was recorded in detail by Taylor (1937) and later by Reinhard (1957) and Pantelouris (1965).

The earliest references to the aetiology of liver rot or fasciolosis were based on guess work and had little foundation in fact. Adult flukes had, for many years, been observed in livers of infected hosts, but it was not until 1752 that the first record was made of any other stage in the life cycle. This was by a Dutch microscopist, Swammerdam, who, in the course of the dissection of a snail, observed what he described then as 'worms'. From the drawings he made it was later found that these were actually cercariae. The first encapsulation of cercariae in water was observed by Nitzschin in 1807, who interpreted the occurrence as 'an unusual kind of death'.

In 1800 Zeder observed the hatching of trematode eggs and the escape of the ciliated embryos into water, whilst in 1837 Creplin actually observed this happening in liver fluke eggs. The first description of rediae and the connection of cercariae with water snails was made in 1754 by Bojanns. Towards the end of the 18th century, it became recognised that some parasites divide their life-time between two or more hosts; the idea known then as 'alternation of generations'. This theory helped connect the different stages of the liver fluke for the first time.

All these facts and ideas paved the way for the unravelling of the life cycle of trematodes such as the liver fluke and for the identification of the snail intermediate hosts. The

impetus was provided by the fasciolosis epidemic of 1879-80 when three million sheep died in Britain. It was then that A. P. Thomas at Oxford was given a grant by the Royal Agricultural Society to investigate the disease. At the same time the problem was being tackled by Professor Leuckart of Leipzig in Germany. It was in 1881 that the intermediate host of *F. hepatica* was discovered and the complete life-history came to light. These findings were published in 1882 by Thomas in Britain and Leuckart in Germany. Leuckart had confused the identity of the snail intermediate host with that of *Lymnaea peregra*, so that the greater credit for the last step has been attributed to Thomas.

The work of these two scientists was supplemented by Lutz in 1892-3 who demonstrated the infectivity of metacercariae and by Sinitzin in 1914 who established the route followed by the metacercariae from the gut to the liver in the definitive host. Following the description of the different stages of *F. hepatica*, the life cycle is therefore well known and can be summarised as follows: Fluke eggs passed in faeces of infected animals develop into miracidia and hatch in about 9 days at optimum temperatures (22-26°C). The miracidium, which is motile, locates and enters the mud snail, *L. truncatula*, and multiplies through sporocyst and redial stages to produce cercariae which leave the snail and encyst on herbage as infective metacercariae. This development takes at least 5 weeks. Metacercariae ingested by grazing animals excyst and migrate to the bile ducts via the intestinal wall, peritoneal cavity and liver parenchyma to become mature flukes in 10-12 weeks. The entire cycle requires at least 17-18 weeks under temperate conditions such as those which prevail in Britain.

1.3.1.2 **Life cycle of *Fasciola gigantica***

The life cycle of *F. gigantica*, found in most of the tropics, was not fully known until 1920 when *Lymnaea natalensis* was described as its intermediate snail host in South Africa (Porter, 1920).

The adult stages of this liver fluke are found in the bile ducts of the mammalian host. These are hermaphrodite and are prolific egg producers. The eggs are yellowish brown in

colour and operculate with a clear area near the opercular end. The darker, granular egg contents are aggregated with uneven masses that completely surround the clear area. The eggs pass with the bile to the gall bladder and subsequently to the intestine and are finally deposited into the environment with the faeces of the host. The eggs in the gall bladder and intestine are at the earliest stage of development with the embryo being represented by a single cell. These single-celled eggs remain dormant while in the bile and intestine of the host and Dinnik and Dinnik (1959) have suggested that egg development at this time is arrested due to oxygen shortage in the alimentary canal.

In the external environment the egg contains an early embryo. Under favourable conditions the embryo develops further, while still within the egg to form a conical larva called a miracidium, which is covered with a ciliated epithelium and has a pointed tip at its anterior end. Hatching of the eggs is temperature dependent. Dinnik and Dinnik (1959) showed that at 26°C hatching had begun by Day 17, whilst outdoors, with temperatures varying from 10°C during the night to 24°C during the afternoon, the hatching period was spread over 52 to 107 days. These findings were confirmed by Ogambo-Ongoma and Goodman (1973). An extension of the hatching period increases the chances of miracidia encountering a suitable snail host and also reduces the possibility of high snail mortality as a result of over-infection (Dinnik and Dinnik, 1959). Hatching of the miracidia is known to occur in water and may commence in faecal pats before they dry up but the exact mechanism involved is not clear. Rowan (1957) studied the hatching mechanism of *F. hepatica* and concluded that the miracidium releases a proteolytic enzyme which dissolves the operculum bond while, Wilson (1968), working with the same parasite, concluded that light stimulates the miracidium which, after being activated, alters the permeability of the membrane on the internal surface of the egg. Hatching was also thought to be facilitated by a decrease in the size of the membrane in *F. gigantica* (Dinnik and Dinnik, 1959).

On hatching from the egg, the miracidium rotates and moves in the water by the action of its cilia. The miracidium has a short active life of only a few hours (Ogambo-Ongoma and Goodman, 1973), during which time contact and penetration of the intermediate host

must occur if the life cycle is to continue. The miracidium is attracted to the snail where it penetrates into the soft tissues. Penetration of the molluscan host by miracidia is effected by a combination of cytolysis of the snail's epithelium caused by secretions from the miracidia and suctorial activity of its blunt apical papilla (Wright, 1966; Colin, 1977). The process of penetration does not appear to cause much damage or provoke tissue reaction. Most miracidia penetrate the snail around the mantle though some penetrate through the tissues of the foot (Ogambo-Ongoma and Goodman, 1973). In the process of penetration the miracidia lose the ciliated cover and elongated shape, to become sac-like sporocysts. The sporocyst grows within the snail, developing into new and different larvae called rediae. This initial development takes place close to the point of penetration (Wright, 1966).

The rediae are motile and break free by rupturing the wall of the mother sporocyst. They then migrate to the digestive gland or 'liver' of the snail where they feed on its substance. The rediae give rise to daughter rediae each one of which is capable of repeating the process, growing and producing a further generation of rediae. There are conflicting views about the number of redial generations that take place in the life cycle. Thomas (1882) observed two redial generations during his work describing the life cycle of *F. hepatica*. Porter (1920), working on the life cycle of *F. gigantica* in South Africa, observed the same number, while Dinnik and Dinnik (1956) and Ogambo-Ongoma and Goodman (1976) observed three and four redial generations respectively. The redia gives rise to another type of larva, the cercaria. These are round with long unforked tails. They leave the snail through the pulmonary cavity and swim freely in water. Cercariae attach themselves to grass blades or other objects, lose their tails and encyst becoming metacercariae. These are the stages infective to grazing animals and are ingested with grass.

In the final host the metacercariae excyst in the small intestine (Sinclair, 1967) to release immature flukes which penetrate through the intestinal wall into the abdominal cavity. The young flukes reach the surface of the liver by swimming through the peritoneum and bore into the liver parenchyma. Although the liver is the usual organ sought by the young

flukes, there are many reports of the parasite becoming established in other locations, most frequently the lung (Sinclair, 1967; Pandit, Mir and Banday, 1991). The period of migration in the liver before the adult flukes reach the bile ducts is longer for *F. gigantica* than for *F. hepatica* (Sewell, 1966). In *F. hepatica* this period is between 5 and 6 weeks (Reinecke, 1983), the flukes reaching the main bile ducts in 7 weeks. This is in contrast to *F. gigantica* which does not reach the bile ducts until 9 to 12 weeks post infection. The migration period also varies with the host species, taking longer in larger animals than in smaller animals. The flukes reach sexual maturity and commence egg production 8 to 12 weeks after infection.

1.3.3 **Ecology of the intermediate hosts**

1.3.3.1 **Ecology of the Intermediate host of *Fasciola hepatica***

Lymnaea truncatula is the intermediate host for *F. hepatica* in the northern hemisphere (Urquhart *et al.*, 1996). It is a small snail, approximately 4-5 mm in length and occurs in both aquatic and semi-aquatic environments. These snails occur in many areas of Europe including the British Isles, Ireland and the islands in the Mediterranean (Over, 1967). Outside Europe, *L. truncatula* is reported to occur in the Ethiopian Highlands, Yemen, South Africa and Cameroon. This snail is not the only possible intermediate host for *F. hepatica* and there are a number of other snail species cited as intermediate hosts outside Europe such as *L. mweruensis* in Kenya (Dinnik and Dinnik, 1956), *L. tomentosa* in Australia, New Zealand and USA, *L. luteola* in India, *L. allula* in Japan, *L. brazieri* in Australia (Pantelouris, 1965) and *L. columella* in South Africa (Reinecke, 1983).

From studies of the habitats of *L. truncatula* in the Netherlands, Over (1967) found that these snails can exist in all soil types with temperature and humidity being the limiting factors. In Britain, snail habitats have been described by Armour (1975) as muddy soils that are slightly acidic and saturated with moisture. These include badly drained pastures, irrigation ditches, springs, broken drains, shallow ditches and water meadows. The snails reproduce by means of self fertilisation, starting at the age of five to eight weeks. According to Over (1967) one egg mass, containing 8 to 10 eggs, is laid per day with the eggs taking one month to hatch at 9°C. At a temperature of 17 to 19°C snail eggs

hatched in 17 to 22 days while at 25°C hatching took only 8 to 12 days. Snail activity is insignificant below a mean day/night temperature of 10°C (Ollerenshaw, 1959) and snail propagation in Britain therefore only occurs from spring through autumn with hibernation occurring during the winter.

1.3.3.2 **Ecology of the Intermediate host of *Fasciola gigantica***

The intermediate host of *F. gigantica* in East Africa is *L. natalensis* (Dinnik and Dinnik, 1957; Bitakaramire, 1968b; Hammond, 1970; Ogambo-Ongoma, 1971). It had been described at different times as *L. caullaudi* (Van Someren, 1946; Dinnik and Dinnik, 1954) and as *L. natalensis caullaudi* (Dinnik and Dinnik, 1955). It is possible that *L. natalensis* is the only valid intermediate host of *F. gigantica* in Kenya although a small mud snail, *Lymnaea mweruensis,* has been successfully infected with miracidia of both *F. gigantica* and *F. hepatica* by Dinnik (1956). *L. mweruensis* is believed to be the main intermediate host of *F. hepatica* and occurs in wet mud and temporary waters.

Early studies by Van Someren (1946) described suitable *L. natalensis* habitats as those with clear, permanent and shallow water with a light current. The oxygen tension of the water, reported as a limiting factor, should not fall below 75% saturation. This belief that *L. natalensis* is a true water snail occurring only in permanent water has since been dispelled by observations of these snails in temporary habitats. For example, Bitakaramire (1968a) observed the emergence of snails from a habitat that had been dry for six months. In this instance snails were observed 18 days after the start of the rains. The same author later confirmed in the laboratory that *L. natalensis* could survive in mud for at least 24 weeks following the drying up of water in an aquarium (Bitakaramire, 1968a). Additional evidence of the possibility of this snail surviving in temporary habitats was provided by Cheruiyot and Wamae (1986) who observed the emergence of snails in a seasonal stream which had dried up. Therefore it seems that a typical habitat for *L. natalensis* was not adequately described in the early literature.

The distribution of *L. natalensis* in Kenya is confined broadly to the western parts of the country around Lake Victoria and the central areas around Mt. Kenya (Cheruiyot, 1987).

There is no information on the occurrence of the snail in the coastal area of Kenya, but its spread to this and other parts of the country is likely in the future as water resources such as dams and irrigation canals are developed (Hammond, Fielding and Nuru, 1994). The snails are present throughout the year in permanent habitats though infection rates with *F. gigantica* vary markedly with the season (Wamae and Cheruiyot, 1990).

1.3.4 **Pathogenesis of fasciolosis**

The final host becomes infected through ingestion of the encysted metacercariae with herbage. Once ingested, the metacercariae are triggered by the high concentration of carbon dioxide and the bile content of the duodenum to undergo excystment (Dixon, 1966). The infectivity of the metacercariae depends not only on the climatic conditions to which they have been exposed but also on the environmental temperature during the development of the pre-cercarial stages in the snail (Harith, 1977). Sinclair (1967) reported that metacercariae which had developed at 29-32°C had a longer prepatent period in sheep (an increase from 109 to 115 days) compared with those that had developed at 23-24°C. Metacercariae which developed at these higher temperatures were also more infective for sheep than those which developed at 23-24°C. In a similar experiment, Harith (1977) showed that metacercariae of *F. hepatica* recovered from snails incubated at 27°C were more infective in rabbits than those cultured at 20°C.

There have been many studies on the pathogenicity of *Fasciola* spp. in domestic ruminants during the past 30 years. The findings indicate that pathogenicity generally depends on the number of metacercariae ingested and their infectivity (Sinclair, 1967; Pullan, Sewell and Hammond, 1970 and Ogunrinade, 1984). In all host species the most significant lesions of fasciolosis are in the liver. The host species, and hence the size of their liver, is considered to be an important factor in determining the effect on the host of a given number of infective metacercariae (Euzeby, 1973). This may partly explain the observed variation in susceptibility to *F. hepatica* and *F. gigantica* in different host species. From studies on the pathogenicity of *Fasciola* spp. in sheep, it is clear that *F. gigantica* is more pathogenic than *F. hepatica*. Hammond (1973) reported that as few as 34 *F. gigantica* in the liver resulted in the death of one sheep whilst 122 to 870 *F.*

hepatica did not kill any of ten infected sheep. The longer migration period for *F. gigantica* and its larger size are believed to be the reasons for its greater pathogenicity in sheep. In cattle, infections with either species are similar in severity (Sewell, 1966), though *F. gigantica* had been reported to be better adapted as a parasite of cattle than *F. hepatica* (Sinclair, 1967). For this reason the liver calcification and fibrosis, which are characteristic of *F. hepatica* infections are less marked with *F. gigantica* infections in the bovine host.

1.3.5 **Disease manifestations**

Two main types of fasciolosis are recognised, namely the acute and chronic forms (Sewell, 1966; Ross, 1967a and 1967b; Sinclair, 1967; Roberts, 1968; Pullan, Sewell and Hammond, 1970; Hammond, 1973). The acute disease is associated with the migration of young flukes through the liver parenchyma while the chronic form is associated with the presence of the adult flukes in the bile ducts. The acute disease in sheep has been studied more than in cattle in which it is reported to be rare (Sinclair, 1967). Roberts (1968) showed that infection with 5,000 *F. hepatica* metacercariae was necessary to elicit this acute syndrome within a period of seven to eight weeks after infection in Welsh Mountain sheep. In another study by Ross *et al.* (1967), acute fasciolosis was produced by infecting sheep with between 1,000 and 2,500 metacercariae. In more recent work on *F. gigantica* by Ogunrinade (1984), acute fasciolosis occurred in sheep infected with 1,000 to 2,000 metacercariae, with infected animals dying 80 to 90 days after infection. In these studies, goats appeared to be more susceptible than sheep as they died earlier; i.e. within 70 to 83 days after a similar infection. Earlier, Hammond (1965) had made similar observations in naturally infected sheep and goats, where goats were found to succumb to infections of lower intensity.

The clinical signs based on both natural and artificial infections in animals with acute fasciolosis, have been described by many workers. These have been observed to start from four to six weeks following infection (Sewell, 1966; Roberts, 1968; Pullan, Sewell and Hammond, 1970; Ogunrinade, 1984). Affected animals show progressive weakness, pallor of the mucous membranes and abdominal distension. This is followed by anorexia

and death. Anaemia in fasciolosis is usually normocytic and normochromic (Sewell, 1966; Ogunrinade, 1984) and becomes pronounced by the eighth week of infection. Death from acute fasciolosis can occur as early as 49 days after infection (Pullan, Sewell and Hammond, 1970) depending on the infecting dose of metacercariae.

The chronic disease occurs more commonly in cattle, in which the acute syndrome is rare (Sinclair, 1967). Under experimental conditions Ross *et al.* (1966) showed that calves could survive infections of up to 15,000 metacercariae of *F. hepatica*. The effects of chronic fasciolosis have been investigated by many workers but much of this work was based on slaughterhouse liver examinations (Froyd, 1960; Bitakaramire, 1973; Froyd, 1975; Reid and Armour, 1978; Castellino and Preston, 1979; Cheruiyot, 1983) though some work has also been carried out using experimental infections. Sewell (1966), Bitakaramire (1968b) and Hammond and Sewell (1974, 1975) described experimental work with *F. gigantica* in Africa. Infections within the range of 500 to 2,000 metacercariae in young cattle resulted in a reduced rate of growth from 10 weeks after infection (Hammond and Sewell, 1974) which coincided with the period when the flukes would enter the bile ducts. In another study, Sewell (1966) found that fluke burdens of 300 to 500 were fatal to the White Fulani Zebu cattle of Nigeria. In these animals there was weight loss and anaemia before death. The outcome of chronic fasciolosis in cattle seems to depend, among other factors, on plane of nutrition, intercurrent infections and age of the animal (Hammond and Sewell, 1973). The breed of the animal has also been thought to have some influence on the course of the disease (Wamae, Hammond, Harrison and Onyango-Abuje, 1998). In an experiment to compare production losses from chronic *F. gigantica* infection in yearling cattle, it was found that the Boran cattle suffered more severe reductions in weight gain compared to the Friesian. From 8 weeks post infection, the infected Borans had a significantly lower live weight gain than uninfected controls of the same breed as well as both infected and uninfected groups of Friesians.

1.3.6 Epidemiology of fasciolosis

1.3.6.1 Epidemiology of fasciolosis caused by *Fasciola hepatica*

Fasciolosis caused by *F. hepatica* occurs in almost all countries where the climate, in terms of humidity and temperature, favours the exogenous development of the parasite (Euzeby, 1973). The few exceptions include countries in South Eastern Asia, Far Eastern Asia, some countries in tropical Africa and Central Canada. Even in these countries, liver fluke disease still occurs as other pathogenic trematodes exist in these areas such as *F. gigantica* in Africa and Asia and *Fascioloides magna* in Central Canada (Pantelouris, 1965). For the establishment of the infection in any area there must be the initial presence of an infected final host, a suitable intermediate host and an opportunity for the final host to feed on contaminated herbage (Armour, 1975). The epidemiology of fasciolosis is therefore closely linked to factors controlling the population dynamics of the snail intermediate host. From studies of the seasonal prevalence of fasciolosis and snail ecology, Ollerenshaw (1959) described two annual cycles of infection with *F. hepatica* in Britain. The first cycle involves infection of snails in summer via miracidia from eggs deposited on pasture in spring by fluke infected animals. This infection takes at least five weeks to reach the cercarial stage and fresh metacercariae appear on the herbage from mid-August onwards. If sufficient metacercariae are ingested by susceptible grazing animals clinical fasciolosis occurs from November to March. If not ingested, a considerable proportion of these metacercariae survive the winter and are capable of infecting livestock in the following spring. A high mortality of overwintered metacercariae occurs by mid-summer.

The other cycle is known as the winter infection of snails. The snails are infected in autumn by miracidia from eggs excreted by infected animals in the late summer. Multiplication of the fluke within the snail ceases during winter hibernation but resumes in the spring and metacercariae reach the herbage by mid-summer. These are responsible for the disease experienced in June and July. Studies on the epidemiology of fasciolosis over a five year period in Northern Ireland (Ross, 1970) and over a two year period in the West of Scotland (Bruce *et al.*, 1973) indicated that the summer infection of snails was the more important cycle, resulting in clinical fasciolosis in cattle and sheep during

the winter months.

The epidemiology of fasciolosis in Australia was described by Boray (1969). It was found that most infections occurred in spring, summer and autumn. The spring infection, from overwintering metacercariae was thought to be the most important. In a study of the epidemiology of fasciolosis in cattle in southern Queensland, Baldock and Arthur (1985) found that infections were present in only two areas where conditions were suitable for the snail intermediate host, *L. tomentosa*. They concluded that fasciolosis in southern Queensland was a parasitic disease of minor importance though it caused a considerable loss of production. This was because of its restricted distribution and low prevalence of 0-2.1%.

In the central Ethiopian highlands, *F. hepatica* occurs from altitudes above 2,000 meters, *F. gigantica* at altitudes below 1,500 meters while both species exist at intermediate altitudes (Scott and Goll, 1977). From a two year epidemiological study of fasciolosis due to *F. hepatica* they found that in the Ethiopian highlands sheep were infected from August through to January. This was the period following the long rains. Graber (1978) found a prevalence of 61% in 8,500 sheep from eight provinces in the country. Studies by Njau *et al.* (1989) found that migration of snail intermediate hosts from primary multiplication sites in water-logged low-lying land and introduction from distant areas by floods could be responsible for spreading fasciolosis to well drained pasture. They also found that watering sheep in natural ponds in water-logged low-lying areas or at concrete ponds in well drained areas, had no influence in the amount of *F. hepatica* transmission. Similarly, Tembely *et al.* (1988) suggested that it was the prolonged grazing rather than brief watering in the water-logged low-lying lands and their environs that influenced *Fasciola* transmission. In an investigation of the role of husbandry practices on infection prevalence, Njau and Scholtens (1991) reported that metacercariae could survive up to three months in hay harvested from endemic highland areas. The hay is fed to livestock in arid and lowland areas during the dry season when suitable grazing pastures were scarce. Such hay could therefore serve as a vehicle to disseminate fasciolosis from endemic to non-endemic areas in Ethiopia. More recently, Yilma and

Malone (1998), using a GIS forecast model, showed that *F. hepatica* was the most important fluke species in Ethiopian livestock, with a distribution over three quarters of the country. Surplus water significantly influenced infection prevalence due to *F. hepatica* at altitudes above 1,900 m.

1.3.6.2 **Epidemiology of fasciolosis caused by *Fasciola gigantica***

The geographical distribution of *F. gigantica* is mainly determined by the distribution of the snail intermediate hosts (Malone, 1997). In the tropical areas it is transmitted by aquatic snails of *L. auricularia* group. The principal species of this group are *L. natalensis* in Africa and *L. tomentosa* in Asia (Soulsby, 1982). In most of the tropical areas, temperatures are favourable for the development of both the snail host and the parasite throughout the year (Ogambo-Ongoma,1971). In these areas, rainfall is the more important factor determining prevalence.

In West Africa, the epidemiology of *F. gigantica* infections have been studied in many countries. For example, Tembely, Coulibally, Dembele, Kayentab and Kouyate (1995) studied the epidemiology of infections in cattle in central Mali and found that animals picked up most infections from March to June, a period that coincided with the dry season. Similar observations were made in Cameroon (Asanji, 1988) and Nigeria (Schillhorn *et al.*, 1980). The prevalence in Mali has been estimated at 50% in Zebus from the Sahel area and 7% to 12% respectively for Zebu cattle from the semi-desert region (Traore and Wilson, 1988).

In East Africa, the epidemiology of *F. gigantica* has only been studied in a few regions. In an abattoir survey at Mwanza in Tanzania, Masaba, Kanyambo and Mayo (1977) found a prevalence of 7.7% amongst cattle slaughtered, while in Uganda the study by Ogambo-Ongoma (1971) observed that the number of snails harbouring cercariae increased as rainfall decreased and decreased as rainfall increased. Higher prevalence of infections in cattle were found during the dry season. Hyera (1984) found the prevalence of fasciolosis, based on condemnation of bovine livers at Iringa abattoir, to be higher during the dry season than during the rain season. In Ethiopia, *F. gigantica* was

considered important in a quarter of the country, the rest being only suitable for *F. hepatica* transmission (Yilma and Malone, 1998). The altitude range suitable for *F. gigantica* infection varied from1,455 m in the southern region and 2,563 m in the western region.

Fasciola gigantica is the most important species affecting livestock in Kenya (Dinnik and Dinnik, 1959; Bitakaramire, 1968b; Preston and Castellino, 1977). The majority of prevalence data on fasciolosis in Kenya are based on abattoir surveys (Cheruiyot, 1983; Anon, 1986; Nginyi *et al.*, 1995; Onyango-Abuje *et al.*, 1996). A major study on bovine fasciolosis in Kenya was carried out by Bitakaramire (1968b). The study involved an abattoir survey of liver condemnations due to fasciolosis for a period of 10 years (1954-1966). The study established that the prevalence of fasciolosis was highest in districts with a mean annual rainfall of over 40 inches. Based on that study, the prevalence in cattle in different districts in Kenya was grouped into three categories; low (0-10%), medium (10-40%) and high prevalence (40-90%). The prevalence figures for sheep and goats in Kenyan abattoirs were found to be low ranging from 0.3-4.4% (Anon, 1986; Nginyi *et al.*, 1995). Studies by Bitakaramire (1973) and Castellino and Preston (1979) indicated that the prevalence of infections with fasciolosis was influenced by the breed of cattle. Bitakaramire (1973) showed that the small East African Zebu had lower prevalence of fasciolosis than exotic breeds or large Zebu. Castelino and Preston (1979) also showed that Boran cattle (*Bos indicus*) had lower prevalence rates and fluke burdens than *Bos taurus* types such as Aberdeen Angus, Friesian x Boran crosses and Herefords. They further showed that the Aberdeen Angus had lighter infections than Friesian x Boran and Herefords.

From retrospective studies based on abattoir and veterinary diagnostic laboratory records, it was found that peak fasciolosis prevalence occurred one to two months following the rainfall peak (Anon, 1986). These studies concluded that there was a direct relationship between the amount of rainfall and the prevalence of fasciolosis, with the effects being delayed by one to two months. A similar association was reported by Wamae, Ihiga, Ongare and Mahaga (1990) who in a study of the epidemiology of

fasciolosis on a ranch in the Central Rift Valley in Kenya, found that the highest snail infection rates occurred in September which then declined in December; in this study September and the preceding three months had recorded very low rainfall. The majority of infections in cattle occurred in October. In a study of monthly incidence of *F. gigantica* intra-molluscan stages in *L. natalensis* in the Kenya highlands, Wamae and Cheruiyot (1990) found that the highest incidences of infected snails were encountered in the months of March, May, June and July. There were infected snails throughout the one year duration of the study, though the incidence was lower during the other months. The timing and occurrence of fasciolosis in many other regions in Kenya have not been established and efforts towards establishing this information have been recommended to enable accurate timing of strategic treatments (Anon, 1986; Maingi and Mathenge, 1995).

1.3.7 **Control of fasciolosis**

The best approach to the control of fasciolosis should involve integration of the available control methods (Armour, 1975). These include strategic medication with anthelmintics to eliminate the parasite from the host at the most convenient time for effective prevention of pasture contamination; a reduction in the number of intermediate host snails by drainage or molluscicide application and other agricultural practices such as reducing the chances of infection by efficient farm and grazing management. The basis of an effective control programme is a thorough knowledge of the epidemiology of the disease based on weather analysis and seasonal surveying of infections in both intermediate and final hosts (Anon, 1994).

The currently available drugs for use against fasciolosis belong to five chemical groupings i.e. halogenated hydrocarbons, nitrophenolic and bisphenolic compounds, salicylanilides, benzimidazoles and pro-benzimidazoles and sulphonamides (Mohammed-Ali, 1985). The pharmacology of these drugs was reviewed by McKellar and Kinabo (1991), whilst Taylor (1987) described the dose rates, efficacy data and withdrawal periods of the common commercial preparations. In the U.K., the commonly used anthelmintics are oxyclozanide, nitroxynil, and triclabendazole (Taylor, 1987). More

recently clorsulon, a sulphonamide, has been used in combination with ivermectin for treatment of cattle fasciolosis (McKellar and Kinabo, 1991). In the temperate regions, where disease due to *F. hepatica* occurs, strategic use of anthelmintics is aimed at preventing the deposition of fluke eggs on pasture in spring and summer when snail breeding is maximal (Armour, 1975). In the UK three annual treatments for sheep are generally recommended; one in October to prevent acute fasciolosis, a second one in December-January to remove adults and late parenchymal stages acquired in the autumn and a third in the spring (March-May), to remove any surviving flukes. This last treatment reduces pasture contamination at the onset of snail breeding. In young cattle (Taylor, 1987; Taylor, 1989) treatment at housing in winter is administered using triclabendazole or 6-8 weeks after housing using nitroxynil or oxyclozanide.

The establishment of the relationship between the incidence of fasciolosis due to *F. hepatica* and climate (Ollerenshaw, 1959) provided a basis on which a system of forecasting the probable incidence of the disease was developed. The first forecasting system in Britain was designed by Ollerenshaw and Rowland (1959) based on the disease incidence recorded from a veterinary investigation centre and local rainfall and transpiration data. This method enabled a forecast based on the summer infection of snails, to be made at the end of August, hence enabling necessary control measures to be put in place early enough to prevent outbreaks of disease. This formed the basis of a fasciolosis advisory service in Britain. Another system based on a recording of wet days to predict the incidence of fasciolosis was described by Ross (1970) and allowed an earlier forecast in July. More recent work in Northern Ireland on the epidemiology of fasciolosis has led to the establishment of a computerised information retrieval system including abattoir liver condemnations due to fasciolosis and meteorological data (McIlory *et al.*, 1990a). This system was later used to formulate a mathematical model that accurately forecasts the annual prevalence of fasciolosis (McIlory *et al.*, 1990b). It is possible that the system could be adopted for use in other countries where relevant abattoir condemnations due to *F. hepatica* infections and meteorological data are available. Additionally, geographical information systems (GIS) technology has provided a new tool for epidemiological studies on vector borne diseases with strong climatic

determinants. This technology has enabled the development of GIS models for estimating farm-specific risk of fasciolosis in cattle in Louisiana, USA (Malone *et al.*, 1987; Malone and Zukowski, 1992). GIS are also being applied in research and control of animal diseases in Europe and New Zealand (Gettinby and Byrom, 1991; Hadley, 1995). Recently, a GIS-based forecasting system was described by Malone, Gommes, Hansen, Yilma, Slingenberg, Snijders, Nachtergaele and Ataman (1998) for the Intergovernmental Authority on Development (IGAD) sub-region of Eastern Africa.

The most suitable methods and regimens of control for fasciolosis are unknown in many tropical areas, including Kenya, due to a lack of information on the epidemiology of the disease (Fabiyi, 1987; Maingi and Mathenge, 1995). In most instances, treatments are restricted to clinical cases or the most seriously affected herds and flocks (Mbaria *et al.*, 1995). Detailed studies on the epidemiology of fasciolosis in endemic areas where the disease causes heavy losses have been recommended in order to design cost effective control programmes (Anon, 1986; Malone *et al.*, 1998).

Different chemical substances, effective against snail intermediate hosts have been used in the past in attempts to control fasciolosis. Copper sulphate and sodium pentachlorophenate, previously recommended for snail control (Ross, Taylor and Morphy, 1970), were abandoned due to dangers of toxicity to livestock. The chemical, N-tritylmorpholine, previously recommended for control of snail hosts of human schistosomosis has been found to be effective against *Lymnaea* species. Crossland, Bennett and Cawdery (1969) working in Ireland showed that the application of N-tritylmorpholine in the spring was effective in controlling the transmission of fasciolosis in the autumn in low infection areas. Subsequent studies by Ross, Taylor and Morphy (1970) concluded that the application of this molluscicide alone was ineffective in high infection areas as this could neither completely stop snail repopulation nor infection in tracer lambs grazing on these areas.

There are few reports on the use of N-tritylmorpholine for the control of fasciolosis due to *F. gigantica*. Ogambo-Ongoma (1971) and Preston and Castellino (1977) tried the

molluscicide in reservoirs that harboured *L. natalensis* and demonstrated reductions in snail populations as well as in infection rates of cattle grazing around the reservoirs. Both these studies recommended the application of the molluscicides in the middle of the wet season when the highest numbers of infected snails were present in the habitats and the level of water in the dam was at its maximum.

The use of molluscicides involves certain hazards on the environment such as the accumulation of toxic residues in water and in soil which may have immediate or long term effects on the surrounding non-target fauna (Haroun and Hillyer, 1986). Molluscicide use may also be contraindicated in some instances since the large water bodies are important fishing areas. Furthermore the regular application of molluscicides into extensive habitats does not result in complete eradication (Ross, Taylor and Cawdery, 1970), making the need for repeated applications to maintain optimum concentrations in these habitats an expensive means of control.

Due to the limitations of conventional methods of controlling fasciolosis, molluscicides of plant origin have been investigated as substitutes to chemical molluscicides with *Eucalyptus* spp. being a good example (Hammond, 1970). The most detailed study of the molluscicidal effects of *Eucalyptus* was that by Cheruiyot, Broberg, Wamae and Wachira (1981) in which 62 different species were tested for their molluscicidal potency. The most potent molluscicidal agent appeared to be an extract from the leaves (Cheruiyot and Wamae, 1988). It was suggested by Hammond, Fielding and Nuru (1994) that when planted orientated to the prevailing winds so that the leaves fell directly into the targeted area, *Eucalyptus* trees could provide a cheap, self-delivery molluscicide for the control of fasciolosis.

There have been attempts to stimulate resistance to *Fasciola* spp. infections in different hosts with the ultimate goal of producing a vaccine. There is evidence from the literature to indicate that primary sensitisation of cattle with irradiated metacercariae of both *F. hepatica* and *F. gigantica* stimulates resistance in terms of a reduction in the number of flukes recovered from challenge infections (Boray, 1969; Haroun and Hillyer, 1986;

Yournis *et al.*, 1986). Attempts to immunise sheep in this way have only resulted in reductions in size and egg production of adult flukes and a delay in the onset of anaemia (Sinclair, 1970; Haroun and Hillyer, 1986). Although vaccination against fasciolosis may be possible in the future, control will continue, in the meantime, to rely upon the application of anthelmintic control programmes based on a knowledge of both the epidemiology of the disease in ruminants and the ecology of the snail intermediate hosts.

1.4 **Summary and objectives of the study**

The current state of knowledge on various aspects of parasitic gastroenteritis and fasciolosis in ruminants has been examined with respect to the temperate and tropical environments. The infections with parasitic gastrointestinal nematodes and liver flukes have been studied in detail in the developed, temperate countries, culminating in the application of effective control programmes, involving both anthelmintic treatments and grazing management. Farmers in these countries have access to, and can afford, the best drugs available. Additionally, weather-based forecasting systems for fasciolosis are now available in some countries such as Britain and the USA that advise farmers on anticipated times of high disease risk. These advances in the developed world have subsequently reduced the adverse effects of parasitic helminth infections in these countries.

In contrast, the epidemiology of infections with parasitic helminths is not well understood in many areas in the tropical countries in Africa, including Kenya. Parasitic gastroenteritis and fasciolosis continue to cause mortalities and lowered productivity due to inadequate and inappropriate control strategies. In the smallholder farming system, common in many parts of Kenya, farmers rely on anthelmintics alone to control helminth infections because grazing management cannot be relied on due to the small sizes of the holdings and widespread use of communal grazing. Recent surveys in different parts of the country (Kinoti *et al.*, 1994; Mbaria *et al.*, 1995; Wanyangu *et al.*, 1996a; Maingi *et al.*, 1997a) showed that the current practice employed by smallholder farmers involved haphazard use of anthelmintics, based on a three monthly dosing interval in most cases. The timing of these treatments was not based on any knowledge of the epidemiology of

the infections. This knowledge is essential for the design of cost-effective control strategies for the different agro-ecological zones in Kenya.

The present study was initiated to study the epidemiology of parasitic helminth infections in ruminants amongst smallholder farms in the central Kenya highlands with the objective of using the results from these studies to design appropriate helminth control strategies for these and other areas of the country with similar ecological characteristics. The following were the specific targets of the study:

1. To study the seasonal pattern of infections with gastrointestinal nematodes and liver flukes in ruminants in the central Kenya highlands.

2. To design control strategies for parasitic gastroenteritis and fasciolosis of sheep, goats and cattle based on the information obtained from the epidemiological study.

3. To evaluate these control strategies against the current control practices amongst smallholder farms, by conducting on-farm trials.

4. To make recommendations on the most appropriate helminth control strategies based on the epidemiological study and the intervention trials for both PGE and fasciolosis and to pass this information on to the farmers.

CHAPTER TWO

2. MATERIALS AND METHODS

2.1 Introduction

In order to achieve the objectives described in Chapter 1.4, this study was planned in three phases. These phases of the study were divided into problem identification, epidemiological investigation and testing of possible solutions and recommendation phases. These steps are briefly described below and represented schematically in Figure 1:

1) Problem identification: In order to identify the current status of helminth diseases and their control in the study area as well as the relevant management practices, local knowledge was sought from both the farmers and the veterinary extension staff. Rapid epidemiological appraisals with veterinarians and animal health assistants (AHAs) were conducted to determine the existing helminth control practices and the livestock marketing patterns. The extent of the helminth problem in the area was determined through an interrogation of the existing veterinary investigation laboratory records over the previous 10 years while the details of the various aspects of the livestock enterprise was investigated through a cross-sectional questionnaire survey involving the local farmers.

2) Epidemiological investigation: Longitudinal studies were conducted to establish the infection pattern with gastrointestinal nematodes and liver fluke in sheep and cattle in smallholder farms in Nyeri district. This was carried out through monthly monitoring of faecal egg counts of animals in 58 randomly selected smallholder farms for 20 months, pasture sampling to monitor pasture contamination with infective nematode larvae and monthly introduction of tracer lambs to monitor pasture infectivity with both nematode larvae and liver fluke metacercariae. The pasture samples and introduction of tracers continued for 36 months. Local sheep were also purchased from farms in the area to monitor infections in local animals in the smallholder farms. Based on the results from this phase of the study, two control programmes, one for gastrointestinal nematodes in

small ruminants and another for fasciolosis in cattle were suggested.

3) Evaluation of control programmes and recommendations: On-farm evaluation of helminth control strategies designed according to epidemiological information obtained from the longitudinal studies in smallholder farms was carried out and compared with the current anthelmintic control practices by local farmers. The two trials: control of PGE in small ruminants and control of fasciolosis in cattle were evaluated on the basis of parasitological as well as productivity data collected over the study period. Finally, on the basis of the results obtained from the entire study, proposals were made on the future of helminth control in smallholder farms in the study area and other parts of Kenya with similar agro-ecological and husbandry characteristics.

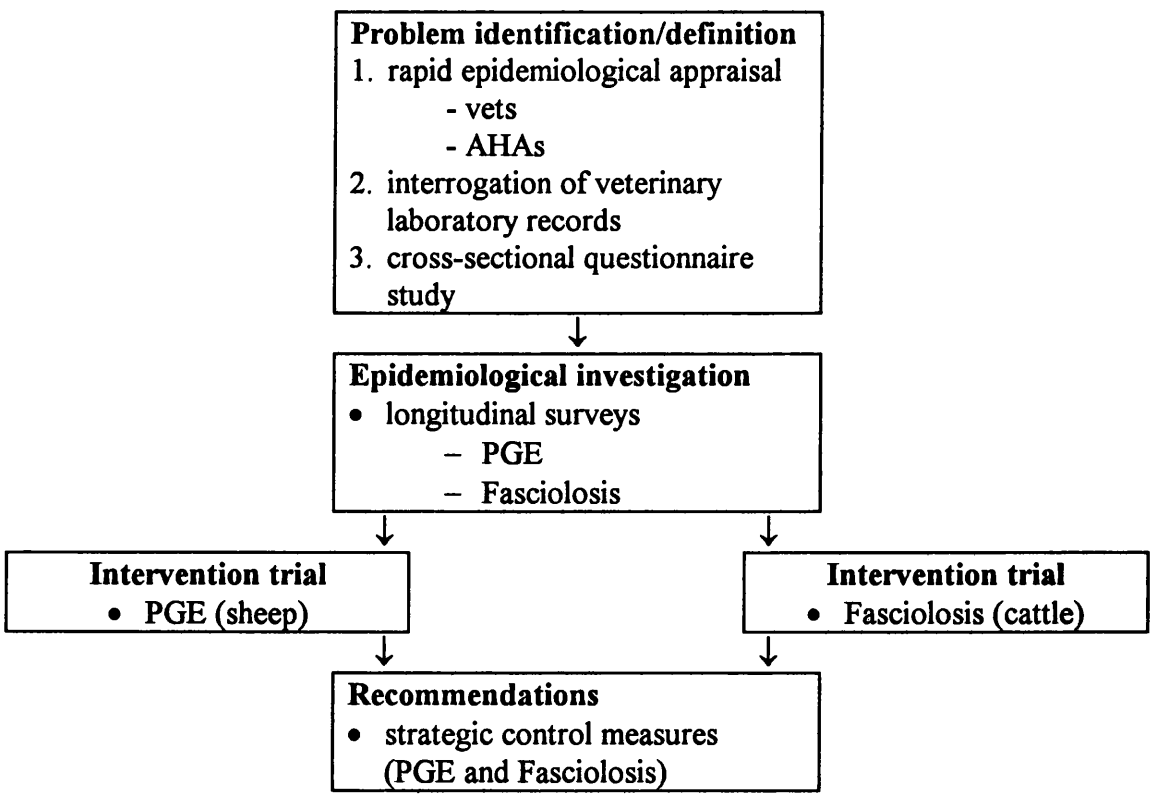

Figure 1: A schematic representation of the study design into phases i.e. problem identification, investigation, testing of possible interventions and recommendations.

2.2 Study area

The area of study was located in Mathira division of Nyeri District in central Kenya at an altitude of approximately 2,000 m. The location of Nyeri district on the map of Kenya is shown in Figure 2. This area experiences a bimodal rainfall between 750 mm and 1500 mm annually. The long rains occur between March and May and the short rains between October and December. The mean monthly minimum temperatures vary from 10°C to 15°C and the mean monthly maximum temperatures from 20°C to 25°C (Sagana State Lodge Metereological station).

The land topography is characterised by hills and valleys, with streams and rivers at the bottom of the valleys. Dams and marshy areas, which serve as communal watering and grazing grounds for livestock, are common in this area. Due to a high human population density, most of the area has been cleared of natural vegetation to accommodate farming practices. The majority of farm holdings are small with the average being under five acres.

2.3 Selection of farms

2.3.1 Selection of farms for the epidemiological study

The farms for the epidemiological study were selected along a road transect to ensure that those selected were easily accessible by a vehicle. The farms along the road transect were visited, and the numbers of sheep, goats and cattle kept on the farms were recorded. A total of 100 farms were listed by this process. This exercise was facilitated by collaboration with local AHAs because of their good rapport in their areas of operation. The list of farms (which included the number of each class of livestock kept) formed the sampling frame from which the trial farms were selected. The farms were then randomly selected using a set of random numbers generated by a calculator to give a total of 200 cattle and 100 sheep and goats. This number of animals was obtained from a total of 58 smallholder farms. The number of animals to be included was decided based on logistics, as the number of animals that could be sampled over a two day sampling period; this was the time allocated for this exercise due to the demands on resources such as transport which were shared with projects in other parts of the country. Sheep

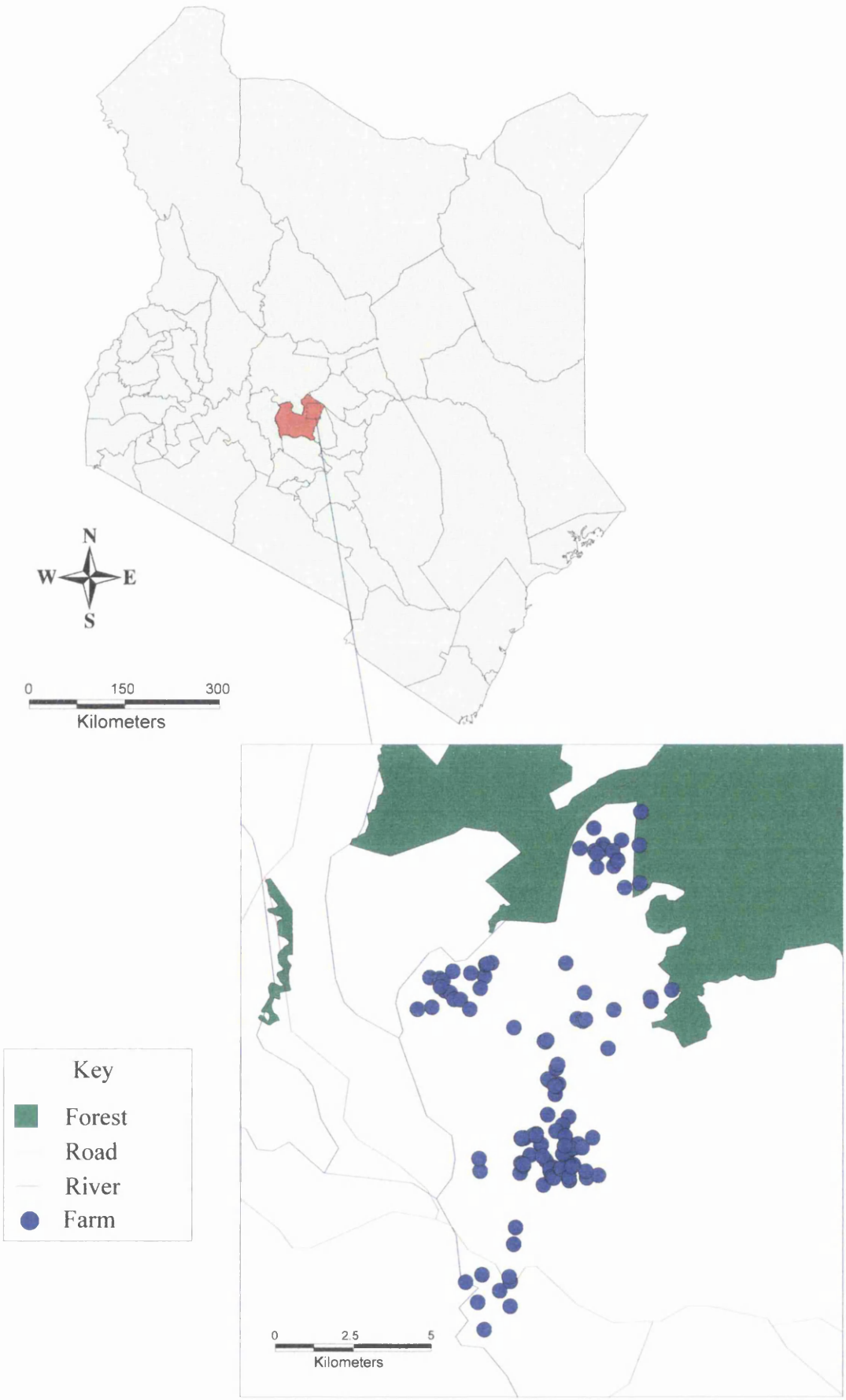

Figure 2: Map showing the location of study farms within Nyeri district, Kenya.

outnumbered goats by a ratio of 4:1. For the purpose of analyses, calves were defined as animals less than one year of age, and adult cattle as animals of one year of age or older. As for sheep and goats, lambs and kids were defined as those aged six months or younger while adults were those aged over six months. The farms were visited a second time before final selection to explain to the farmers the objectives of the study and to ascertain whether they would be able to extend the necessary co-operation.

2.3.2 **Selection of farms for the cross-sectional (Questionnaire) survey**

The farms that participated in the cross-sectional survey were selected according to the administrative boundaries. The administrative map of Kenya comprises of 8 provinces which in turn consist of districts, divisions, locations and sub-locations in that order. Numbers were allocated to all of the locations comprising Mathira division and 5 locations were selected using random numbers generated using a calculator. Similarly, sub-locations within these locations were allocated numbers and one sub-location was selected at random for each location. In each of the five sub-locations selected, lists of farmers were made using milk collection centre records of the local members of the dairy co-operative. A total of 61 farms from the 5 sub-locations were randomly selected to participate in the cross-sectional survey. These farms were identified to the research team by the local AHAs and agricultural extension staff, who also introduced the team to the farmers.

The 61 farmers were interviewed along with 55 of the farmers who had already been recruited for the epidemiological study.

2.3.3 **The questionnaire design**

The questionnaire was divided into two parts; part one dealing with farm characteristics and part two dealing with animal health aspects, including helminth control practices. These two parts in the questionnaire were then sub-divided into four sections, each dealing with specific aspects of the two broad areas as shown in Table 1 and detailed in appendix 1.

To enable accurate analysis of responses, the type of questions used varied according to the anticipated response. Where a numerical response was expected, an open ended question was asked. Semi-open ended questions were used for information about management, including drenching regimes. These offered a series of choices and in some there was an option for 'other, please specify'. In general the questions in each section were arranged in a logical order starting with specific attributes of each subject followed by the more subjective questions.

2.3.4 **Implementation**

In view of the workload involved, the assistance of one senior animal health assistant, who had been trained to administer the questionnaire, was enlisted. In each case the interviewer (the author or the AHA) entered his initials in the introduction section of the questionnaire.

Part	**Section**	**Subject covered in questionnaire**
1	A	Introduction: location of farm, farmer's details, etc.
	B	Farming enterprise characteristics
	C	Livestock management
	D	Household information
2	A	Livestock numbers and structure at time of visit
	B	Constraints to production
	C	Helminth control practices
	D	Other animal health practices

Table 1: Summary of the layout of the farm questionnaire used in the cross-sectional study showing the division into sections and sub-sections with the information sought in each.

2.3.5 **Data storage and analyses**

The questionnaire data were stored and analysed using the Epi Info version 6 (EPI 6) programme. The Epi Info Version 6, designed by Dean *et al.* (1994), is a series of microcomputer programmes for handling epidemiological data in questionnaire format. It has a series of functions such as the EPED programme, which is a word processor and can be used for creating a questionnaire or for other word processing functions. It has also the ENTER programme which produces data files automatically from a questionnaire created in EPED or other word processor programmes. This programme manages entry of data from a questionnaire into a disk file. It also allows revision of file format even after records have been entered. Using the CHECK programme Epi Info enables error checking during data entry by specifying field properties for different variables, setting ranges, legal limits and automatic data coding. The other programme in Epi Info is the ANALYSIS programme which enables data from the questionnaire to be analysed. Records can be analysed by using different commands such as frequencies, means and probabilities of true differences between different data sets. It also produces lists, frequencies, cross-tabulations and a variety of other results from the data files.

2.4 **Selection of farms for the intervention trial**

2.4.1 **Cattle trial**

A total of 84 smallholder farms (42 in the treated and 42 in the control groups) were randomly selected from the total of 116 farms that had participated in the cross-sectional survey. The selection took into consideration the number of eligible cattle per farm from cross-sectional survey data, intra-herd correlation coefficient, annual weight gain (from data obtained during the epidemiological study) and the smallest weight gain of interest (2 Kg). The number of farms required per treatment group were calculated as described by Duncan and Otte (1996) with the final sizes inflated by 20% in order to account for anticipated mortalities and withdrawals. Farmers were randomly assigned to treatment and control groups after a stratification of the farms based on management practices such as use of anthelmintics (routinely or for clinical cases), grazing systems (semi-zero-grazing or free grazing) and herd sizes. This was to ensure a uniform distribution of farms employing various management practices in the two groups. Only farms practising

free grazing or semi-zero-grazing were selected for the intervention trial, those practising zero-grazing were excluded.

2.4.2 Sheep trial

A total of 80 smallholder farms (40 in the treated and 40 in the control groups) were selected using the same principles as for the cattle trial described in above (2.4.1). In farms where both sheep and goats were present, goats were considered in the same way as sheep.

2.4.3 Mapping the location of the intervention trial farms

The locations of the farms participating in the trials were mapped using a GPS instrument (Garmin GPS45®, Garmin Corporation, Lenexa, Kansas, USA). The antenna of the device was mounted on the windscreen of the vehicle, with power cables connected to the vehicle battery. When the vehicle was parked at the gate of each farm, the grid references were read when there was coverage by at least three satellites. Care was taken to ensure that the antenna was not under any objects that could interfere with satellite reception, for example, under trees. The GPS device gave grid references, both latitude and longitude, with the manufacturer's claim of an accuracy of ± 45m as long as there was adequate satellite coverage. Before recording the locations of all the farms, the accuracy of the device was tested by using two devices to record the locations of 10 farms. This was necessary because of the concern as to whether the GPS device could distinguish the locations of some farms that were separated by relatively short distances. The readings for farm locations from the two devices were plotted and overlaid on a scanned map of the study area using MapInfo version 4.5 GIS software (MapInfo Corporation). The two sets of readings were in close agreement. The mean ± semi-quartile range of real distance between the two readings was 27 ± 20m (range 3-104m) and at this level of accuracy the identity of individual farms could not be confused.

A data set of farm locations, by latitude and longitude were produced by entering the points in Microsoft Access (Microsoft Corporation). The figures for the latitudes were entered as negative readings as required by the MapInfo programme for locations south

of the equator. The other variables such as trial status, animal numbers etc were obtained by querying tables in Microsoft Access. These data were used to map the locations of the trial farms and to show the distribution of different variables. These maps were created by overlaying points on background digitised boundary files for Nyeri district, Kenya.

2.5 **Design of data collection forms**

The data collection form was designed on one A-4 page to contain details of the individual animal as well as the monthly visits, recording all events (Appendix 2). On top of the form the name and identification number of the farmer were recorded. The individual animal details on the record form were: species, ear tag number, ear tag colour, sex, entry date (into the trial), whether born on farm, bought from another farm or acquired as a gift, birth date (estimated or true). The details of each visit were entered into columns as follows; visit date, animal weight, name and dose of any anthelmintic drug used that month, any other events (such as parturition, disease, injuries, treatments, vaccination, if absent and reason for absence), nematode faecal egg counts and liver fluke egg counts. All the forms for animals in one farm were carried in a folder which was identified by the farm identification number and trial name (sheep or cattle).

2.6 **Database for the intervention data**

A Microsoft Access database was designed to store all data from intervention trials for both small ruminants and cattle. The package was chosen for its flexibility, the ease of data entry, power of database interrogation and compatibility with other software. Within the database, forms were designed corresponding to the layout of the data collection forms to facilitate intuitive data entry. Wherever possible, information was coded to avoid time consuming typing and reduce data entry errors. Examples of this were anthelmintic names, reasons for absence of animals during visits, events recorded in the studies such as drenching and diseases encountered. Queries were designed to check data integrity and identify errors made during data entry.

Microsoft Access allows storage of data in related tables, designed by naming and specifying the properties of fields (columns) which relate to one entry in the individual

animal data collection form. There were two tables in each of the trials, one for individual animal details such as ear tag number, sex, birth date, name and identification number of the farm. The other table was used to record data from the farm visits, where animal weights, parasitological data and other events were recorded. Field properties may be specified relating to the format of data held in the field such as number, date or text. Properties were specified in some fields to limit the permissible entries as a means of reducing errors in data entry. Each record, whether animal or visit record, occupied a single row of the table with an entry in all appropriate columns. Fields common to the two tables for each trial, could be used to relate these tables for the purpose of querying across tables. Single or multiple tables could be queried by specifying criteria and writing functions to limit and aggregate the data in any desired way. Simple descriptive statistics were carried out by means of queries.

2.7 **Rapid Epidemiological appraisal**

A rapid appraisal of livestock marketing patterns, price fluctuations, current and recommended anthelmintic usage in Mathira Division, Nyeri District was carried out. It involved discussions with field veterinarians and AHAs in Nyeri district. The exercise was conducted in the form of a participatory appraisal, where probing questions were put to the participants and records made on the points agreed in the ensuing discussion. The principle of a participatory appraisal is that local people are more knowledgeable about their own circumstances. The meetings with the veterinarians and the AHAs were held separately but on the same day. A list of subjects to be covered (Appendix 3) was prepared before the meetings and were used by the facilitators to guide the discussions.

2.8. **Animals**

2.8.1 **Tracer lambs**

Tracer lambs were used to indicate the levels of pasture contamination with nematode infective larvae and liver fluke metacercariae at different times of the year. The tracer lambs were used for the entire duration of the epidemiological study and intervention trial. A decision was made to use six tracers every month after considering the logistics of ferrying them to and from the study area in a vehicle (Land Rover 110), as well as

what was considered to be suitable number (Tembely *et al.*, 1997) to reflect accurately the infection patterns. The Dorper breed of sheep was used in this study. This breed was selected because they are susceptible to nematode infections and because they are easily available in many ranches in Kenya. Kamogi ranch in Laikipia district was contracted to supply weaner Dorper lambs for use in this study. Lambs were supplied when they were approximately three months of age, to the National Veterinary Research Centre (NVRC), Muguga. They were quarantined under worm-free conditions for one month during which time they were treated with a levamisole-based anthelmintic (Wormicid®, Cosmos Ltd., Kenya). The Dorper breed was developed in South Africa by crossing the Dorset and the Blackhead Somali breed and was introduced in Kenya in the 1960s for meat production. Six of these lambs were introduced to the communal grazing areas, including roadsides, every month from March 1995 to April 1998. They grazed every day from about 8.00 a.m. to 4.00 p.m. after which they were housed overnight in a pen with a slatted floor. They had access to tap water *ad libitum* during housing whilst during the day they watered at the same dams and streams as the local flocks.

2.8.2 **Permanently grazed sheep**

Adult ewes bought from farmers in the study area were mainly Red Maasai crosses. The Red Maasai is an indigenous breed in East Africa and such cross-bred sheep are present on the majority of smallholder farms in many parts Kenya. The Red Maasai crosses were used in this study because they were the only sheep available on many farms. They were used to give an insight into the infections in the local permanently grazed sheep flocks and to help compare these infections with those picked up by the susceptible Dorper tracer lambs introduced every month. The adult ewes were purchased directly from the farmers because those available at the local livestock market often came from far away, mostly from outside the district. Adult ewes were preferred for this part of the study because they were more available for sale in the local farms than rams or young stock. The decision to use four ewes every month was based on the same considerations as the tracer lambs. These four adult sheep and the six tracer lambs were about maximum number that could be carried in the back of a Land Rover when they were ferried from the field to NVRC.

2.8.3 **Indoor maintenance at NVRC**

The sheep were fed on a mixture of grass and lucerne hay, stock pellets (Young Stock Pencils, Belfast Millers Ltd.) given as a supplement once a day and water provided *ad libitum*.

2.9 **Parasitological Techniques**

2.9.1 **Nematode egg counts**

Rectal samples, collected into labelled plastic bags, were examined using the following modification of the McMaster egg counting technique described by Gordon and Whitlock (1939). A three gram sample was weighed using a double pan balance and put into a plastic beaker containing 42 ml of tap water. The faeces were homogenised until completely broken up by rotary agitation (Whirlmixer, Scientific Industries). The suspension was then passed through a tea strainer and the filtrate collected in a bowl. The filtrate was then mixed and a sub-sample poured into a 15 ml tube and centrifuged at 1,000 RPM for five minutes. The supernatant was poured off and the pellet at the bottom of the tube loosened using a vortex mixer.

Saturated salt (NaCl) solution was added to the centrifuge tube up to the original suspension level, the contents mixed by inverting slowly six times and using a disposable pipette the chamber of a clean McMaster slide (Weber Scientific Instruments, Middlesex, England) was filled with suspension. The slide was allowed to stand on the bench for five minutes and all of the eggs under the etched area of the chamber were counted. The number of eggs recorded was multiplied by 100 based on the following calculation:

- three grams of faeces in 42 ml = one gram in 15 ml
- volume under one square = 0.15 ml
- number of eggs seen under 1 square x 100 = number of eggs in 15 ml which equals the number of eggs in one gram of faeces.

Examinations were carried out using a x250 magnification of a stereoscopic microscope and a tally counter was used to count the number of eggs present.

2.9.2 **Faecal cultures and recovery of infective larvae**

Sheep and cattle faecal samples from each farm that were positive for nematode eggs were cultured for recovery of infective larvae (L_3). The faeces were cultured separately for different host species in the farm. The bulked sheep or cattle faeces were incubated in 250 ml wide-mouthed containers at 26°C for 10 days in a compact incubator (Leec Ltd., Nottingham, England). The lids were not tightened to allow for aeration of the cultures. After the incubation period, larvae were recovered by a Baermann technique. The containers were removed from the incubator. Warm water at approximately 37°C was then added and containers left to stand for three hours after which the contents were then passed through a coarse mesh sieve (250u) or an ordinary sieve to remove the faecal material. The filtrate was passed through double milk filters (Maxa Milk Filters, A. McCaskie Ltd., Stirling) held on a Buchner funnel-conical flask assembly which was connected to a small vacuum pump (Stanhope-seta Ltd., Surrey, England). The filters were then removed and placed on the top of a urine jar in contact with warm water contained in the jar; the larvae migrated through the filters and settled at the bottom of the jar. Larvae were pipetted out and stored at 4°C in universal bottles before examination. The bottles were labelled as to the host species, name of the farm and the month the sample was taken. During examination, three ml of Lugols iodine was added to the sample in the universal bottle, which was then mixed by inverting several times and sufficient suspension transferred by pipette to an Eel counting slide. The area under the grid was examined for the presence of larvae using a x50 magnification of a stereomicroscope. A differential larval count was carried out by counting and identifying (to genus level) at least 100 larvae in each sample. Larval identification relied on morphological features as described in the Manual of Veterinary Laboratory Techniques (Ministry of Agriculture, Fisheries and Food, 1986).

2.9.3 **Trematode egg counts**

A modification of the sedimentation technique described by Boray and Pearson (1960) was used to determine *Fasciola* spp. egg counts. Three grams of faeces were weighed into a plastic tub, approximately 200 ml tap water were added and the mixture was homogenised until the faeces were completely broken up. The mixture was passed

through a tea strainer and the filtrate was collected into a plastic tub and allowed to sediment for three minutes. The supernatant was poured off, and an equivalent volume of water was added, mixed and the mixture was again allowed to sediment. Four sedimentation stages were usually necessary to clear the sample of the fine particulate matter which makes examination difficult. At the end of these stages, the supernatant was poured off to leave approximately 10 mls of sediment. This sample was examined at x160 magnification using a stereoscopic microscope. All of the *Fasciola* eggs seen were counted and recorded as the number of eggs in three grams of faeces.

2.9.4 *Post mortem* worm recovery technique

Half of each group of sheep, three tracer lambs and two permanently grazed sheep, were necropsied at three and six weeks respectively. The reason for the extended housing, beyond the pre-patent period of most gastrointestinal nematodes, was to enable easier recovery of liver flukes when they were at least six weeks old. The tracers and permanently grazed sheep were humanely killed and immediately exsanguinated. They were then opened along the ventral midline, the entire gastro-intestinal tract was removed and placed on a tray and the abomasal-duodenal junction ligatured as soon as possible. The liver and gall bladder were removed and put into a labelled plastic bag. The abomasum, small and large intestines were separated and placed into different buckets.

2.9.5 Liver fluke recoveries

The gall bladder was removed, opened in a separate container and the bile examined in a petri dish for the presence of fluke eggs and parasites using a stereoscopic microscope at x160 magnification.

After trimming off the diaphragm the liver was cut into small pieces, returned to the plastic bag and homogenised using a stomacher until completely macerated. The contents of the plastic bag were washed through a tea strainer and the retentate backwashed into a black tray. Under light, the contents were examined for the presence of immature and adult liver flukes. These were collected and counted. In the case of broken parasites, the heads and tails were counted separately. The higher of the two counts was taken as the

number of broken parasites. The presence of other parasites such as *Stilesia hepatica* and tapeworm cysts was recorded.

2.9.6 **Worm recovery from the abomasum**

The abomasum was opened along its greater curvature and the contents emptied into a bucket. The abomasal mucosa was then washed under running water into the bucket and the volume made up to two litres. After mixing, duplicate 200 ml (10%) samples were transferred to labelled honey jars. These samples were preserved by adding 2-3 ml of iodine (made by dissolving 225 grammes of potassium iodide in 160 ml boiling water, adding 125 grammes of iodine crystals and making the resulting solution up to 250 ml with water).

The mucosal lining of the abomasum was removed by scraping with a scalpel blade, put into a labelled honey jar and 250 ml warm pepsin/HCl solution were added. This was incubated at 37°C for four hours. The digest was made up to two litres and duplicate samples of 200 ml taken and fixed as above.

2.9.7 **Worm recoveries from the small intestines**

The small intestine was separated from the mesenteric attachments and opened lengthwise using gut scissors, ensuring that all the contents remained in the bucket. The cut intestine was then pulled through the fingers with the thumb rubbing along the mucosal surface to ensure that the mucus and remaining contents were retained in the bucket. The volume was made up to two litres and samples taken and preserved as for the abomasum. No mucosal digests were carried out on small intestinal samples.

2.9.8 **Worm recoveries from the large intestine**

The large intestine was opened and the contents washed into a household sieve. These were then washed under running tap water and any macroscopically apparent worms picked out and transferred to a labelled universal bottle for counting and microscopic identification. The worms were fixed by adding 1 ml of iodine.

2.9.9 **Worm identification and differential counts**

Ten aliquots each of 4 ml from the 10% samples of abomasal contents, abomasal digests and small intestinal contents were examined in a petri dish using the x160 magnification of a stereoscopic microscope. Sodium thiosulphate was added to the sample prior to examination to produce a clear background against which the stained parasites were more easily visible. Nematodes were identified by morphological characteristics such as size, mouth parts, bursal arrangement, shape and size of spicules and presence and form of vulva flaps as illustrated by Dunn (1978) and Urquhart *et al.* (1996). Speciation was carried out by transferring a selection of parasites to slides, adding cover slips and examining them in detail under a compound microscope. The different species were counted and the numbers (from the total of 40 ml) were multiplied by 50 to give the total count in two litres and hence an estimate of the total worm burden in the abomasum and small intestine.

2.9.10 **Pasture larval recovery technique**

2.9.10.1 **Collection of samples**

Pasture samples were collected from eight sites every month. In the communal grazing areas, pasture was sampled by walking in a 'W' shaped traverse of these areas, stopping every ten steps to take plucks of grass. A pluck of grass was the amount of herbage that could be grasped between the thumb and forefinger. At each stop four plucks were taken; from front right, front left, rear right and rear left. The plucks were carried in a large polythene bag which was labelled with the site identity and date of collection.

Along the roadsides samples were collected by stopping every ten steps to take plucks of grass as above. In both cases about 250 gms of herbage was collected at each site. Samples were transported to the laboratory in a coolbox for processing.

2.9.10.2 **Larval recovery, identification and counting**

In the laboratory the weight of the sample was recorded. The bag was then filled with warm water, leaving enough space to tie it, and a drop of Tween detergent was added. The bag was tied and washed by giving a total of 200 revolutions (100 revolutions in

each direction) in a Wonderwash® hand operated washing machine. The bag with the sample was removed from the machine and the washings passed through a series of 212, 150 and 38 micron sieves, care being taken that the 38 micron sieve did not clog and overflow. The grass was rinsed twice with tap water, passing the washings through the series of sieves. The grass was then taken for drying outdoors inside labelled wire mesh boxes. Once dried the dry weight of the sample was recorded.

The retentate in the 150 micron sieve was washed with a wash bottle to ensure that no larvae were trapped in the debris. This retentate was eventually discarded while that in the 38 micron sieve was washed to the side of the sieve and poured off into a beaker. The suspension in the beaker was poured through a Whatman No.113 grade filter paper using a Buchner apparatus, a milk filter placed on top and the whole inverted onto the top of a Baermann apparatus. After 12 hours the material together with the filters was carefully lifted off the Baermann apparatus and the sample left for a further one hour to settle.

A 7 ml sample was drawn off from the bottom of the funnel, transferred to a universal bottle and stored at 4°C. Prior to examination, 3 ml Lugol's iodine was added to the 7 ml sample, mixed well, and an aliquot was transferred to an Eel counting slide. A further three aliquots were counted and the mean number of larvae per ml of original sample calculated. The total number of larvae in the sample (now 10 ml) was calculated and expressed as larvae per kilogram of dry herbage as follows:

L_3 per Kg dry herbage = count x original volume (10) x 1,000 divided by the dry weight.

Larval identification relied on examination of the size of larvae, prolongation of the L_3 sheath beyond the tail of the L_2, presence of refractile bodies and other morphological characteristics as described in the Manual of Veterinary Laboratory Techniques (Ministry of Agriculture, Fisheries and Food, 1986).

2.10 Weighing of animals

All sheep, goats and calves were weighed using an electronic weighing scale (Ezi-Weigh2®, Tru-test Ltd., Auckland, New Zealand). The accompanying set of four feet (Ezi-feet®, Tru-test Ltd., Auckland, New Zealand) were fitted beneath a 1.0m x 1.5m wooden board at each farm. The size of the wooden board was designed to fit the back of a Land Rover for ease of transportation from one farm to another. The small ruminants and calves were weighed by first the operator stepping on the board, zeroing the device and then taking the animal to be weighed on the board. The device was set to give an accuracy of ± 0.5kg. The birth weights of lambs and kids were taken by the farmers using spring balances supplied to them at the beginning of the trial. The live weights of adult cattle were estimated by placing a weighing tape (Farmer's Boy®, Dalton Supplies Ltd., England) around the heart girth and reading off the weight when the animals were standing with forelegs together and the head held up as recommended by Nicholson and Sayers (1987).

CHAPTER THREE

EPIDEMIOLOGICAL AND SOCIO-ECONOMIC ASPECTS OF LIVESTOCK FARMING IN THE SMALLHOLDER FARMING SYSTEM IN NYERI DISTRICT, KENYA

3.1 INTRODUCTION

The smallholder farming system is an important component of the agricultural sector in Kenya (Omore, *et al.*, 1994). Smallholder farms in Kenya's context cover less than 12 hectares (Stotz, 1983). A distinctive feature of smallholder farms is that they are family properties and that farmers grow food crops and/or cash crops in addition to rearing livestock (Schaik *et al.*, 1996). Livestock farming is integrated with cropping activities, using crop by-products as livestock feeds and animal manure for crops. Culturally, possession of a farm is very important in Kenyan society. The farm provides a regular source of income, social security and a dwelling for the entire family.

Nyeri district is located in the highlands of Central Province of Kenya and lies in agro-ecological zones one to four (Sombrock *et al.*, 1982). The district has a livestock population of 144,100 cattle, 112,800 sheep and 47,200 goats (Peeler and Omore, 1997), the majority of which are under smallholder production. Due to the small size of farm holdings in the district, farmer co-operative groups are common, as in many other such areas in Kenya (Omore *et al.*, 1996). These provide an increased degree of commercialisation and economies of scale, especially in the smallholder dairy sub-sector (Nderitu and McLeod, 1995) which in Kenya accounts for between 75% and 90% of all milk produced (Brumby and Gryseals, 1985). Therefore, the current consensus among development planners is to direct efforts to improving productivity in the smallholder sub-sector (Gitau *et al.*, 1994a).

Systematic disease prevention and control measures, especially for tick-borne and helminth diseases, are practised by a proportion of the farmers, although the rationale for these preventive measures may not be based on epidemiological analysis of disease prevalence (Maingi and Mathenge, 1995; Mbaria *et al.*, 1995). In this regard, delivery

of appropriate helminth control strategies for both smallholder dairy and small ruminant (meat sheep and dairy/meat goats) sectors in agro-ecological zones one to four have been ranked among priority areas for research in Kenya (Mulinge and McLeod, 1998).

The objective of the study reported in this Chapter was to appraise the current importance of helminth diseases to livestock farming based on existing records at the local veterinary investigation laboratory (VIL) and the perceptions of the local veterinary extension staff and farmers. Other factors associated with livestock farming in the area, notably, farm size, grazing systems and livestock marketing were also considered. The results from this study were intended to provide useful information for the subsequent epidemiological and helminth control intervention studies.

3.2 MATERIALS AND METHODS

3.2.1 Examination of helminthological data from Karatina VIL

Karatina VIL is a regional disease investigation laboratory serving 12 districts in the central Kenya area. The majority of diagnostic cases handled by the laboratory come from Nyeri district, where the laboratory is located, and in 1996 Nyeri district submitted 78.9% of the total samples whilst 17.8% came from the neighbouring Kirinyaga district. The remaining districts contributed very few or no samples.

The laboratory day books were examined for results from sheep and cattle faecal samples which had been examined to assist in the diagnosis of suspected cases of parasitic gastroenteritis and fasciolosis. Samples from goats were not considered because they were so few in number. For parasitic gastroenteritis, mean monthly nematode faecal egg counts (FEC) were calculated for sheep and cattle for the period between January 1985 and December 1994. Cattle samples examined for *Fasciola* eggs were scored, on the basis of finding eggs in faeces, as either positive or negative. The number and percentage of cattle samples positive for *Fasciola* were recorded each month and monthly means calculated for the ten year period. These results were compared with the weather pattern for the area over the same ten-year period.

3.2.2 **Rapid epidemiological appraisal**

Separate meetings were held with veterinarians and animal health assistants (AHAs) to appraise livestock marketing patterns, price fluctuations and current and recommended anthelmintic usage in Mathira division, Nyeri district. The participants included five veterinarians (three working in the field and two from the VIL), and seven animal health assistants (four from the field and three from the VIL). The veterinarians were invited to their meeting at a visit two weeks prior to the proposed date when the venues and objectives of the meeting were discussed. The veterinarians were visited again a day before the meeting to confirm their participation. The AHAs were invited through their respective veterinary officers and those identified were again visited prior to the proposed meeting to explain the objectives of the study and to confirm the date and venue as above.

The discussions were facilitated by five research staff, three from the Epidemiology and Socio-economics Division of KARI and two from the helminthology project (including the author). The meeting with the veterinarians was held in the morning of 22nd May 1996 whilst that with AHAs was held on the afternoon of the same day; both meetings were held at the VIL. A checklist for the subjects to be covered had been prepared earlier and was used to prompt discussion by the facilitators. Notes were made on points that were agreed at these discussions.

3.2.3 **Selection of participants for the questionnaire survey**

In addition to the 55 farmers who were already participating in the epidemiological study, 61 others were randomly selected as described in Chapter 2.3.2. These 61 farmers were visited individually and it was explained that the objective of the survey was to generate data vital for the provision of improved veterinary services in the future. During this initial visit by the author and the appropriate AHA or the agricultural extension staff, a tentative appointment for an interview was made. The district veterinary officer for Nyeri and the divisional agricultural extension officer for Mathira division were briefed on the intended study prior to involvement of their staff. This was considered essential to help ensure good working relations with all of the extension staff during both this phase of the study and the subsequent proposed intervention.

3.2.4 **Questionnaire design and implementation**

The details on how the questionnaire was designed and implemented are given in Chapter 2.2.3. and 2.2.4 respectively.

3.2.5 **Data storage and analyses**

The questionnaire data were stored and analysed using the Epi Info version 6 (EPI 6) programme as described in Chapter 2.3.5

3.3 **RESULTS**

3.3.1 **VIL data**

3.3.1.1 **Sheep faecal egg counts**

Data were analysed from VIL records over a ten year period to give the mean monthly FEC for the sheep samples. These are shown in Figure 3 and the ten year mean monthly rainfall, minimum and maximum temperature for the area are shown in Figure 4. The highest mean FEC were recorded in January and December and the lowest in April and October, which were the only months where the mean fell below 1,500 EPG; high mean FEC also occurred in March and June. The sheep results could not be split into lambs and adults because the ages of the animals were not indicated in the VIL records.

3.3.1.2 **Cattle faecal egg counts**

The mean monthly FEC for cattle samples submitted to Karatina VIL over the ten year period are shown in Figure 5. The mean counts were low throughout ranging from 125 to 343 EPG. Again the data could not be split between calves and adults because the ages of the animals were not indicated in the records.

3.3.1.3 **Cattle infections with liver fluke**

The results of faecal examinations of cattle for liver fluke infection were recorded in the VIL records on the basis of presence or absence of *Fasciola*. The level of infection was indicated subjectively in most records by a scoring method, one + for few and +++++ for many eggs. This scoring was ignored and the results expressed as

monthly mean percentage of cattle found infected on examination of samples submitted over the ten year period, as shown in Figure 6. The highest proportion of infected cattle was recorded in January, August and November (30.8%, 28.5% and 28.3% respectively) followed by April and September (26.1% and 24.6% respectively). The lowest mean percentage of infected cattle was 17.7% recorded in December. The overall prevalence of liver fluke infection for the ten year period was 24.0%.

3.3.2 **Rapid Epidemiological Appraisal**

3.3.2.1 **Livestock marketing patterns**

3.3.2.1.1 **Reasons for sale, ages and weights at time of slaughter**

Table 2 summarises the views from the veterinarians and AHAs regarding livestock marketing in Mathira Division, Nyeri District. These results suggest that, in general, farmers do not sell animals according to a particular marketing strategy; rather they are sold as the need for cash arises, with the major cash expenditure being school fees. Male sheep and goats were generally sold at two years of age, weighing about 30 to 35 kg. Male cattle were often sold for slaughter as young as one year old, weighing about 150 kg. The most common reasons for sale of breeding cattle were: poor fertility, chronic mastitis or other diseases which were either expensive to treat or did not respond well to treatment. In addition, aggressive cattle were also often selected for disposal.

3.3.2.1.2 **Seasonal changes in volume of sales and prices**

It was considered that there were no significant fluctuations in the volume of cattle traded or in prices paid for cattle. Seasonal changes in the volume of small ruminant sales were believed to exist. The demand for small ruminants was seen to increase in October, mainly due to the payment of tea bonus in that month, hence the increased demand for meat as people were more able to afford it. The rise continues through November, peaking in December and January. November and December sales are for the Christmas holidays, whilst the trade in January is demand driven as farmers attempt to raise cash to pay school fees. After this there is a reduction until trade picks up again in April, due to the payment of school fees at that time. The highest

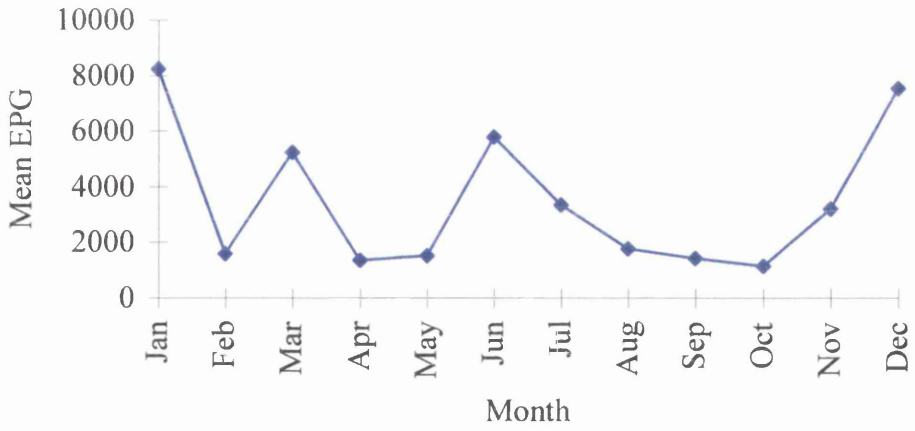

Figure 3: Ten year mean monthly FEC for sheep faecal samples submitted to Karatina VIL between January 1985 to December 1994.

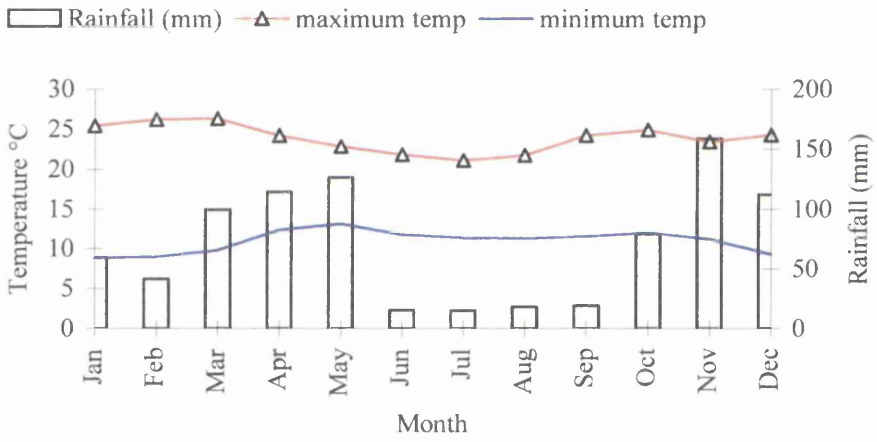

Figure 4: Ten year mean monthly rainfall, minimum and maximum temperatures for Mathira Division, Nyeri District.

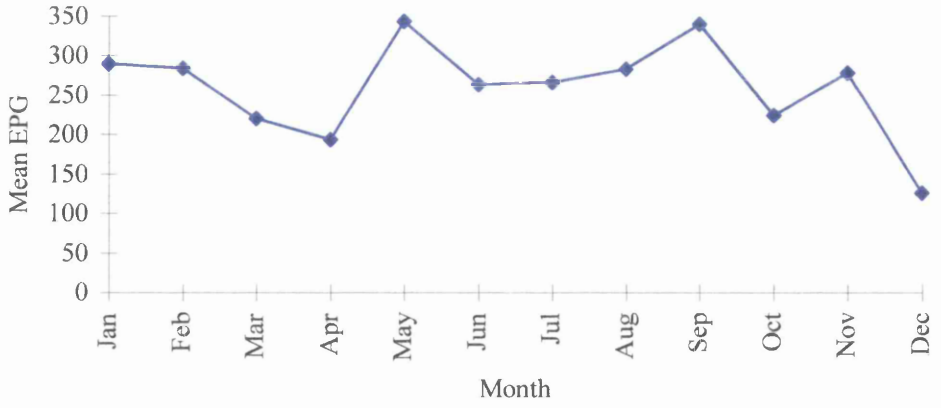

Figure 5: Ten year mean monthly FEC for cattle faecal samples submitted to Karatina VIL between January 1985 to December 1994

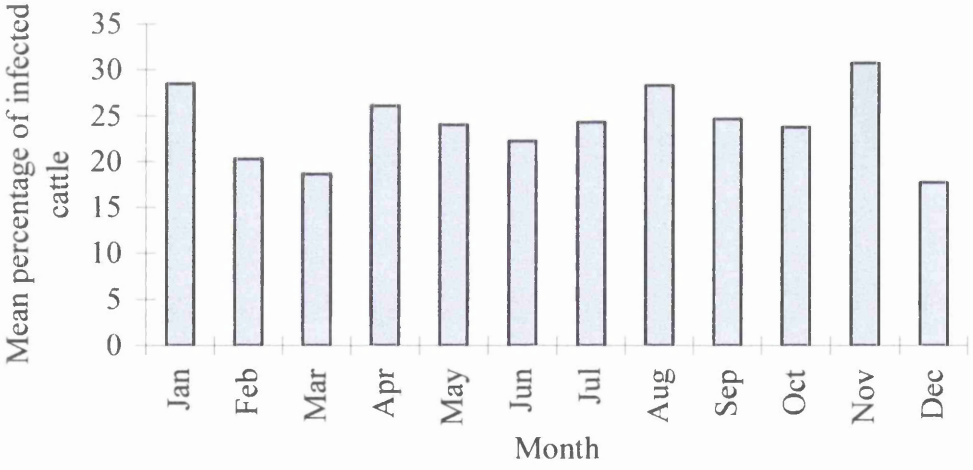

Figure 6: Mean monthly percentages of cattle infected with liver fluke from faecal samples submitted to Karatina VIL over a ten year period between January 1985 to December 1994.

prices paid for small ruminants are in November and December. The prices decline slowly from January onwards to plateau in April to September.

3.3.2.1.3 **Other factors affecting prices of livestock**

It was estimated that the price of small ruminant breeding females was two to three times the value of a slaughter animal of equivalent weight. Similarly, an in-calf heifer would be worth more that four times her slaughter value. There was thought to be a small premium paid for young animals, compared with older cull slaughter stock of all species. Dorper sheep were also thought to fetch higher prices as slaughter or breeding animals than local sheep of similar weight.

3.3.2.1.4 **Livestock markets**

Both butchers and livestock traders purchase animals at the market. Farmers may buy breeding stock at the market but prefer direct purchase from neighbours which, though more expensive, is considered more reliable in terms of getting a good animal. Occasionally, veterinarians are asked to undertake pre-purchase examinations. Prices in the market are highest in the morning and lowest late in the afternoon, because butchers need to buy early in order to slaughter the animals and sell the meat on the same day. Sellers will also accept lower prices later on in the day to avoid having to take the animals home. It was agreed that the majority of livestock slaughtered at Karatina slaughterhouse are bought from outside, principally from the ranches in Laikipia district.

Item	Views from Vets	Views from AHAs
Reason for sale of livestock	infertility chronic mastitis other diseases, school fees	as vets, plus; poor condition aggressive animals
Ages at time of disposal	2 years (sheep) 2 years (male cattle)	2-3 years (sheep) 1 year (male cattle)
Weight at time of disposal	35-40kg (sheep)	30kg (sheep) 150kg (male cattle)
Seasonal changes in volume of sales for cattle	no seasonal fluctuation	prices stable-Feb. to Nov. prices increase in Dec. and fall in Jan.
Seasonal changes in volume of sales for small ruminants	seasonal fluctuation	seasonal fluctuation
Highest demand	Oct., Nov. and Dec.	as vets
Lowest demand	May to Sept.	as vets
Highest price	Nov. and Dec.	Dec.
Lowest price	Jan. to Apr.	Jan.
Other factors affecting price:		
Breed	no premiums for breeds	premiums for Dorpers
Age	no premiums for young	small premium for young
Sex	breeding females	as vets
Livestock market		
a) source of animals	majority from Laikipia	as vets
b) Who sells	farmers, stock traders	as vets
c) Who buys	farmers, butchers, traders	as vets
d) Time for highest price	morning	as vets
e) Time for lowest price	late afternoon	as vets

Table 2: Summary results for the rapid epidemiological appraisal of livestock marketing patterns and price fluctuations in Nyeri district, Kenya, by the veterinarians and animal health assistants.

3.3.3 Helminth control practices based on the rapid epidemiological appraisal

3.3.3.1 Current control strategies practised by farmers

Table 3 summarises the views from veterinarians and AHAs with regard to helminth control practices by farmers in Mathira Division, Nyeri District. Farmers were mainly concerned about helminth infections in their cattle. The majority of faecal samples submitted to the VIL for examination for parasites were from cattle, reflecting a greater willingness to spend money on cattle health than on small ruminants. Since many farmers were dependent on the sale of milk as a regular cash income they were willing to drench lactating females if the milk yield fell, disregarding recommended milk withdrawal periods. If cash to purchase drenches for the entire herd or flock was a problem, farmers would generally treat their animals in the following order of preference: milking cows, other cattle, adult small ruminants and young small ruminants. Normally little attention was given to sheep and goats so long as they were alive and the majority of the participants thought that only about 15% of farmers routinely drenched their small ruminants, the remainder only treating individual sick animals.

Current practice for farmers who routinely drenched their animals was to treat every three months, but there was no rationale behind the timing of these treatments. It was agreed by all participants that dosing with anthelmintics was the only helminth control strategy practised in the area. The majority of the farmers bought anthelmintics from pharmacies and agro-chemists and dosed the animals themselves. The commonest packages were single adult cattle dose bottles and it was thought that under-dosing was common due to underestimation of animal weight which was assessed based entirely on visual appraisal. Only a small proportion of farmers would call a veterinarian or AHA to drench their animals. These veterinarians and AHAs purchased their anthelmintics from the same chemists/agro-chemists as the farmers, but usually in greater quantity.

Generally, it was thought that farmers would buy the most expensive anthelmintic they could afford. The most common anthelmintic brands used in the area were given as Wormicid® (1,5% levamisole, Cosmos Ltd), Valbazen® (10% albendazole, Kenya

Swiss Ltd), Nilzan-plus® (1.5% levamisole and 3.0% oxyclozanide, Cooper Animal Health, Kenya) Fasinex® (10% triclabendazole, Kenya Swiss Ltd) and Ranide® (rafoxanide).

3.3.3.2 **Adoption of new control strategies**

Both veterinarians and AHAs thought that farmers would be prepared to change worming strategies. Good relations existed between farmers and vets/AHAs, and it was thought they represented the best way to channel new recommendations to farmers. The participants also considered themselves very open to changes with regard to advice on parasite control strategies.

3.3.4 **Results of the cross-sectional study**

3.3.4.1 **Farm characteristics**

Characteristics of the participating farms are summarised in Table 4. The mean sizes of all the farms (55 farms that were participating in the epidemiological study and 61 that were selected later for the cross-sectional study) was 3.67 acres, with individual farms ranging from 0.8 to 17.2 acres. All farms practised mixed farming (livestock and crops) and 40.5% reported livestock as the most important for cash income. The majority of farmers kept grade cattle, sheep and goats.

3.3.4.2 **Grazing management practices**

The distribution of grazing management practices for sheep, goats and cattle among the participating farms are listed in Table 5. Only a small proportion of livestock were zero-grazed, the majority being either on a semi-zero-grazing system or free grazing. Semi-zero-grazed animals were partly stall-fed with forage and partly grazed on pasture. Overall, a lower proportion of goats were free grazed and a higher proportion zero-grazed compared with sheep and cattle.

Category	Views from Vets	Views from AHAs
Treatment frequency	every 3 months	as vets
Timing of treatment	not specific	as vets
Animals treated in order of preference	lactating cows other cattle small ruminants	as vets
Proportion treating routinely		
cattle	majority	as vets
small ruminants	minority	as vets
Proportion treating sick animals only		
cattle	minority	as vets
sheep	majority	as vets
Source of advice	chemists vets/AHAs	chemists agricultural shows adverts, vets/AHAs
Common advice by vets/AHAs	FEC prior to treatment	every 3 months
Common brands of drenches used	Valbazen® Wormicid® Nilzan plus®	Fasinex®, Wormicid® Nilzan plus® Ranide® ,Valbazen®
Cost of a dose of anthelmintic (valbazen®)		
Adult cow	Ksh. 150	Ksh. 120
Calf (6 months old)	Ksh. 60	Ksh. 30
Adult sheep/goat	Ksh. 20	Ksh. 10-15
Possibility of adoption of new control strategies by:		
Farmers	Good	Good
Vets/AHAs	Good	Good

Table 3: Summary results of helminth control strategies practised in Nyeri district from the rapid epidemiological appraisal by veterinarians and animal health assistants.

Variable	Mean
Acreage farmed (acres)	3.67
Number of animals kept per farm:	
Sheep	4.10
Goats	2.79
Cattle	3.88
Percentage of farms keeping:	
Zebu cattle	2.6
Grade cattle	94.0
Sheep	56.3
Goats	42.0
Rabbits	12.9
Pigs	1.7
Chicken	83.4
Bees	7.0

Table 4: Summary of farm characteristics in all the farms that participated in the cross-sectional study. All figures are means.

Type of livestock	Zero grazing	Semi-zero grazing	Free grazing
Sheep	9 (13%)	24 (34%)	37 (53%)
Goats	15 (30%)	18 (36%)	17 (34%)
Cattle	12 (10%)	37 (31%)	70 (59%)

Table 5: Number and percentage of farmers practising different grazing systems for each of the livestock.

3.3.4.3 **Off-farm (communal) grazing**

The proportions of farms practising off-farm or communal grazing for sheep, goats and cattle are shown in Table 6. Figure 7 shows dairy cattle grazing on one of the farms while Figure 8 shows cattle in one of the communal grazing areas. The communal grazing areas included roadsides, open ground around dams and rivers, edges of the forest and other public reserve land. On average, 10% of the farmers practised off-farm grazing throughout the year. The majority of sheep and cattle were grazed off-farm at one time or another, though this was not the case with regard to goats, which were grazed exclusively in the farms in the majority of the times. Figure 9 shows local sheep grazing on a smallholder farm whilst Figure 10 shows a communal grazing area commonly grazed by local sheep and cattle.

3.3.4.4 **Helminth control practices by farmers**

All farmers keeping all three classes of ruminant livestock used anthelmintics (Table 7). The majority (80%) used anthelmintics routinely for prevention while the remaining proportion (20%) used them only to treat clinical cases. All the anthelmintics used by farmers were supplied by either animal health personnel (veterinarians and AHAs) or chemists/agro-chemists, with the former supplying the majority as shown in Table 8. The majority of the farmers in the two groups of farms relied on veterinarians and AHAs for advice on which brand of anthelmintic to use with a smaller proportion receiving this advice from the pharmacies/agro-chemists.

3.3.4.5 **Frequency of anthelmintic usage**

The frequency of anthelmintic usage, given as the number of anthelmintic treatments given to various classes of livestock in the previous 12 months, is shown in Table 9. In all the animals, anthelmintic medication started after weaning, with the highest frequency of anthelmintic treatment being reported in grade cattle as compared to Zebu cattle, sheep and goats. The anthelmintic usage amongst sheep and goats was similar, with frequencies ranging from one to four treatments as compared to adult grade cattle where the range was one to eight treatments in 12 months.

Figure 7: Dairy cattle on a farm that practises on-farm grazing only.

Figure 8: Dairy cattle on one of the communal grazing areas.

Figure 9: Local sheep on one of the farms in the area.

Figure 10: A communal grazing area used by local sheep and cattle.

Livestock type	Frequency of off-farm grazing			
	Always	Majority of days	Minority of days	Never
Sheep	7 (10%)	21 (30%)	11 (16%)	31 (44%)
Goats	5 (10%)	10 (21%)	6 (12%)	28 (57%)
Cattle	12 (11%)	29 (26%)	22 (20%)	44 (43%)

Table 6: Number and percentage of farms practising off-farm (communal) grazing for different classes of livestock.

Type of livestock	Category of anthelmintic usage		
	Never use	Only for sick	Routinely
Sheep and goats	0	17(20%)	68 (80%)
Cattle	0	22 (20%)	89 (80%)

Table 7: Anthelmintic usage by farmers showing the number and percentage of farmers using each category for different livestock species.

Variable	Number of farmers and percentage
Sources of anthelmintics:	
Vets/AHAs	62 (55%)
pharmacy/Agro-chemists	50 (44%)
Other sources	1 (1%)
Criteria for choice of anthelmintic:	
Price	6 (5%)
Advised by Vets/AHAs	78 (69%)
Advised by chemist/Agro-chemists	22 (22%)
Other criteria	4 (4%)

Table 8: Number and percentage of farmers who obtained anthelmintics from different sources, showing the criteria for the choice of particular brands of drug.

Age category	Type of livestock			
	Zebu cattle	**Grade cattle**	**Sheep**	**Goats**
Sucking	0	0	0	0
Weaned	2.5 (2-3)	3.5 (1-4)	3.3 (1-4)	3.3 (1-4)
Adults	3 (2-4)	3.5 (1-8)	3.3 (1-4)	3.2 (1-4)
No. of farms	3	39	19	18

Table 9: Anthelmintic treatments given to different types of livestock in the previous 12 months showing the mean and (range) for each age group.

3.4 DISCUSSION

This study relied on retrospective investigations as well as cross-sectional surveys. These had the advantage of enabling the generation of data rapidly and at low cost. The study was intended to provide the preliminary information required for more detailed follow-up longitudinal investigations. The results from examination of VIL diagnostic records showed the levels of infection with helminths amongst sheep and cattle whose samples were submitted to the laboratory over a ten-year period. One of the main values of laboratory records is usually to reveal the flock/herd problems which are a source of concern to farmers and veterinarians in areas served by the laboratory. This is because only the clinically sick or unthrifty proportion of the animal population are sampled. It was, however possible to relate the results directly to Nyeri district because, in practice, the Karatina VIL received most of its samples from this district, although it was a regional laboratory. From the results of this investigation, it was obvious that helminth diseases such as parasitic gastroenteritis in sheep and fasciolosis in cattle, were important concerns to farmers in Nyeri district. The data from the VIL were from animals suspected by the owners or the animal health personnel to be suffering from helminthoses. The samples were therefore not representative of the animal population of the area, because apparently healthy animals are not normally sampled. Therefore, it was not surprising that the results from both gastrointestinal nematodes and liver fluke egg counts did not show any seasonal trends. However, the results served to demonstrate the existence of disease caused by these parasites in livestock in Nyeri district.

From the appraisal of livestock marketing it was evident that due to the size and nature of the local farming enterprises, most animals, with the possible exception of dairy cattle, were kept more as a means of saving than as a commercial enterprise. In general, no structured production and marketing strategy, with targets for age and weight at off-take, was followed. Instead, livestock sales were related to specific cash demands rather than to a particular marketing plan. It was therefore in the farmers' interest to maintain their herds/flocks in such a way that sufficient healthy animals could be selected for sale when such a need arose. It was not surprising that in an attempt to maintain healthy animals anthelmintics were widely used, as they are in most other smallholder farming areas in Kenya (Kinoti *et al.*, 1994). The three

monthly treatment regime observed in this investigation was similar to that reported by Kinoti *et al.* (1994) in a study on the sale and use of anthelmintics in some other parts of Kenya. Mbaria *et al.* (1995) and Maingi *et al.* (1997a) also found that the same regime was adopted for deworming sheep and goats in Nyandarua and Nakuru districts respectively. However, in all of these areas the timings for the treatments were not related to particular months of the year, or any epidemiological information of helminth diseases in these areas. They were therefore considered to be largely ineffective (Mbaria *et al.*, 1995) in the control of the parasitic infections and hence a waste of farmers' money. It was also apparent that most of the anthelmintics used in the treatment of cattle could not be justified in view of the low levels of helminth infection observed, with the possible exception of farms in areas where fasciolosis was endemic. There was evidence of underdosing of small ruminants due to the inaccurate estimation of live weights of animals by visual appraisal. Farmers were not following the recommendation that sheep or goats should be dosed according to the heaviest in the group (Reinecke, 1980). Studies in Australia have shown that anthelmintic resistance, especially in *Haemonchus contortus,* was significantly greater on farms that used visual estimation as a basis for dose calculation than on those where sheep were dosed according to the heaviest in the group (Edwards *et al.*, 1986). Such underdosing is likely to increase the selection pressure for anthelmintic resistance in farms in this area.

The cross-sectional survey showed that farm sizes and flock/herd sizes in the study area were typical of the smallholder farming system in Kenya (Stotz, 1983; Gitau *et al.*, 1994; Schaik *et al.*, 1996). Sheep, goats and cattle were kept in a majority of the farms in addition to cultivation of various cash (mainly tea and coffee) and food crops. A higher proportion of the livestock were kept at pasture with supplementary feeding of planted forage than were zero-grazed. Equally, a higher proportion, with the exception of goats, were grazed communally outside the farm compared with the number which remained entirely on-farm. These grazing practices had important implications on the potential to acquire helminth infections and the formulation of possible control strategies for livestock in the area. An obvious implication was that most farmers could not adopt any grazing management practices as an adjunct or alternative to anthelmintics in the control of helminthoses because the grazing areas,

including the watering places, were used by many animals from different farms. This was supported by the observation that the only local helminth control practices involved the routine use of anthelmintics. The development of any epidemiologically based strategic measures would require to be adopted by the majority of farmers in any area for it to have an impact in reducing pasture contamination in the communal grazing areas. This would, in turn, depend on effective and well focused extension messages to ensure a high adoption rate. The concept of routine treatment for parasite control was found to already exist amongst the majority of farmers in the study area unlike in other districts such as Nakuru where only three out of 32 farmers were found to be deworming routinely to control helminths (Mbaria *et al.*, 1995). The anthelmintic treatment frequency was highest in adult grade cattle, with some farmers treating up to eight times a year as compared to sheep and goats which were treated up to four times a year. These results from the cross-sectional survey supported the findings from the rapid appraisal with animal health workers and were also comparable with those reported by Maingi *et al.* (1997a) in Nyandarua district. From the results of this survey it was apparent that basic information on the local epidemiology of the important helminth infections was missing and the acquisition of this information would enable the development of effective control programmes. This justified the need for an epidemiological study to establish the infection patterns of parasitic gastrointestinal nematodes and liver flukes. The results from such a study could be the basis for the design of effective helminth control strategies for different hosts and sites which were appropriate to the local farmers. In view of the role played by veterinarians and AHAs both as sources of drugs and advice to the farmers, it would be important that any new recommendations on worm control were passed on to the farmers through them.

CHAPTER FOUR

EPIDEMIOLOGY OF PARASITIC GASTROINTESTINAL NEMATODE INFECTIONS OF RUMINANTS ON SMALLHOLDER FARMS IN CENTRAL KENYA.

4.1 INTRODUCTION

Domestic ruminants are of great importance to many people in tropical areas, providing valuable protein for the human population and occupation for many families engaged in different aspects in the livestock industry (Fabiyi, 1987). There are therefore many benefits to be derived from increased production, both in terms of human welfare and for national economies, by reducing losses as a result of disease. Diseases caused by helminth infections result in major economic losses in sheep, goats and cattle in many parts of the tropics (Allonby and Urquhart, 1975; Fabiyi, 1987; Carles, 1992). In the high potential areas of Kenya, where ruminant livestock are kept on pasture throughout the year (Maingi *et al.*, 1997a) and climatic conditions are favourable for the development and survival of their free living stages (Dinnik and Dinnik, 1961), infections with parasitic nematodes are very important as a limiting factor to production. This problem, in turn, might be exacerbated by additional factors such as management practices and nutritional stress. In smallholder farms the situation is further complicated due to limitations of land and other resources. For example, communal grazing and watering places are very common in these areas and may be major sources of helminth infection for animals. This is due to a combination of over stocking associated with these areas and the fact that helminth control is not co-ordinated, with farmers deworming their animals at different intervals and with different anthelmintic preparations (Mbaria *et al.*, 1995; Wanyangu *et al.*, 1995; Maingi *et al.*, 1997a). With increasing population pressure on farm holdings the problem of overstocking is now occurring within farms. The resultant increased infection pressure by gastrointestinal helminths is more serious in small ruminants which tend to suffer more from acute disease, particularly haemonchosis (Chapter 1.3.2). Chronic helminthosis is more widespread and probably of more significance in all grazing ruminants because of its insidious effects which reduce weight gains, milk

yield, wool production and carcass quality especially in situations where nutrition is poor (Fabiyi, 1987).

Infection with gastrointestinal nematodes has been extensively studied in many developed countries, especially in Europe, America and Australia, and appropriate times for anthelmintic intervention have been determined for specific regions. This is not so for many tropical areas, especially those in Africa. Treatment regimes are often based on extrapolation of findings from studies carried out elsewhere, and may therefore be ineffective due to differences in ecological parameters and management practises that exist between different areas. Appropriate information about a given agro-ecological area and the local farming practices are critical issues for consideration for an effective control regime (Gatongi, 1995). This study was devised with the objective of establishing the infection pattern of gastrointestinal nematodes in smallholder farms in a high potential area in the highlands of central Kenya. Due to the small size of the holdings and the limited resources in this area, these farmers have unique problems in the management of helminthoses compared with large scale farms with greater resources. The other aim of the study was to use the information obtained to design appropriate strategic intervention measures not only for this area but for other parts of the country with similar ecological and husbandry characteristics.

4.2 MATERIALS AND METHODS

4.2.1 Study farms

There were 58 smallholder farms in this study, on which there were usually a total of approximately 200 cattle, 120 sheep and 30 goats. All the farms were located in Mathira division of Nyeri district in Central Province, Kenya. The details on how the farms were selected are given in Chapter 2.3.1. The cattle were all grade animals (exotic or exotic-crosses), while the sheep were of the local Red Maasai type and the goats were generally of Small East African type.

4.2.2 Study design

The monthly monitoring of nematode infections in sheep, goats and cattle in the smallholder farms was carried out between March 1995 to October 1996. After the examination of faecal samples for nematode and trematode eggs, those samples from each host species (i.e. sheep, goats and cattle) on individual farms that were positive for nematode eggs were pooled and cultured. A differential count was carried out on a minimum of 100 larvae harvested from these samples. In addition, herbage samples which were collected from eight sites in the study area, were processed, larvae harvested, differentiated and expressed as number of infective larvae per kilogram of dry herbage (L_3/kg DH).

Tracer lambs were introduced monthly for 18 months, from May 1995 to October 1996. Local permanently grazed sheep were purchased monthly for 16 months, starting from July 1995 to October 1996. Each month the tracer lambs which had grazed for the previous month together with the permanently grazed sheep, were transported to NVRC and housed. Half of each group of sheep, three tracer lambs and two permanently grazed sheep, were necropsied at three and six weeks respectively and differential worm counts carried out. The reason for the extended housing, beyond the pre-patent period of most gastrointestinal nematodes, was to enable easier recovery of liver flukes when they were at least six weeks old. The results from the fluke component of the study will be reported in Chapter 5. The parasitological data were examined in conjunction with weather data from Sagana State lodge meteorological station, which is within the study area.

4.2.3 Tracer lambs and permanently grazed sheep

The use of young tracer lambs and purchased adult permanently grazed sheep to monitor the pattern of parasite infections in this study are described in Chapter 2.8.

4.2.4 Parasitological methods

The parasitological methods used in this phase of the study are described in Chapter 2.9

4.2.5.Statistical analyses

Mixed model repeated measures analysis of variance was used to test the effects of various factors on the observed patterns of parasite infection. The analyses were carried out in the Mixed and General Linear Models (GLM) programmes within the SAS package (Statistical Analysis Systems Institute, Cary, North Carolina, USA). Faecal egg counts were logarithm-transformed in the form of $\log_{10}$(EPG +1) to stabilise the variance before analysis. Total worm counts as well as the individual parasite species were compared between the tracer lambs and the permanently grazed sheep. The effects of time and duration of housing on worm burdens were also tested.

4.3 RESULTS

4.3.1 Weather pattern

The rainfall pattern in the study area as well as the minimum and maximum temperature for the duration of the study are shown in Figure 11. The weather pattern during this period was typical for the area as described in Chapter 2.2.

4.3.2 Nematode faecal egg counts (FEC)

4.3.2.1 Sheep

The results of faecal examination for nematode eggs in lambs and adult sheep in the smallholder farms are shown in Figure 12. The mean faecal egg counts for lambs and adults showed a similar pattern over the study period but those from the lambs were generally higher than those from the adults. On a few occasions, i.e. August, 1995, January and March 1996, the lambs and adult sheep had almost similar mean FEC. For the majority of the months the mean FEC for lambs were below 2000 EPG. The times when the mean FEC exceeded 2000 EPG were April 1995 and February and October 1996. The adult sheep on the other hand, had mean FEC generally below 1000 EPG in all months except in February and October 1996. The lowest mean FEC of less than 300 EPG for both groups of sheep were recorded in August 1995 and January 1996.

Statistical analyses examined the effects of age, animal within farm, farm and time (month of sampling) on the faecal egg counts (Table 10). There was a highly

significant variation in FEC between farms and at different times of the year ($p< 0.0001$). There was also a significant variation attributable to age; the lambs having a significantly higher faecal egg counts than adults but no significant variation in FEC attributable to individual animals within farms.

4.3.2.2 **Goats**

Results of the goat mean FEC are shown in Figure 13. There were on average 30 goats sampled every month, but the number of kids sampled at each point was so low that the data are presented from adults only. The mean FEC ranged from 138 EPG in August 1995 to 1489 EPG in October 1996 and were above 1000 EPG in only seven of the 20 months of the study. The infection pattern in goats was less defined than that observed in sheep but the adult goat mean FEC were generally higher.

Statistical analyses examined the effect of individual animals, farm and time (month of sampling) on the faecal egg counts (Table 10). There was significant variation in FEC between farms and at different times of the year ($p< 0.0001$). There was no significant variation in FEC attributable to individual animals within farms.

4.3.2.3 **Cattle**

The mean FEC for calves and adult cattle in the smallholder farms are shown in Figure 14. The mean FEC for calves were higher than for the adults although they remained generally low in both groups. In the calves, mean egg counts were highest in August and February 1996 (744 and 426 EPG respectively) whilst in adult cattle the mean FEC were less than 200 EPG in most months. Statistical analyses (Table 10) showed highly significant variation in FEC due to time, age and individual animals within the farms ($p< 0.0001$). Differences in FEC attributable to individual farms were also significant ($p<0.05$).

4.3.3 **Pasture larval counts**

The results of mean larval recoveries from herbage taken from up to eight sampling sites are shown in Figure 15. The results for the total and differential larval counts from the individual sites each month are shown in Appendix 4. The mean larval counts

for the sites sampled ranged from 59 L_3/kg DH in September 1996 to 995 L_3/kg DH in February 1996. Other months with high mean larval counts were July, August and December 1995 (978, 858, 969 L_3/kg DH respectively), while other months with low counts were September and November 1995 and October 1996 (96, 96 and 91 L_3/kg DH respectively) Overall, the majority of the larvae recovered from herbage were *Haemonchus* spp. (71.2%) followed by *Trichostrongylus* spp. (14.6%), *Cooperia* spp.(10.4%) and *Oesophagostomum* spp. (3.8%).

Statistical analyses showed that there was a highly significant effect attributable to time of the year on the total number of infective larvae ($p< 0.0001$), but that there were no significant differences between the different sites where herbage samples were taken.

4.3.4 **Differential larval counts from coprocultures**

4.3.4.1 **Sheep**

The percentage distribution of infective larvae from sheep coprocultures according to genera are shown in Figure 16. The mean percentages for sheep samples each month are shown in Appendix 5. The majority of larvae were *Haemonchus* followed closely by *Trichostrongylus*. The others were *Oesophagostomum, Strongyloides* and *Cooperia* respectively in decreasing order of abundance. The monthly mean percentages for the distribution of the larvae by genera varied widely each month.

4.3.4.2 **Cattle**

The distribution of the larvae harvested from cattle faeces according to genera is shown in Figure 17 and Appendix 6. The overall prevalence of the different genera in decreasing order of abundance were *Haemonchus, Trichostrongylus, Oesophagostomum, Cooperia* and *Strongyloides. Haemonchus* and *Trichostrongylus* were almost similar in terms of abundance but as with the sheep coprocultures, there was considerable monthly variation in larval distribution.

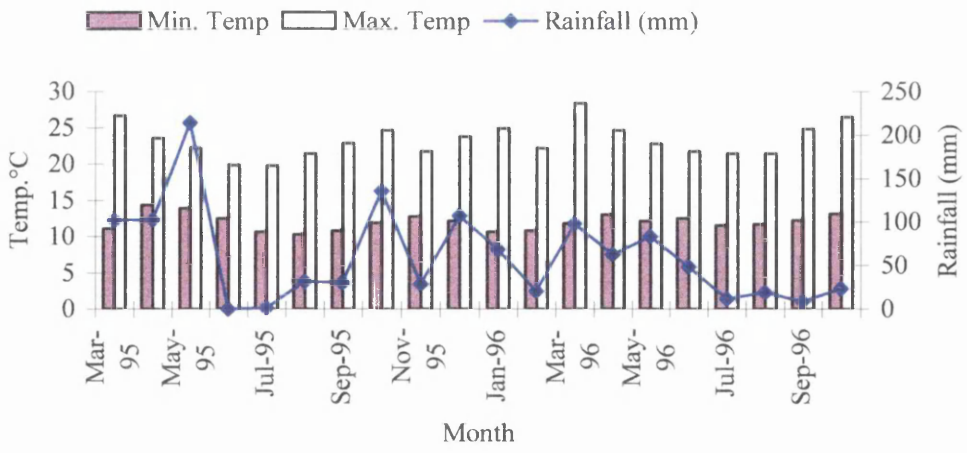

Figure 11: The rainfall pattern together with the minimum and maximum temperatures in the study area over the study period. The weather data were collected from Sagana State lodge weather station.

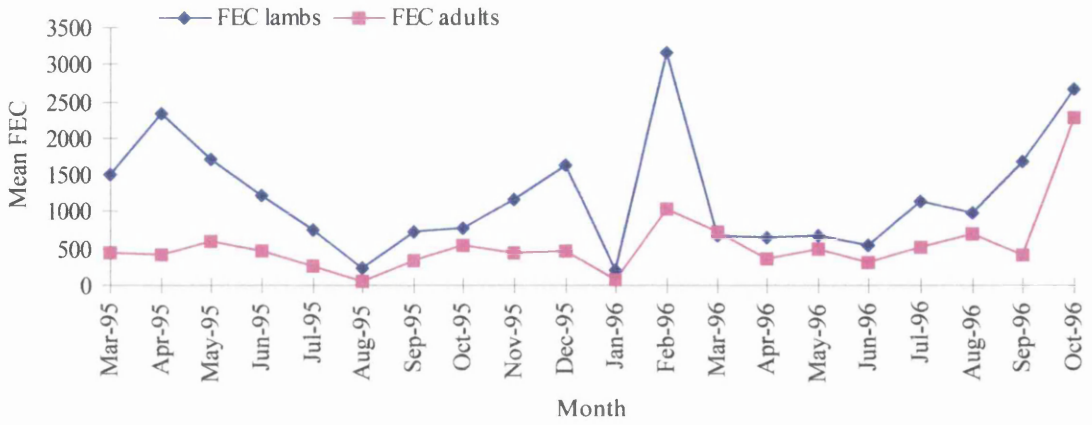

Figure 12: Mean monthly faecal egg counts for lambs and adult sheep in the smallholder farms.

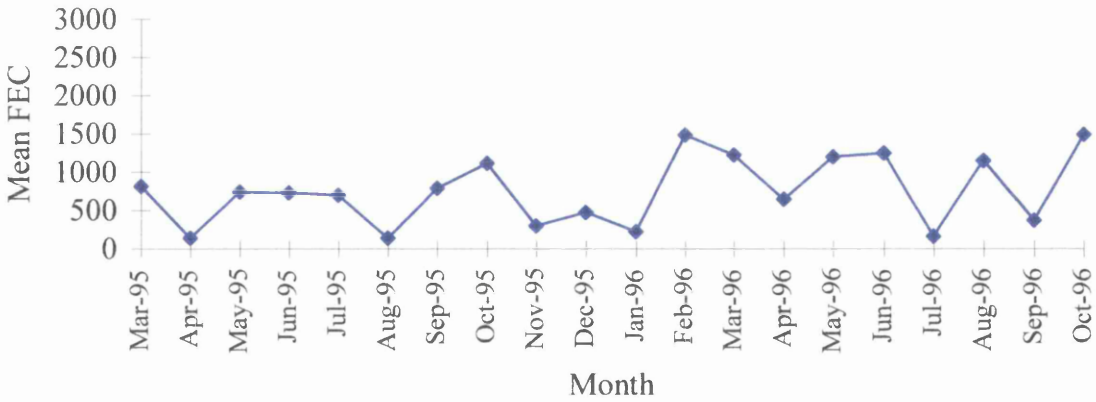

Figure 13: Mean monthly faecal egg counts for adult goats in the smallholder farms in the study area.

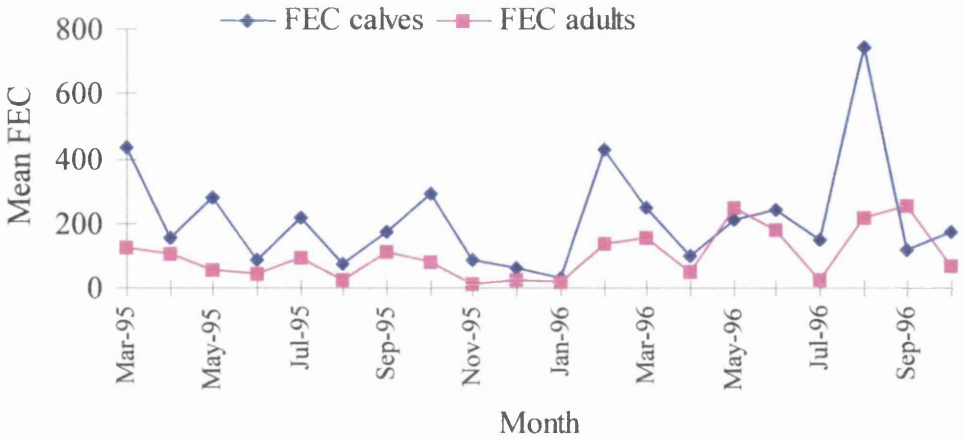

Figure 14: Mean monthly faecal egg counts for calves and adult cattle in the smallholder farms in the study area.

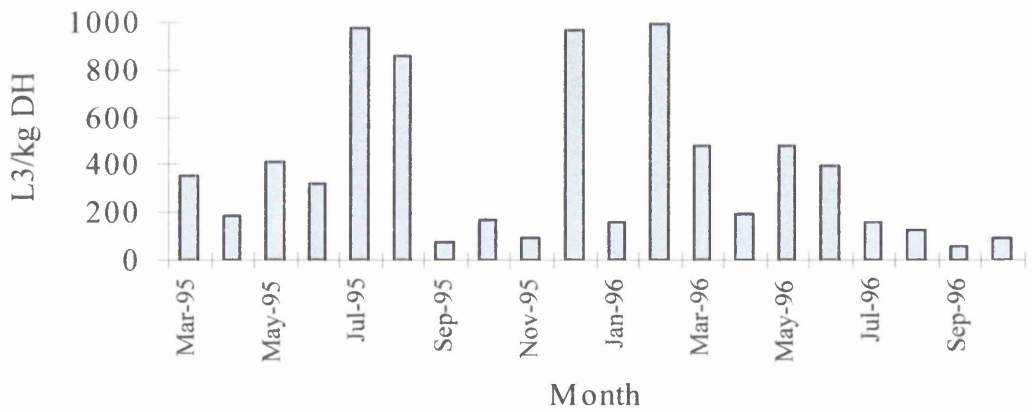

Figure 15: Mean larval counts for the eight sites from which herbage samples were collected.

Source	P-value		
	Sheep	Goats	Cattle
Time	0.0000	0.0034	0.0000
Farm	0.0000	0.0100	0.0385
Animal(Farm)	0.0587	0.5742	0.0001
Age	0.0025	Not analysed	0.0001

Table 10: Results of mixed models analysis of variance of faecal egg counts of sheep, goats and cattle in 58 smallholder farms in Nyeri district. The analyses showed the effect of time, farm, individual animals [(Animal(Farm)] and age on the FEC.

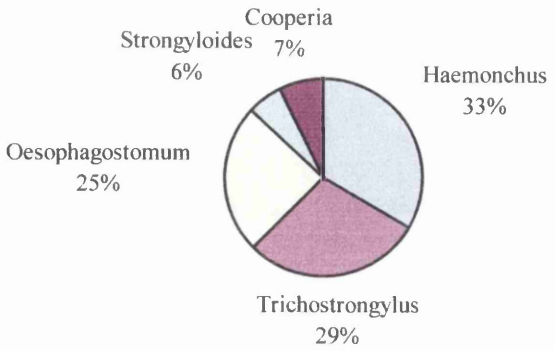

Figure 16: Mean percentage distribution of sheep nematode larvae by genera from coprocultures.

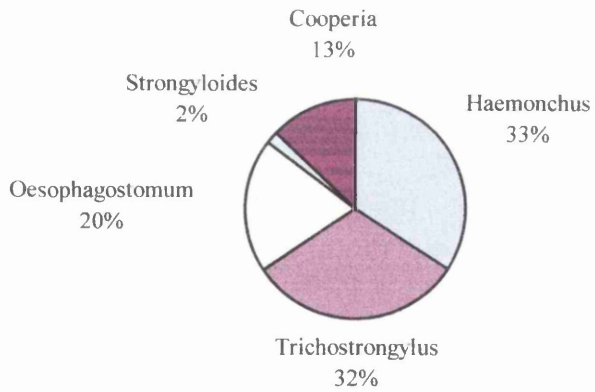

Figure 17: Mean percentage distribution of nematode larvae by genera from cattle coprocultures during the study period.

4.3.5 Total worm counts

4.3.5.1 Tracer lambs

Out of the expected 108 lambs, a total of 100 were examined for nematode infections over the duration of the study. There were six tracers examined in each of 13 months, five in each of three months and four and three in one month respectively. The reduction in number of animals examined was due to early deaths in the field from various causes.

The total worm counts from the tracer lambs over the study period are shown on Figure 18. The total and differential counts from individual tracers are shown in Appendix 7 for each of the months studied. *Haemonchus contortus* was the most prevalent nematode recovered from the tracers. This was followed by *Trichostrongylus axei, T. columbriformis* and *Cooperia curticei.* Counts for *Oesophagostomum columbianum* were not included in these calculations because these parasites may have come with the lambs from the ranch where they were bought and the anthelmintic used to treat the lambs during quarantine was found to be ineffective in eliminating the larvae of *Oe. columbianum* in pimply gut lesions. There were no larvae recovered from the abomasal mucosa in any of the tracers. All immature stages were found in the ingesta of a few lambs slaughtered a few days before the end of the 3 week-housing for welfare reasons.

The tracer lambs were infected with very few nematode parasites from pasture in the months of May, June and July 1995 and August, September and October 1996. These times coincided with months in which low rainfall was recorded. The months with the highest mean worm counts (> 2000 worms) were November 1995, January, May and June 1996. The mean worm counts for the three most predominant species of nematodes, *H. contortus, T. axei* and *T. colubriformis* are compared in Figure 19. In the majority of the months, *Haemonchus* was the most predominant species. Overall, the distribution of the different nematode species recovered from the tracer lambs were as follows: *H. contortus* (55.6%), *T. axei* (16.7%), *T. colubriformis* (20.7%), *Cooperia* spp. (3.6%), *Oesophagostomum* spp. (3.1%) and *Trichuris* spp. (0.3%).

Statistical analyses examined the effects of time (month of grazing) and duration of housing after grazing (three or six weeks) on the total worm burdens and different worm species (Table 11). The total and differential worm burdens were also compared between the tracers and the permanently grazed sheep. There were highly significant differences due to time ($p< 0.0001$) on the total worm burdens. The duration of housing did not influence the total worm burdens ($p> 0.05$). The tracer lambs had significantly higher *H. contortus* burdens than the permanently grazed sheep and significantly lower *T. axei* burdens ($p< 0.0001$). The differences in total worm burdens and in *T. colubriformis* and *Cooperia* spp. burdens between the tracer lambs and the permanently grazed sheep were not significant ($p> 0.05$).

4.3.5.2 **Permanently grazed sheep**

A total of 58 adult ewes were examined for nematode infection over the period of the study. There were 4 animals examined in each of 10 months and 3 in each of 6 months. The results of the mean total worm counts for the permanently grazed sheep each month are shown in Figure 20. The total and differential counts for the individual sheep are shown in Appendix 8 for each of the months studied. The permanently grazed sheep harboured nematode infections throughout the study period, including the months that had very low rainfall. All of the abomasal parasites were recovered from the contents and none from the abomasal digests. Overall the months with high worm recoveries (mean of >2000 worms) were September and November 1995, and January, February, May and August 1996. Low mean recoveries were recorded in July and December1995 and September, 1996. The relative prevalence of the three most predominant species are compared in Figure 21. *Trichostrongylus axei* and *T. colubriformis* were more abundant than *Haemonchus contortus* with the exception of a few months where the latter was more abundant. The overall distribution of different nematode species recovered from the permanently grazed sheep were as follows: *H. contortus* (19.6%), *T. axei* (36.7%), *T. colubriformis* (36.8%), *Cooperia* spp. (5.0%), *Oesophagostomum* spp. (1.1%) and *Trichuris* spp. (0.3%).

Statistical analyses compared the same parameters as for the tracers (Table 11). The results showed a highly significant effect of time of purchase of the permanently grazed sheep on worm burdens ($p< 0.0001$) but the duration of housing (three or six

weeks) had no effect. The permanently grazed sheep had significantly higher *T. axei* counts than the tracers ($p < 0.0001$) but there were no significant differences in total worm burdens, or in burdens of *T. colubriformis* and *Cooperia* spp. ($p > 0.05$).

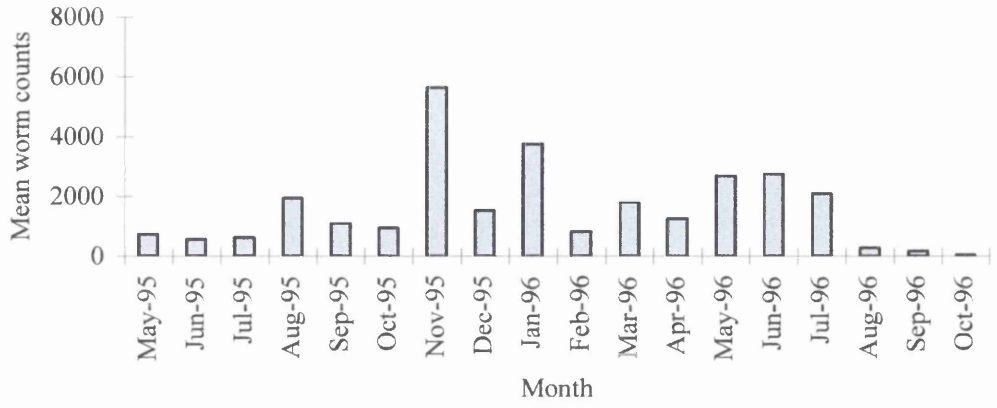

Figure 18: Mean total worm counts for the six Dorper tracer lambs introduced into the communal grazing areas every month.

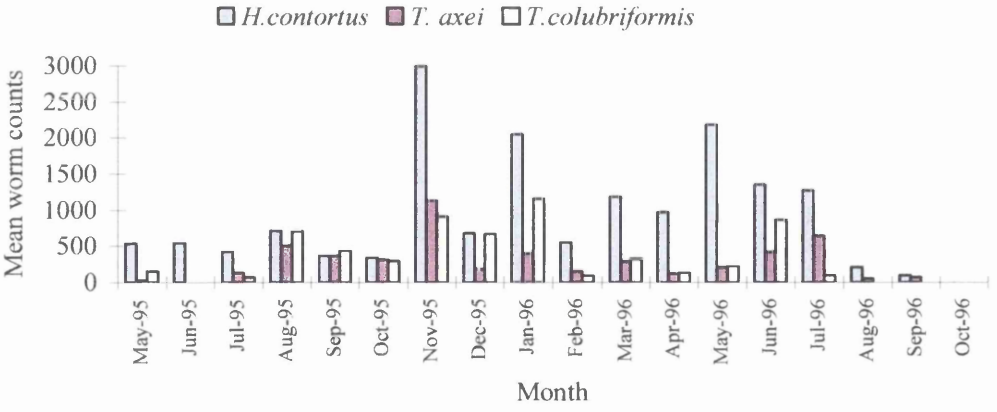

Figure 19: A comparison of *Haemonchus contortus, Trichostrongylus axei* and *Trichostrongylus colubriformis* from the tracer lambs.

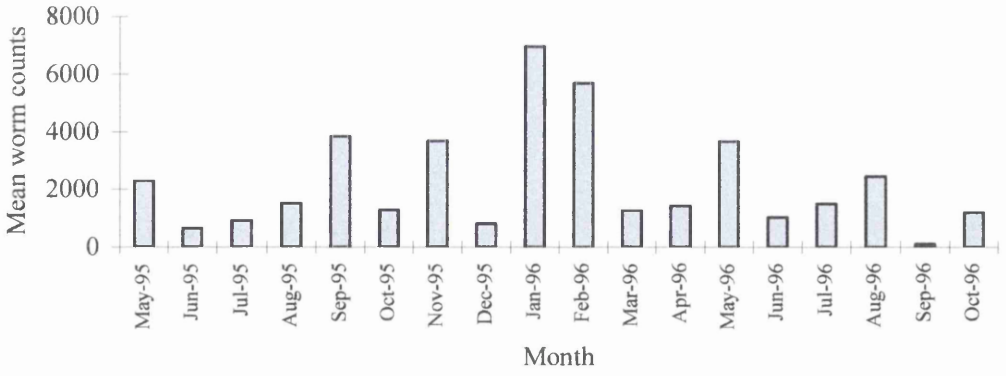

Figure 20: Mean total number of nematodes recovered from local permanently grazed sheep purchased from farms in the study area.

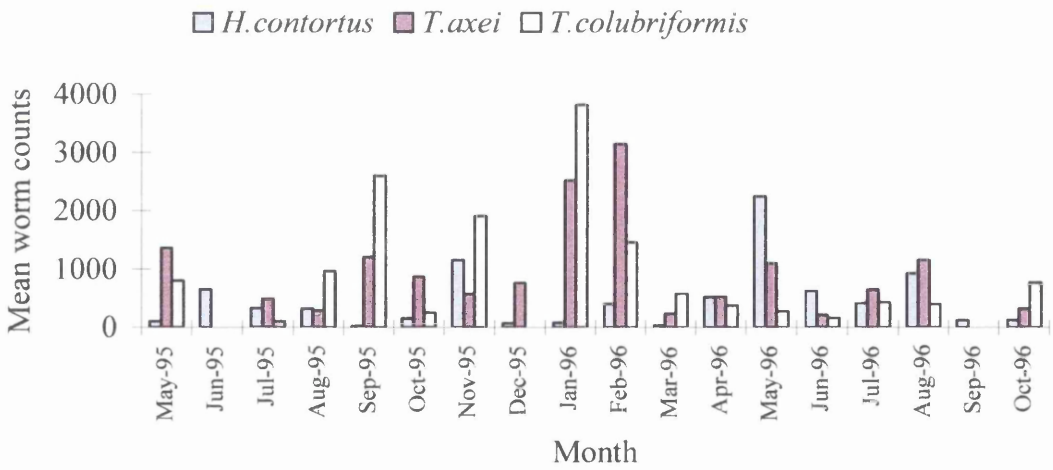

Figure 21: A comparison of *Haemonchus contortus, Trichostrongylus axei* and *T. colubriformis* from the local permanently grazed sheep purchased from the farmers in the study area.

Source	p-value		
	Time[1]	**Housing**[2]	**Type**[3]
Total worm counts	0.0001	0.8599	0.4023
H. contortus	0.0001	0.8703	0.0001
T. axei	0.0001	0.3872	0.0001
T. colubriformis	0.0001	0.6674	0.0872
Cooperia spp.	0.0001	0.6250	0.1178

[1]Denotes the month that the tracer sheep were grazing in the study area or the permanently grazed sheep were purchased.
[2]Denotes the duration of either three or six weeks that the sheep were housed prior to necropsy.
[3]Denotes the type of sheep, tracer or permanently grazed.

Table 11: Results of statistical analyses of the worm burdens in the tracers and permanently grazed sheep. The effects on total and differential worm counts of time and duration of indoor housing before necropsy were also analysed.

4.4 DISCUSSION

The results of faecal examinations from sheep, goats and cattle in the smallholder farms in this study showed that infections with parasitic gastrointestinal nematodes were present throughout the year. However, the levels of infection were different in small ruminants and cattle. The mean FEC for calves, though higher than those from the adult cattle, remained low throughout the study. The infection levels in adult cattle were found to be below the threshold above which anthelmintic treatment would be recommended in tropical areas (Hansen and Perry, 1994). In the sheep (lambs and adults), the mean FEC were above 500 EPG for most months, with distinct peaks of infection occurring during the wetter months of the year, especially during the months of February and October 1996. These findings are in agreement with other studies which have showed that rainfall is an important factor in determining levels of infection (Southcott *et al.*, 1976; Gatongi *et al.*, 1987; Wanyangu *et al.*, 1997). The results from the goat FEC, though fewer in number, were generally higher than those from sheep and showed a less defined pattern. In this study the problem of infections with parasitic gastrointestinal nematodes was found to be of greater significance in small ruminants than cattle.

The findings from the faecal examinations of the sheep, goats and cattle in smallholder farms were reflected in the recovery of infective larvae from pasture samples. High levels of pasture contamination with L_3 occurred when the rainfall was high, and this was especially evident during the two main rainy seasons. There were low numbers and occasionally no larvae recovered from pasture during the intervening dry periods. The results also showed that *Haemonchus* was the most abundant nematode genus on pasture throughout the study period. This nematode has a high fecundity compared with the other genera, hence its higher relative abundance on pasture (Gibson and Everett, 1976). Results obtained on the relative prevalence of different nematode genera in this study were in contrast to those reported from studies in other parts of Kenya. Some of these studies, mostly conducted in the drier parts of the country, found that *Haemonchus* was almost exclusively the parasite found in pasture samples and sheep faecal cultures. Gatongi (1995), working in Naivasha, which is a semi-arid area, found that *Haemonchus* accounted for 80% of the larvae recovered from

pasture and *post mortem* worm counts. Earlier studies by Preston and Allonby (1979) had found *H. contortus* to account for 98% in Naivasha and 99% in Machakos, another semi-arid area of Kenya. In addition, in the area covered by the present study, it appeared that *Trichostrongylus* spp. played a more important role in the parasitic gastroenteritis syndrome of sheep and goats than previous studies had indicated. This view was supported by findings from the differential worm counts from the permanently grazed sheep bought from the study area, as *T. axei* and *T. colubriformis* were recovered in much higher proportions than *H. contortus* in the majority of the months. The reasons for this distribution were not immediately clear, especially when both herbage larval counts and tracer worm burdens had indicated that *Haemonchus* was likely to be much more abundant than *Trichostrongylus*. There are several possible reasons for this finding. One possibility is that since the local sheep were of the Red Maasai type, they could be capable of suppressing the establishment of *H. contortus* larvae as previous studies have shown these sheep to be resistant to haemonchosis (Preston and Allonby, 1978 and 1979; Mugambi *et al.*, 1997). The presence of *Trichostrongylus* spp. in much higher proportions in the permanently grazed sheep was consistent with the common clinical finding of diarrhoea in sheep in the study area as opposed to anaemia and sub-mandibular oedema (commonly observed in haemonchosis). The order of prevalence of different nematodes was reversed in the tracer lambs in which *H. contortus* was more abundant than both *T. axei* and *T. colubriformis* throughout the study period. Work by Mugambi *et al.* (1997) has shown the Dorper breed of sheep to be highly susceptible to *H. contortus* infections and this may help to explain the findings reported here. Furthermore, the tracer lambs were younger than the permanently grazed sheep and the development of immunity to trichostrongylid infections has been shown to develop with age, among other factors (Gamble and Zajac, 1992). This age disparity may therefore have contributed to the observed difference in proportions of *H. contortus* and *Trichostrongylus* spp. in tracers and permanently grazed sheep in this study. The finding that both groups of sheep harboured total parasite burdens that were not significantly different was also an interesting observation. The only significant differences were in the helminth species that colonised the abomasum, *H. contortus* and *T. axei*. *Trichostrongylus colubriformis* was present in higher proportions in the

permanently grazed sheep than in the tracer lambs, though the differences were not statistically significant.

The overall significance of the above findings could be that in sheep resistant to haemonchosis, there may be less competition to colonise the abomasum by other abomasal nematodes and these might replace *H. contortus* in abundance. This could have some implications in the establishment of breeding programmes for resistance to *H. contortus* in that resistant sheep may suffer heavier infections with other nematodes. This could diminish the anticipated benefits, such as reductions in anthelmintic usage in such flocks, because these other nematodes, although less pathogenic than *H. contortus*, are still capable of causing substantial production losses (Kimambo *et al.*, 1988; Kyriazakis *et al.*, 1996). Therefore, relative susceptibility to other gastrointestinal nematodes in animals selected for resistance to haemonchosis may be worthy of further consideration in helminth control programmes, especially with regard to the use of narrow spectrum anthelmintics such as those used in Australia for specific *H. contortus* control (Dash, 1986).

The findings of this study gave an insight into the seasonality of helminth infections in the central Kenya highlands. The results from faecal egg counts for sheep, goats and cattle in the smallholder farms as well as those from pasture examination for infective larvae, provided information on different aspects of infection with parasitic gastrointestinal nematodes in this area. In this study, for example, the permanently grazed sheep harboured infections throughout but the levels of infection varied widely. Although the pattern of infection was not always distinct, it was clear that heavier infections were generally harboured during the rainy season, although there were a few months where relatively high mean worm counts were associated with periods of low rainfall. These findings could have been due to the fact that the permanently grazed sheep used in this study were different from those used in many other studies where the type and duration of grazing are known (Duncan *et al.*, 1979; Uriate and Valderarabano, 1989; Wanyangu *et al.*, 1997). The permanently grazed sheep used in this study were purchased from different farms with different grazing management and possibly different helminth control practices. The time from when they were last treated with anthelmintics was consequently not known. It was

therefore possible that the sheep could have been carrying infections picked up over prolonged periods prior to their purchase. This was particularly possible with *Trichostrongylus spp.* which are known to accumulate in the host as opposed to *H. contortus* that has a high turn-over (Waller and Thomas, 1981; Courtney *et al.*, 1983). However, one clear observation was that sheep in the study area had substantial nematode worm burdens at most times of the year. In contrast, the worm burdens of the tracer lambs reflected infections acquired from pasture during the single month that they had been grazing. The results from these animals were therefore more likely to indicate the availability of infective larvae to grazing animals in the study area at different times of the year. The levels of infection in the tracers appeared to be closely related to the rainfall pattern, the highest levels occurring either in the months with peak rainfall or one month later. The highest levels of infection were recorded in January and November. The period from August to October 1996 had the lowest worm recoveries. These were the months that had low pasture larval recoveries as well as low rainfall. This further demonstrated the extent to which rainfall influenced levels of infection with parasitic gastrointestinal nematodes.

In both tracers and permanently grazed sheep, no arrested larvae were identified in the abomasal digests. This was similar to the findings of Mugambi (1994) in Muguga, a highland area in central Kenya, but studies from the arid area of Naivasha (Allonby and Urquhart, 1975; Gatongi *et al.*, 1998) and Machakos (Preston and Allonby. 1979) found hypobiotic *H. contortus* in sheep. The results from the highlands of central Kenya implied that hypobiosis was probably a less important factor in the epidemiology of haemonchosis as opposed to the situation in the low rainfall areas of the country.

The findings from the whole study suggested that a strategic anthelmintic dosing programme for the control of PGE in sheep and goats would be feasible in the highlands of central Kenya. Based on the results from this study, application of two annual anthelmintic treatments, one in January and another in October, using a broad spectrum drug are suggested. The January treatment would be administered at a time when the levels of infection are high following the heavy pasture infectivity during the short rains. In addition, the January treatment would benefit sheep by reducing their

worm burdens during the period of nutritional stress experienced in the dry season. This treatment would also take advantage of the reduced survival time of eggs and other free living stages, expected under the dry conditions at this time of the year. This would in turn help reduce further the pasture contamination by the start of the next wet season in March/April. The October treatment is aimed at removing worm burdens before the peak infection levels observed in the study area in November. Another effect of the October treatment would be to reduce pasture contamination during the rainy season and enable the sheep to benefit from the improved pastures associated with the rains. Since these treatments are unlikely to stop transmission in heavily contaminated areas, particularly in animals grazed off-farm in communal pastures, clinical cases of helminthoses may require to be treated individually when they occur or on a flock basis when the problem is widespread. However, it is most likely that if all farmers within a single locality used the same treatment regime, as one recommended in this study, considerable production benefits may become apparent. The above suggested treatments would ensure that animals are healthier around the times of the year when most sales take place (Chapter 3). This is likely to make the recommendations popular with local farmers, thus resulting in higher a adoption rate.

The results from this study also showed that gastrointestinal nematodes are not a major problem in cattle in this area of Kenya. In places where cattle are zero-grazed or graze pastures where *Fasciola gigantica* infection does not occur, there is unlikely to be any benefit from routine drenching. Treatments therefore could be confined to clinical cases which might occur in young cattle on a few problem farms. Based on the findings from this study, the majority of smallholders in the highlands of central Kenya are in areas where routine and frequent drenching for helminthoses cannot be justified. A reduction in treatment frequency could result in substantial financial benefits to farmers as well as reducing the risk of selecting for anthelmintic resistant nematodes. The control strategy for gastrointestinal nematodes described above is therefore recommended for adoption in the study area and other regions with similar agro-ecological and husbandry characteristics.

CHAPTER FIVE

AN EPIDEMIOLOGICAL STUDY OF *Fasciola gigantica* INFECTIONS IN RUMINANTS ON SMALLHOLDER FARMS IN THE CENTRAL KENYA HIGHLANDS

5.1 INTRODUCTION

Fasciolosis is among the most important parasitic diseases in many regions of the world where sheep and cattle rearing is carried out (Anon, 1994). In most geographical areas the disease is caused by *Fasciola hepatica* or *Fasciola gigantica* while in some it is caused by a combination of the two parasites. Although the life cycle of the liver fluke is complex, the many developmental stages of the parasite have been elucidated and have been described in detail by many authors (Chapter 1.6). In Kenya, and in many parts of Africa, *F. gigantica* is almost solely responsible for fasciolosis of sheep, goats and cattle (Dinnik and Dinnik, 1959) and is the cause of considerable direct and indirect losses in the livestock industry. Heavily infected animals may die, but those less severely affected suffer a substantial reduction of growth and production (Hope, 1984; Wamae and Ihiga, 1991). Losses due to reduced production efficiency result in the greatest economic impact of this disease (Fabyi, 1987; Wamae. *et al.*, 1998).

The establishment and maintenance of fasciolosis in an area depends on many variables including the availability of suitable intermediate and definitive hosts as well as favourable climatic and ecological conditions (Cheruiyot, 1987). In those parts of the world with a temperate climate, most of the parasite's development in the snail intermediate host takes place in the spring and summer months and ceases during the winter (Gettinby and Byron, 1991). The epidemiology of the disease in most of these countries, especially in Britain and America has been studied in detail (Ollerenshaw, 1959; Ross, 1970; Bruce *et al.*, 1973; Malone *et al.*, 1985 & 1987; McIlory *et al.*, 1990a, 1990b; Goodall *et al.*, 1991; Malone *et al.*, 1992) and has allowed the development of accurate disease forecasting systems that form part of the advisory package for farmers in these countries. A geographical information system-based disease forecasting system was described by Malone *et al.*, (1998) for the Intergovernmental

Authority on Development (IGAD) sub-region of Eastern Africa. Lack of accurate prevalence data from the countries in the sub-region was recognised as a limiting factor on the usefulness of the system, but using the available data from four regions in Ethiopia, Yilma and Malone (1998) developed a forecasting system for these areas. Both of these studies recommended further development of the forecasting systems, using all the available data from the East African countries, as well as evaluation of the control programmes that they had proposed.

There are various methods advocated for the control of fasciolosis, including administration of drugs to kill the parasites in the definitive hosts, application of chemicals to destroy the snail intermediate hosts or management either by efficient drainage of pastures to reduce intermediate snail host populations or by keeping livestock from grazing on contaminated pastures (Armour, 1975). Of all of these possible methods, the only practical approach is the use of anthelmintics (Boray, 1997). However, flukicidal drugs are expensive and are therefore best used strategically at times when their use is most cost effective. Advice on the frequency and most effective timing of drug treatments in any region should be based on a sound knowledge of the local fluke infection pattern. From tropical regions, only a small number of studies on epidemiologically based control measures for fasciolosis have been reported. In Kenya there is little precise data on infection patterns in different agro-ecological zones and recommendations for control are based either on information extrapolated from what has been found elsewhere or on limited local abattoir surveys (Anon, 1986). Following extensive literature reviews, general recommendations on fasciolosis control in tropical and sub-tropical areas have been made by Boray (1991) and by the Food and Agriculture Organisation, FAO (Anon, 1994) but any successful local control programme will largely depend on the strategic application of well timed prophylactic and curative treatments appropriate to regional climatic and husbandry practices.

The objective of the study reported in this Chapter was to investigate the liver fluke infection pattern in grazing animals in smallholder farms in the highlands of central Kenya, with the aim of developing a strategic anthelmintic control programme for this and other areas of Kenya with similar climatic and husbandry characteristics. The investigation included farm animal monitoring for infection with liver fluke, assessment

of the monthly infections in tracer lambs which grazed with the local flocks and the purchase of local permanently grazed sheep for parasite recovery throughout the study period (Chapter 2.1).

5.2 MATERIALS AND METHODS

5.2.1 Study farms, animals and methods

The farms and animals used for this study have already been described (Chapter 2) and are the same as those described in Chapter 4. The parasitological techniques have been described in Chapter 2.9.

5.2.2 Study design

The study had three components. The first component involved monthly monitoring of faecal samples from the sheep and cattle in 58 smallholder farms for infection with the liver fluke. Samples were collected once every month and were taken to the laboratory at NVRC for examination for *Fasciola* eggs. The presence of eggs of other trematodes i.e. paramphistomes, were also recorded. The second component involved introducing six fluke-free tracer lambs to the communal grazing areas, including roadsides, for one month. After this month of grazing the tracer lambs were taken to NVRC, housed in worm-free accommodation for either three or six weeks (three tracers in each category) and necropsied. The livers, lungs and a section of the duodenum were then examined for liver flukes, which when present were counted as described in Chapter 2.9.5. The third and final component involved the purchase of four adult ewes from farmers in the study area. These were housed, necropsied and examined for liver flukes in the same way as the tracers. Each month, the liver fluke burdens in the two groups of sheep were recorded as individual counts, as the mean for each month of grazing and as total fluke burden for each group. The monitoring of animals in the smallholder farms was carried out over a period of 20 months from March 1995 to October 1996. The introduction of tracer lambs covered a period of 18 months from May 1995 to October 1996 while the purchase of the permanently grazed sheep covered a period of 16 months from July 1995 to October 1996.

5.2.3 Statistical analyses

The total liver fluke counts from individual sheep (tracers and permanents) were logarithm transformed as $\log_{10}$ (total count + 1) before analysis in the General Linear Models Procedure of the SAS statistical programme (Statistical Analysis Systems, Cary, North Carolina, USA). The analyses investigated the effects of time (month of grazing in case of tracer lambs or month of purchase for permanently grazed sheep) on the total liver fluke counts. The liver fluke burdens in the tracers and permanently grazed sheep were also compared over time.

5.3 RESULTS

5.3.1 Infection prevalence of sheep in smallholder farms

The number of sheep samples examined every month varied from 71 to 155, with a mean of 115 over the duration of the study. The infection prevalence of sheep with *Fasciola*, expressed as percentage in which the presence of liver fluke eggs was recorded, is shown in Figure 22. The monthly details of number of animals examined and the proportions infected with liver flukes are shown in Appendix 9. There were infected sheep during most months. The samples were not examined for *Fasciola* in March 1996 as a result of a laboratory error. The percentage infected during the other 19 months varied from 0.7% in April 1996 to 13.2% in May 1995. The mean overall infection prevalence for the study period was 5.6 (± 3.2) %. There were a higher proportion of infected sheep in May and November 1995 and May and October 1996. May had consistently the highest proportion of infected sheep over the two years (13.2% and 9.6% respectively). Low infection prevalence (< 5%) were recorded in March, September and December 1995 and January, February, April and July 1996.

5.3.2 Infection prevalence of cattle in the smallholder farms

The number of cattle samples examined varied from 145 to 211 with a mean for all the months of 184. The fluke infection prevalence of cattle in the smallholder farms is shown in Figure 23 while the details of number of animals examined and proportions infected every month are shown in Appendix 10. As in the sheep, samples were not examined for *Fasciola* in March 1996 due to a laboratory error. The number and proportion of cattle infected with liver fluke varied over the study period. There were infected cattle in all of

the 19 months where faecal samples were examined. The percentage of infected cattle varied from 2.4% in February 1996 to 22.2% in May 1995, with a mean of 13.0 (± 6.2) % for the entire study period.

The infection pattern in cattle was similar to that observed in sheep. In 1995, the highest percentage of infected cattle were recorded in May and November (22.2% and 19.2% respectively). In 1996, the prevalence of infection was over 13% from May to October; the highest proportion of infected cattle were found during the months of August and October. Lowest infection prevalence, as in the sheep, were found between December 1995 and April 1996.

5.3.3 **Paramphistome infections in sheep and cattle**

The proportions of sheep and cattle infected with paramphistomes are shown in Figures 24 and 25 with the respective details in Appendices 11 and 12. There were infected animals in every month and between 10% and 22% of sheep and 22% and 42% of cattle were found to be infected over the study period. The prevalence of infection in both sheep and cattle showed no distinct pattern.

5.3.4 **Liver fluke infection pattern in the tracer lambs**

Over the study period, 99 tracer lambs out of the expected 108 were examined for liver fluke infections. The other nine lambs died mainly from respiratory disease early in their grazing period in the field and *post mortem* examinations could not be carried out. In 12 of the months all the six tracers were examined; five tracers were examined in each of four months while for two of the months only four and three tracers respectively were available. Out of the 99 examined, 38 lambs (38.4%) were infected with parasite burdens ranging from one to 79 liver flukes. The total number of liver flukes recovered from the monthly groups of tracers are shown in Figure 26 while the number found infected out of those available each month are shown in Figure 27. The details for the numbers examined, parasite burdens for each animal as well as the mean and total recoveries for each month are shown in Appendix 13.

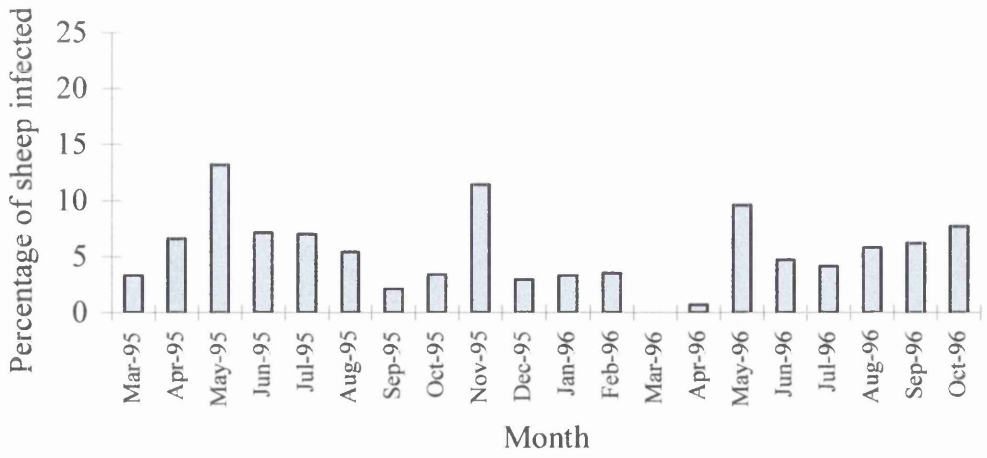

Figure 22: The percentage of sheep infected with liver flukes based on faecal examinations between March 1995 to October 1996. There were no samples examined in March, 1996.

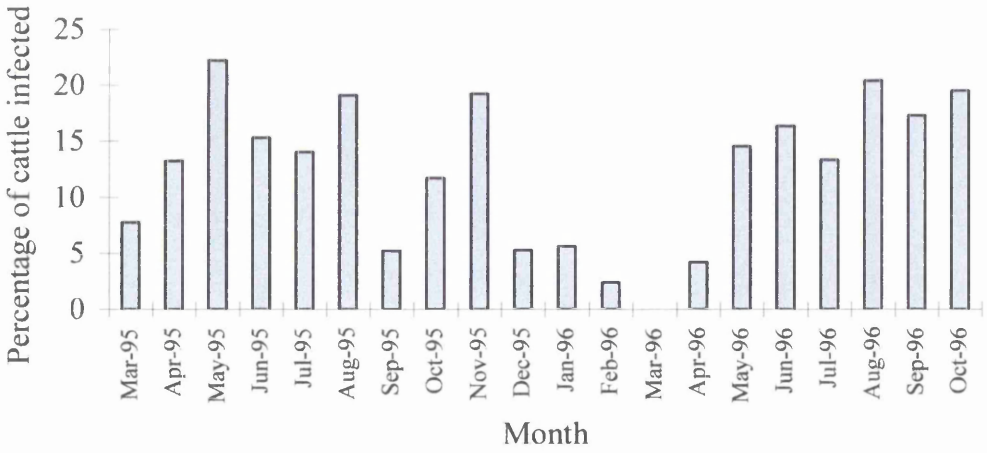

Figure 23: The percentage of cattle infected with liver flukes based on faecal examinations from March 1995 and October 1996. There were no samples examined in March, 1996.

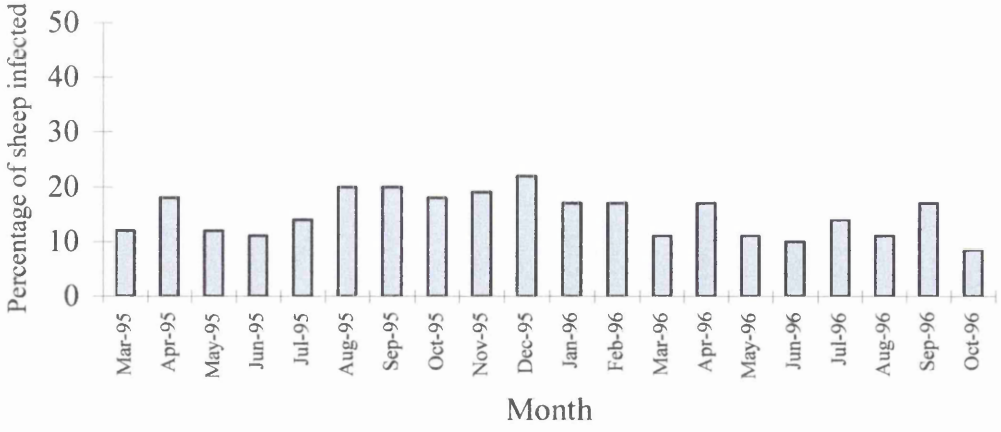

Figure 24: Proportion of sheep in the smallholder farms found infected with paramphistomes between March, 1995 and October, 1996.

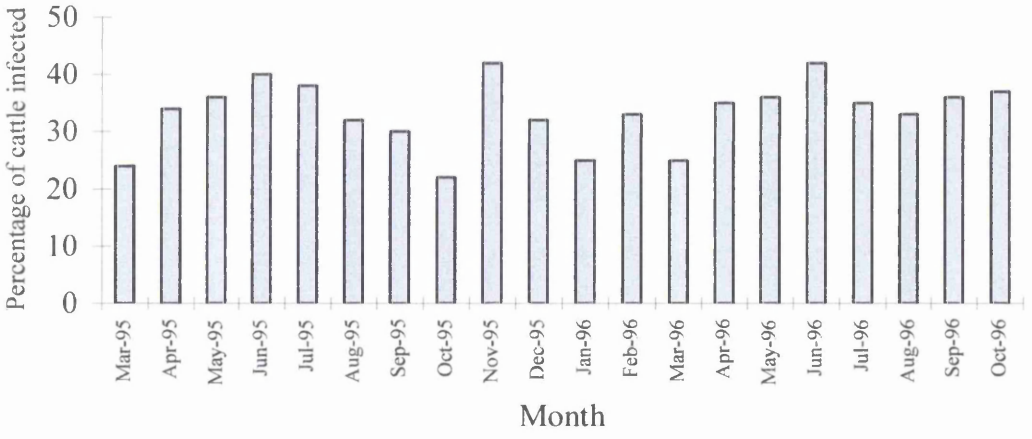

Figure 25: Proportion of cattle in the smallholder farms found infected with paramphistomes between March, 1995 and October, 1996.

Out of the 18 months of the study, tracer lambs were infected with liver flukes in 14 months. All the parasites recovered were identified morphologically as *F. gigantica*. The highest monthly mean recovery for six tracers was 20.7, while the highest among the four months with five tracers was 16.8. None of the tracer lambs were infected in the two months when only four and three animals were examined. The peak levels of infection, expressed as the total number of liver flukes recovered for each month of grazing, occurred from August to October 1995 with the highest total recovery in October (total number of liver flukes: 124, range: 0 to 30 and mean: 20.7). The other period when high infection rates were recorded was from February to April 1996, with February having the highest total recovery (total number of liver flukes: 84, range: 0 to 79 and mean: 16.8).

5.3.5 **Liver fluke infection in the permanently grazed sheep**

Over the study period, three or four adult ewes each month were examined for liver fluke infections. Of a total of 63 sheep examined, 21 (33.3%) were found to be infected with liver fluke burdens ranging from 1 to 199. The total number of liver flukes recovered from the groups of permanently grazed sheep each month are shown in Figure 28 while the number of sheep found infected out of those available each month is shown in Figure 29. The details of individual parasite burdens and the number of animals available for examination each month are shown in Appendix 12.

At least one animal was found to be infected in 14 out of the 16 months when the permanently grazed sheep were examined for liver fluke infection. The highest parasite burden of 199 flukes was recorded in one exceptional animal, sheep number 267 in July 1996. In this sheep, 189 flukes were in the liver, six in the lungs and four in the gall bladder. This sheep was anaemic and emaciated and apart from the liver flukes, it also had a nematode count of 1,850 of which 800 were *H. contortus*, 950 *T. axei* and 100 *T. colubriformis*. The sheep had been housed for six weeks at the time of necropsy. During the same month, the second most heavily infected sheep (number 266) was encountered, which had a parasite load of 115 flukes, all in the liver. Other parasites recovered from this sheep were 2,473 nematodes of which 550 were *H. contortus*, 850 *T. axei* and 1,050 *T. colubriformis*. In this month, the third sheep had three flukes while the fourth was not infected, giving the month the highest total recovery of 317 and a mean of 79.8.

Statistical analyses (Table 12) showed that there were highly significant effects of time of grazing for tracer lambs and time of purchase for permanently grazed sheep on the liver fluke burdens. In both groups of sheep, there were more flukes recovered in those housed for six weeks prior to necropsy as compared to those housed for three weeks. There were also significant differences in fluke burdens between tracer lambs and permanently grazed sheep in some months.

Source	**P-value**
Time	0.0001
Type	0.0213
Type/year/month[1]	0.0001

[1] Denotes the interaction of time and type of sheep (tracer or permanently grazed).

Table 12: Results of statistical analyses to compare the liver fluke burdens in tracer lambs and permanently grazed sheep. The effect of time (month of grazing or purchase for tracer lambs and permanently grazed sheep respectively) was also investigated.

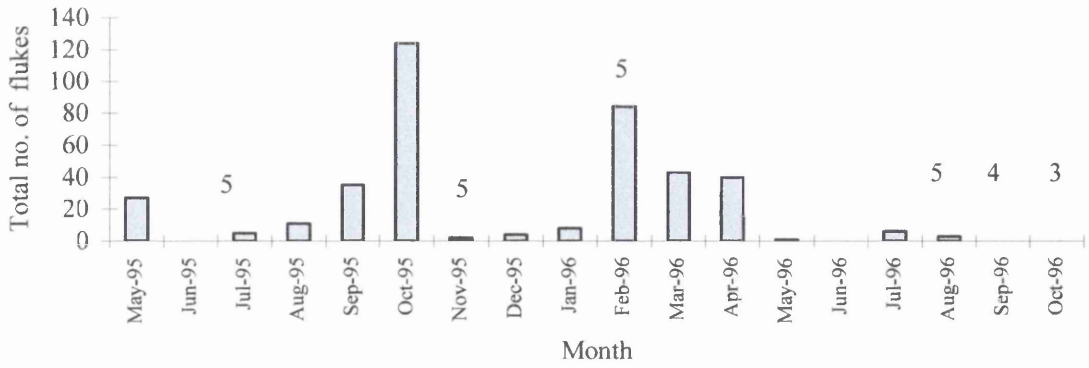

Figure 26: Total number of liver flukes recovered from the groups of six tracer lambs after grazing for one month in the study area. Where less than six were examined, the number of lambs available is indicated.

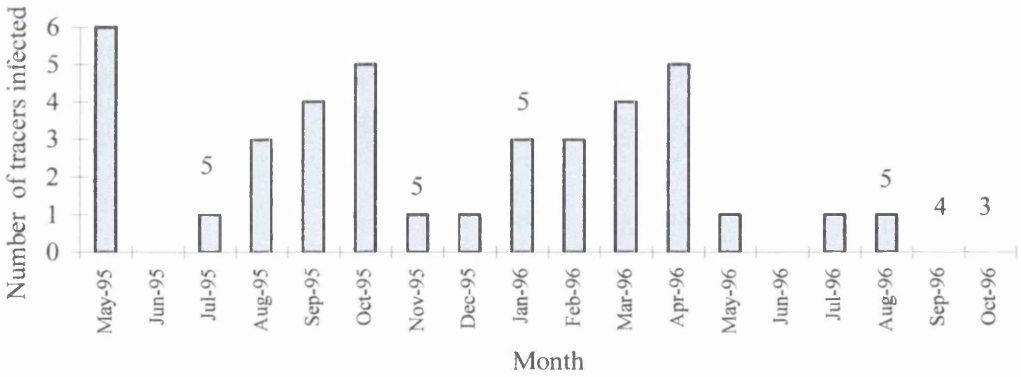

Figure 27: Number of tracer lambs found infected with liver fluke after every month of grazing in the study area. Where less than six were examined, the number of lambs available is indicated.

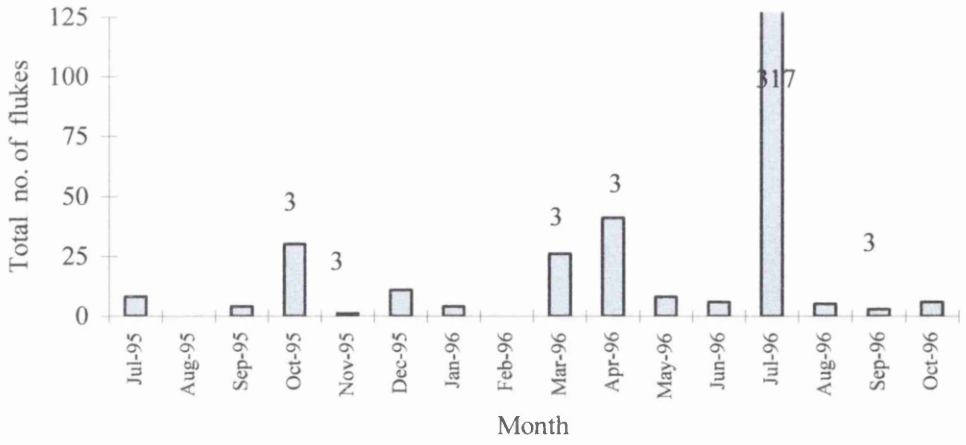

Figure 28: Total number of liver flukes recovered from groups of three or four permanently grazed sheep purchased from farms in the study area every month. Where less than four were examined, the number of sheep available is indicated. The total number of flukes recovered in July, 1996 was exceptionally high (317 liver flukes).

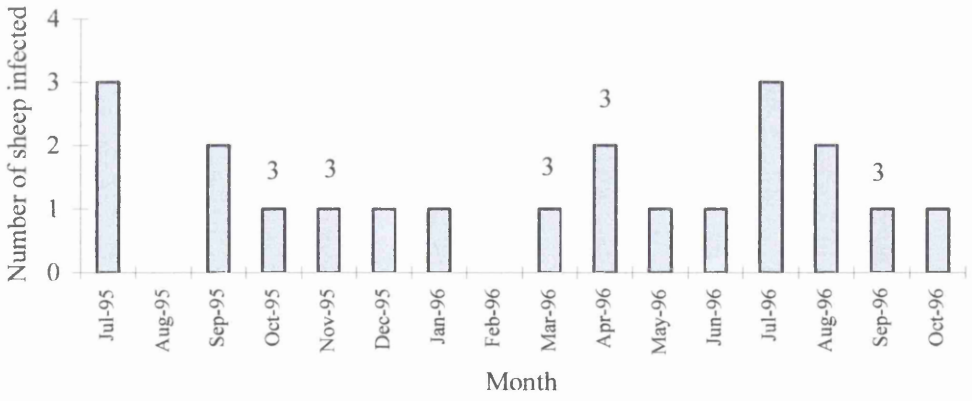

Figure 29: Number of permanently grazed sheep that were infected with liver flukes. Where less than four were examined, the number of sheep available is indicated.

5.4 DISCUSION

The monthly monitoring of sheep and cattle on the smallholder farms in this study showed that infection with *Fasciola gigantica* was endemic in the area. The figures obtained for prevalence in the two host species only included animals harbouring adult flukes, detected by faecal examination for liver fluke eggs. It is likely therefore that the actual mean prevalence of infection was higher than the 5.6% and 13.0% recorded for sheep and cattle respectively. Furthermore, during the study period farmers in the study area were treating livestock, especially cattle, with anthelmintics, most of which included flukicides, and this may also have contributed to an underestimate of the prevalence of infection. However, the method of faecal examination was more appropriate than previous retrospective studies that had relied on the use of abattoir liver condemnation records (Ogambo-Ongoma, 1969; Cheruiyot, 1980; Anon, 1986). Those studies, though quicker and cheaper to carry out, were biased because the data generated was not representative of the source population, considering that young animals, breeding stock and obviously sick animals are not normally taken for slaughter. Animals examined at the abattoirs could also be originating from areas outside those being considered.

The results of this study showed that the prevalence of infection with liver fluke varied between sheep and cattle but the two presented a similar pattern over the period monitored. There was a higher prevalence of infection among cattle than sheep and this difference could be explained by the fact that cattle were more likely than sheep, to be grazed in potential transmission sites both within and off-farm. It is also reported that fasciolosis due to *F. gigantica* is fatal in sheep (Hammond and Sewell, 1974). In this study however, fatalities due to fasciolosis were not common, suggesting probably that the sheep were only subjected to a low challenge. Although sheep and cattle in the study area were expected to be harbouring infections acquired over a long time, the periods of highest prevalence of infection occurred during the two main rainy seasons. This suggested that many of these infections could have been acquired either in the preceding dry season or earlier. Similar findings were reported from Mali (Traore, 1989, Tembely *et al.*, 1995) and in Kenya (Preston and Castellino, 1977; Wamae *et al.*, 1990) where most infections appeared to be acquired during the dry months of the year. Because of the scarcity of good pastures during these times of the year, livestock are forced to graze in potentially infected pastures, such as the shores of dams, water trenches, river beds,

irrigation furrows, marshy seepages and other shallow water habitats occupied by the snail vectors. These areas also serve as watering places during the dry periods. Another practice of local farmers, i.e. the digging of shallow trenches to drain water into the pastures and so improve growth of forage during the dry season, creates and allows the spread of suitable sites for snail intermediate hosts. This practice was observed during this study both within farms and also in communal grazing areas. An additional factor which may contribute to heavy infection with metacercariae during the dry season is the increased shedding of cercariae from snails which has been shown to occur during such periods (Ogambo-Ongoma, 1971).

Examination of faecal samples from animals on the farms was supplemented by monthly examination of local permanently grazed sheep for liver fluke burdens at necropsy. During the period of the study, a total of 63 ewes were examined, of which 21 were found to have various numbers of *F. gigantica*, representing a prevalence of infection of 33.3%. Because sheep infected with different stages of the liver fluke could be detected at *post mortem*, this figure is more likely to represent the actual prevalence of infection in sheep flocks in the study area than the figure of 5.6% obtained by faecal examination for fluke eggs. Although the fluke egg counts and burdens in the local sheep might not accurately reflect the seasonal pattern of infection in the area, they did serve to indicate the prevalence of liver fluke infection in the local flocks. The use of tracer lambs, on the other hand was more likely to show up any seasonal pattern of pasture availability with metacercariae of *F. gigantica* (Njau *et al.*, 1989). In this study, though parasites could be recovered after three weeks of housing, the extended period of six week housing significantly increased the success of parasite recovery for both tracers and permanently grazed sheep. The six week housing ensured that metacercariae picked up during the last days of grazing had the opportunity to develop into juvenile flukes that were large enough to be easily recognisable; this is the likely explanation for the higher counts in the delayed necropsy groups of sheep. Tracer animals have been incorporated in studies of the epidemiology of *Fasciola* infections by Malone *et al.*, (1985) in Louisiana, Owen (1989) in Papua New Guinea, Tembely *et al.*, (1995) in central Mali and Njau *et al.*, (1989) in the Ethiopian highlands. There have been no previous studies to establish infection patterns of *Fasciola* in Kenya by use of tracer animals.

The *post mortem* fluke recoveries from both tracer lambs and the permanently grazed sheep suggested that under natural conditions parasite burdens are generally low. The fluke burdens in the tracer lambs were below 100 liver flukes per animal while in the local sheep, fluke burdens of up to 199 were recorded. Liver flukes were recovered from the lungs on only one occasion, from the sheep that had the highest burden. The lungs are the other organ apart from the liver where flukes are frequently recovered (Sewell, 1966; Pandit, Mir and Banday, 1991). The three permanently grazed sheep that harboured the highest fluke burdens had been purchased from different farms, all of which bordered a large dam. Unfortunately, the history of the infections in the animals in those farms was not known.

Information from the tracer lambs in this study established that there were probably two distinct periods of high pasture infectivity with metacercariae. The first distinct period was during September and October 1995 followed by an apparent low challenge in November 1995 to January 1996. The second apparent period of high challenge was from February to April, 1996; the infection recorded in May 1995 was probably the end of a similar period in early 1995. This indicated that the heaviest contamination of pastures with cercariae probably occurred towards the end of the dry season and early into the rainy season. Similar observations were made in studies carried out in other parts of Africa, where the majority of animals were found to pick up infections in the dry season (Ogambo-Ongoma, 1971; Tembely *et al.*, 1995; Yilma and Malone, 1998). It has also been found that the snail intermediate host, *L. natalensis*, harbours more cercariae than pre-cercarial stages during the dry season (Ogambo-Ongoma, 1978), the reverse being true in the rainy season.

Studies by Malone *et al.* (1998), using geographical information systems had predicted that the highlands of Kenya would be generally unsuitable for *F. gigantica* transmission due to an inadequate thermal regime. It is apparent however, that *Fasciola* infection is widespread in the area of this study, indicating that temperature might be a less important factor than has been suggested in other epidemiological studies. Earlier work by Dinnik and Dinnik (1959) had shown that eggs of *F. gigantica* could develop into miracidia at all seasons of the year under the climatic conditions of the Kenya highlands, and that the

development of cercariae progressed slowly, taking 52 to 70 days in the warmer months and 109 days in the colder months. Later Dinnik and Dinnik (1963) reported that at temperatures less than 16 °C rediae did not develop into cercariae but when the mean maximum temperature reached 20 °C this development was rapid. Snails harbouring cercariae have since been found in areas of the Kenya highlands throughout both cold and the warm periods of the year (Preston and Castellino, 1977; Wamae and Cheruiyot, 1990) and Schillhorn Van Veen (1980) has reported cercarial shedding in Nigeria at temperatures between 13 °C and 18 °C. The results of the study reported here confirm that the Kenya highlands are suitable habitats for *F. gigantica.*

In the absence of accurate epidemiological data or a forecasting system, control of fasciolosis by farmers in any area is dependent either on their own experience of disease occurrence or on insufficient and often arbitrary advice from sources such as animal health workers or the pharmaceutical industry (Kinoti *et al.*, 1996; Malone, 1997). Any successful control programme requires the strategic application of appropriately timed prophylactic and curative treatments. This, in turn requires a good understanding of the local disease epidemiology in order to schedule treatments to achieve maximum effect with the fewest administrations. The FAO (Anon, 1994) has issued guidelines for recommendations on strategic treatment of fasciolosis, assuming the use of anthelmintics which are effective against flukes aged six weeks and older. On the basis of the present study in the central Kenya highlands, one annual treatment in October with a fasciolicide effective against all stages of *Fasciola,* i.e. triclabendazole, followed by treatment of individual clinical cases when they occurred is proposed. This single treatment is considered adequate in view of the low level of infections in cattle in the smallholder farms monitored in this study. It is expected that this treatment would reduce pasture contamination with fluke eggs because it is administered at a time when grazing animals would be harbouring young fluke stages, which are susceptible to triclabendazole. In the absence of triclabendazole, it is important that an alternative treatment regime be in place because most of the other fasciolicides used in cattle are only effective against adult liver fluke stages. Treatments should therefore coincide with the times of the year when grazing animals are harbouring susceptible fluke stages. From the results obtained from this study, three treatments per year are recommended. The first treatment, to be given in October, would be given at a time following a dry period when snail activity would be

low and when animals would be harbouring fluke stages susceptible to most fasciolicides. This treatment would reduce contamination of pasture with fluke eggs during the rainy season, which is the period when snail populations build up (Ogambo-Ongoma, 1971; Preston and Castellino, 1977; Wamae *et al.*, 1990). This would reduce the number of snails harbouring *F. gigantica* intramolluscan stages and thus reduce pasture levels of metacercariae into the next dry season. There is also a potential economic benefit from improved growth rate in young animals and higher production from breeding animals, especially lactating cows, which would better utilise the improved pastures in the rainy season when they are free of liver fluke infection. The second treatment should be in April. This treatment is aimed at removing fluke burdens which have been picked up during the apparent peak times of pasture infectivity with metacercariae in February and March. These infections probably result from animals being forced to graze around transmission sites during the preceding drought period. A third and final treatment should be administered in June. This treatment would ensure that those parasites not eliminated by the treatment in April (being younger than stages susceptible to the fasciolicides) were killed as adults at this time. It is advised that treatments be given within the first week of the months suggested in order to have a synchronised reduction in pasture infectivity. This is particularly important in the study area where off-farm grazing is a common practice. In all cases treatment should be given to occasional clinical cases that might occur between these suggested treatment times.

The above treatment regimes are intended for cattle in areas where infection with *F. gigantica* occurs and conditions favourable for its continued transmission exist. Sheep in these areas could be treated using broadspectrum anthelmintics (against nematodes and flukes) during the suggested times for the control of gastrointestinal nematodes (Chapter 4) in January and October, with a third treatment in April. Other farms in the study area and in other parts of the Kenya highlands where liver fluke infections do not occur should only apply control measures for parasitic gastrointestinal nematodes for both small ruminants and cattle. The above epidemiologically-based treatments for cattle were subsequently compared through an on-farm trial against the current control measures used by farmers in the study area (Chapter 7).

CHAPTER SIX

COMPARISON OF A RECOMMENDED INTERVENTION STRATEGY WITH EXISTING MEASURES FOR THE CONTROL OF GASTROINTESTINAL NEMATODES IN SMALL RUMINANTS ON SMALLHOLDER FARMS IN KENYA.

6.1 INTRODUCTION

The deleterious effects of infections with parasitic gastrointestinal nematodes in ruminants have been extensively investigated (Beck *et al.*, 1985; Nansen, 1986, Anderson *et al.*, 1987; Coop *et al.*, 1995) and the potential benefits of control, in terms of improved weight gains and reduction in mortalities have been demonstrated (Mukhebi *et al.*, 1985; Abdala, 1989; Muenstermann and Tome, 1989). The extent of improvements in productivity which may be derived from any helminth control regime will depend on factors such as magnitude of challenge and rate of re-infection following treatment (Shroder,1981).

Control of parasitic gastrointestinal nematodes can be achieved through the use of anthelmintics, farm management practices or a combination of the two (Brunsdon, 1980) but farm management practices on their own have been found to be ineffective in preventing build-up of infections (Bairden, 1991; Bairden *et al.*, 1991; Taylor *et al.*, 1991). There are also problems associated with frequent anthelmintic use especially the development of anthelmintic resistant parasites (Waller, 1997). The best approach, therefore, should be based on a combination of farm management and anthelmintics. Whereas such control strategies have often been reported in temperate areas of the world (Morley and Donald, 1980; Thomas, 1982) information from the tropics is scanty. Since infective larvae of nematodes can only survive on pasture for short periods at certain times of the year in some tropical areas (Barger *et al.*, 1994), periodic spelling of pastures may be effective in controlling infections (Uilenberg, 1996). This has been demonstrated to be useful in reducing worm burdens in goats in Cameroon (Fabiyi, 1987). A common practice in many countries of tethering and movement of goats to a new grazing area every one to two days could also be an effective low-cost control measure (Barger *et al.*, 1994), especially in view of the cost

of frequent anthelmintic treatment and the risk of selecting for resistant parasites. The option of spelling is difficult to apply in many tropical areas because livestock are reared on small areas of land and communal grazing is commonly practised. This often means that the use of anthelmintics is the only practical option in the control of disease.

The current helminth control practices in Kenya are based on occasional and haphazard anthelmintic treatments (Chapter 3; Mbaria *et al.*, 1995; Wanyangu *et al.*, 1996a; Maingi *et al.*, 1997a; Wanyangu *et al.*, 1997). The commonest practice, especially in cattle, is treatment every three months but in some farms anthelmintics are only used to treat animals when there is a perceived helminthoses problem. A small proportion of farmers do not use anthelmintics in small ruminants for treatment or prophylaxis.

Earlier epidemiological work by Dinnik and Dinnik (1958) showed that the survival of *H. contortus* larvae in pasture in the Kenya highlands was reduced during certain times of the year depending mainly on temperature and moisture. This suggested that strategic use of anthelmintics for chemoprophylaxis was possible in certain areas. In their subsequent studies, Dinnik and Dinnik (1961) suggested that anthelmintics should be given before the rainy season in order to reduce pasture contamination by infected animals at a time favourable for the development of eggs to L_3. Their further recommendation for treatments every three weeks in the rainy season was unlikely to be cost-effective especially for smallholder farms and, in retrospect, was likely to select for anthelmintic resistant strains of nematodes especially *H. contortus*. The recommendation by Chiejina *et al.* (1989) for the savannah region in Nigeria and Wanyangu *et al.* (1995; 1996a) for Kenya, to treat all small ruminants prior to the onset of the rainy season reduces the required treatment frequency and is likely to be more cost-effective in smallholder farming systems.

In the present study, a strategic anthelmintic regime was proposed following a field study of the bionomics of helminth infections in smallholder farms in the study area. This was evaluated in comparison with the existing helminth control practices by the local farmers, as it was not possible to have untreated animals in control farms. The

'control' farmers were therefore allowed to drench according to current practices and any treatments were recorded during monthly visits. Animals in the 'treated' group of farms received recommended treatments at pre-determined times which were based on the epidemiological information gained through the earlier studies. It was hoped that the results of this work would provide a foundation on which to base future helminth control advice for small ruminants in this and other similar areas of Kenya.

6.2 MATERIALS AND METHODS

6.2.1 Trial farms

There were a total of 80 smallholder farms selected as described in Chapter 2. These were randomly divided into 40 'treated' and 40 'control' farms. The details of the selection process for these farms were described in Chapter 2.4.2.

6.2.3 Anthelmintic treatments

The frequency and timing of the strategic treatments were based on the results of the epidemiological study reported in Chapter 4. This involved two annual treatments, one in January, using levamisole and another in October using closantel. Closantel was selected for its ability to prevent re-infection over extended periods of time for both *H. contortus* and *Fasciola gigantica* (Guerrero, 1984). The first treatment was given in January 1997 using levamisole, followed by a closantel treatment in October 1997. Levamisole was again used in January 1998. The drenches Wormicid® (1.5% levamisole HCl B.P., Cosmos Ltd., Kenya) and Flukiver® (1.5% closantel, Janssen Pharmaceutica) were the brands used in this trial. These anthelmintics were administered according to the dosage rates recommended by the respective manufacturers i.e. 7.5 mg per kg body weight for levamisole and 5 mg per kg body weight for closantel.

6.2.4 Trial design

All the sheep and goats in the treated group of farms were treated with the trial drugs at the times described above, whilst those in the control group were treated by the farmers according to their usual routine. A visit was made to the farms every month and the following parameters were recorded: animal weights, birth dates and weights

for lambs and kids born since the previous visit, anthelmintic usage (name and dosage), other treatments and diseases encountered since previous visit, deaths, home slaughter, sales and other reasons for absence of sheep from the farm. In addition, faecal samples were collected for nematode egg count determination. As an incentive to the participating farmers, they were supplied with mineral supplements for their sheep and cattle every three months. This trial was carried out between November 1996 and April 1998.

Monthly pasture samples were collected from the same sampling sites reported earlier and tracer lambs and permanently grazed local sheep continued to be used for monitoring the infection patterns with gastrointestinal nematodes during this phase of the study (Chapter 2).

6.2.5 **Data collection and storage**

Data from this phase of the study were entered into a custom designed form, corresponding to the format of data recording forms in Microsoft Access database as described in Chapter 2.5. Each animal in the trial had a paper data record form (Appendix 2) where all the data collected each month, including faecal egg counts, were recorded. In addition, the records contained the details about the animal including birth date and weight where known, identification number, date of entry into the trial and whether born on the farm or bought in. The individual animal records for a particular farm were carried in a folder which was identified by farm number, location of the farm and trial name, i.e. small ruminant trial.

The records for the animal and data from the visits were stored in a Microsoft Access database, whose design and description are detailed in Chapter 2.6.

6.2.6 **Parasitological techniques**

The parasitological techniques used in this trial were described in Chapter 2.9.

6.2.7.**Statistical analyses**

Simple analyses and transformations of data were carried out in Microsoft Access using specifically designed queries. Further analyses were carried out by first

interrogating the data by use of queries to extract parasitological and production data which were then exported into worksheets in Microsoft Excel. The visit dates were aggregated by month into sample times and given numbers; 1 for November 1996, 2 for December 1996 and so on up to number 18 for April 1998. The Microsoft Excel worksheets were exported to Minitab (Minitab for Windows, Release 10.2, Minitab Incorporation) for analyses.

The effect of the intervention status (treated group or control group) on the faecal egg counts in sheep and goats in the trial farms was investigated using the General Linear Models (GLM) programme in the Minitab computer package (Minitab for Windows, Release 10.2, Minitab Incorporation). Faecal egg counts were logarithm-transformed in the form of $\log_{10}$ (EPG +100) to stabilise the variance prior to analyses. The effects of time of sampling and age category (young or adults) were also investigated. For the purpose of the parasitological analyses, young animals were defined as those aged 6 months and younger and adults those aged over 6 months. Growth rates were compared between treated and control farms in animals aged one year and younger. These were calculated as weight difference from the first sampling to the last sampling and dividing this by the total number of days to give the mean growth rate in grams per day.

6.3 RESULTS

6.3.1 Epidemiology of nematode infections

6.3.1.1 Weather data

The weather pattern (rainfall, minimum and maximum temperature) in the study area during the period of the trial is shown in Figure 30. The pattern was generally similar to the average for the area. There were however some notable differences both at the beginning and at the end of the study. The dry period that followed the short rains at the end of 1996 was more severe in the study area than the previous year while the duration of the short rains which began in November 1997, extended beyond the normal time (i.e. December 1997 to April, 1998). The extended period of rains was attributed to the *el nino* weather phenomenon.

6.3.1.2 **Pasture larval counts**

Pasture larval counts were monitored for a period of 18 months during the intervention trial, from November 1996 to April 1998. The mean of the total larval counts for the sites sampled each month are shown in Figure 31, while the differential counts for each of the sites are presented in Appendix 15. There were no infective larvae recovered from any of the sampling sites in January, February and August 1997, while March, May, and September 1997 were characterised by low mean larval counts of less than 100 L_3/Kg DH. The highest mean larval counts were recorded in April 1997. Other months with high mean larval counts in order of abundance were December 1997, January 1998 and November 1996 respectively.

The majority of infective larvae recovered were *Haemonchus* spp. Overall, the prevalence of the larvae recovered according to genera were as follows: *Haemonchus* (35.4%), *Trichostrongylus* (26.8%), *Cooperia* (26.8%) and *Oesophagostomum* (11.0%). Statistical analyses showed that time of sampling had a significant effect on the number of larvae recovered from herbage but there was no difference between sampling sites.

6.3.1.3 **Total worm counts**

6.3.1.3.1 **Tracer lambs**

The mean monthly nematode counts from the tracer lambs are shown in Figure 32 while the total and differential counts from individual animals are presented in Appendix 16. The mean worm counts were low during the initial months of the study from November, 1996 to March, 1997, with no parasites recovered from the tracer lambs in February, 1997. There was a slight increase in mean worm burdens from April to July 1997 followed by a period of low counts in August and September. The mean number of worms recovered from the tracers increased from October 1997 and remained high up to the end of the study in April with the exception of a reduction observed in January 1998.

In the majority of the months, *H. contortus* was the most predominant nematode species recovered from the tracer lambs. Over the duration of the study, the overall

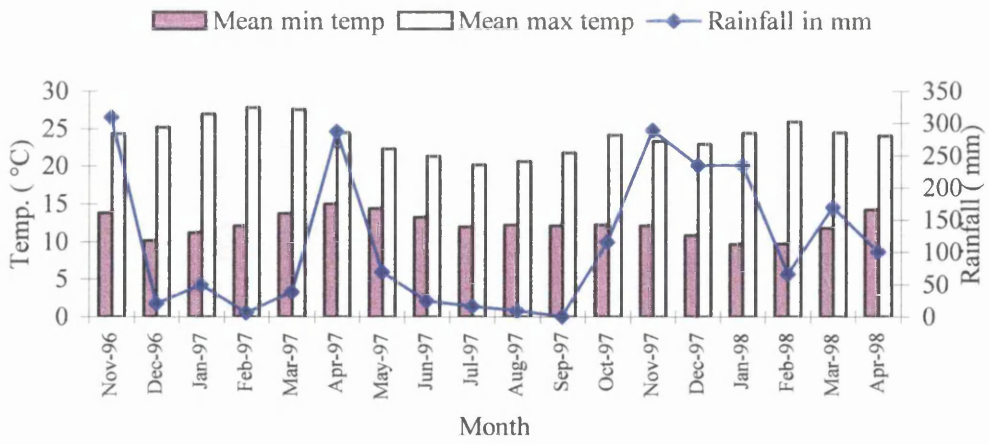

Figure 30: Monthly rainfall, minimum and maximum temperatures for the duration of the intervention trial between November 1996 and April 1998.

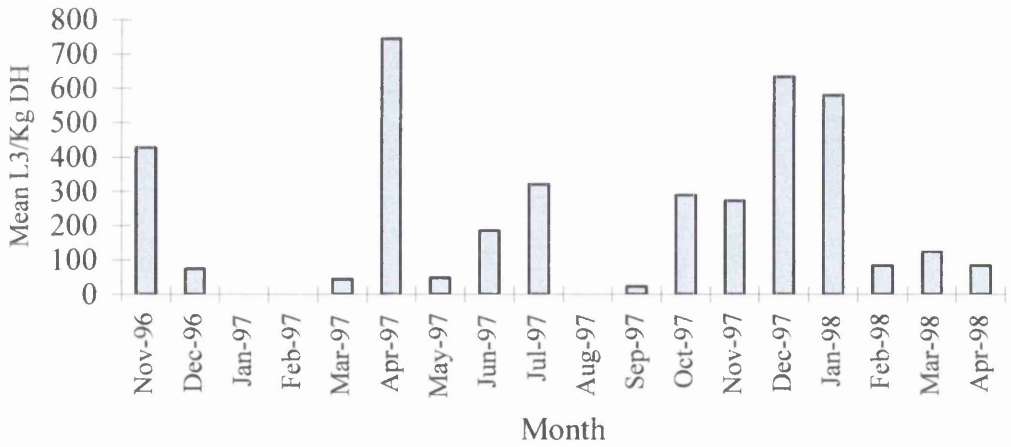

Figure 31: Mean pasture larval counts for the eight sampling sites at the study area from November 1996 to April 1998.

prevalence of different nematode species in the tracers was as follows: *H. contortus* (59.9%), *T. axei* (28.9%), *T. colubriformis* (10.1%), *Cooperia* spp. (1.1%). The three major species are compared in terms of abundance in Figure 33.

Statistical analyses showed that there was highly significant variation over time ($p< 0.0001$) in the total worm burdens carried by tracer lambs but the duration of housing prior to necropsy did not influence the total worm burdens ($p> 0.05$).

6.3.1.3.2 **Permanently grazed sheep**

The mean total worm counts from the permanently grazed sheep are shown in Figure 34, while the details of the differential and total counts are shown in Appendix 17. There were infected sheep in every month of the study but the worm burdens varied widely during the study. The months with high mean worm counts (>2000) were February, April, June, October and December 1997 and January 1998. The other months were associated with lower mean worm counts. On many occasions, *T. axei* were more prevalent than *H. contortus*. *Trichostrongylus colubriformis* were also recorded in high proportions during the study. The relative prevalence of these three common species has been compared in Figure 35. The overall distribution of the different nematode species over the 18 month study period was as follows: *H. contortus* (27.4%), *T. axei* (50.6%), *T. colubriformis* (20.9%), *Cooperia* spp. (1.0%) and *Oesophagostomum* spp. (0.1%).

Statistical analyses showed a highly significant effect of time of purchase of the permanently grazed sheep on worm burdens ($p< 0.0001$) but the duration of housing prior to necropsy (three or six weeks) had no effect. The permanently grazed sheep had significantly higher *T. axei* and *T. colubriformis* counts than the tracer lambs ($p< 0.0001$) but there were no significant differences in total worm burdens or in numbers of *Cooperia* spp. ($p> 0.05$).

The tracer lambs had significantly higher *H. contortus* burdens than the permanently grazed sheep and the reverse was observed for burdens of *T. axei* ($p< 0.0001$). The

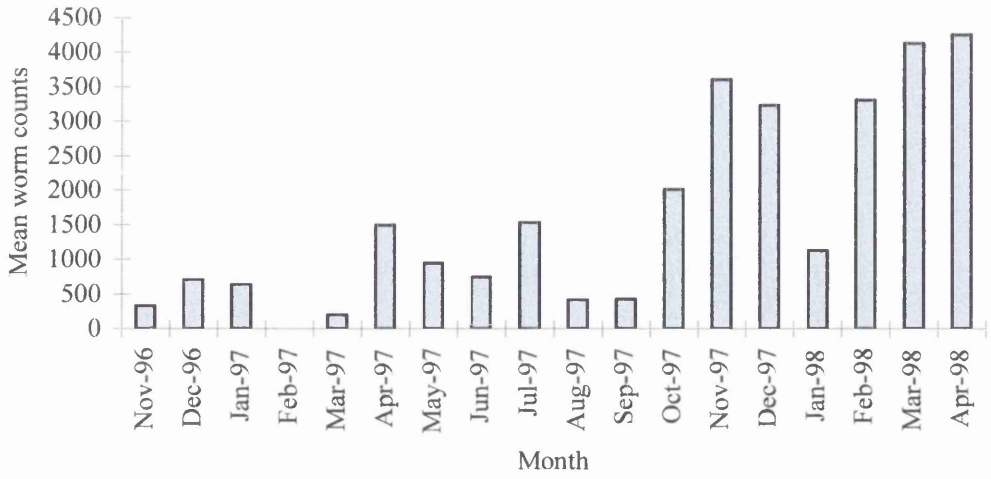

Figure 32: Mean nematode worm counts from the group of six tracer lambs during each month of grazing at the study area from November 1996 to April 1998.

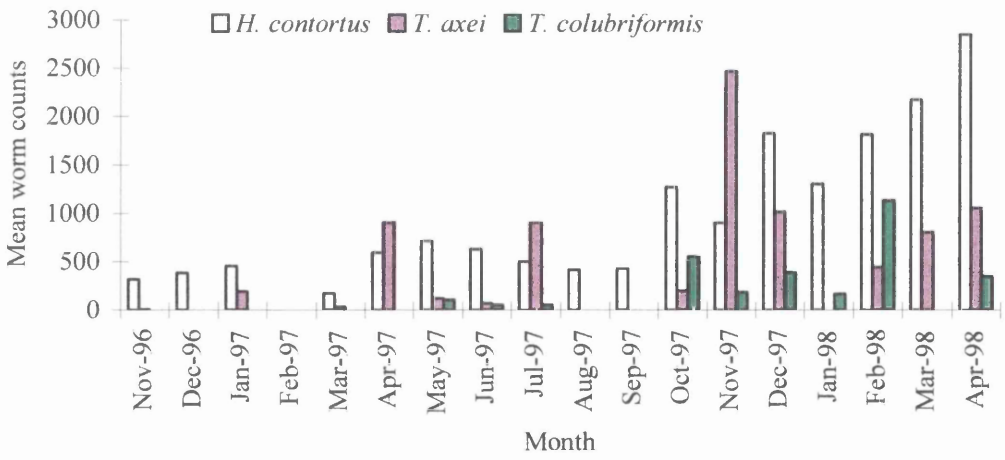

Figure 33: A comparison of *H. contortus, T. axei* and *T. colubriformis* worm burdens in the tracer lambs during the 18 months of the study.

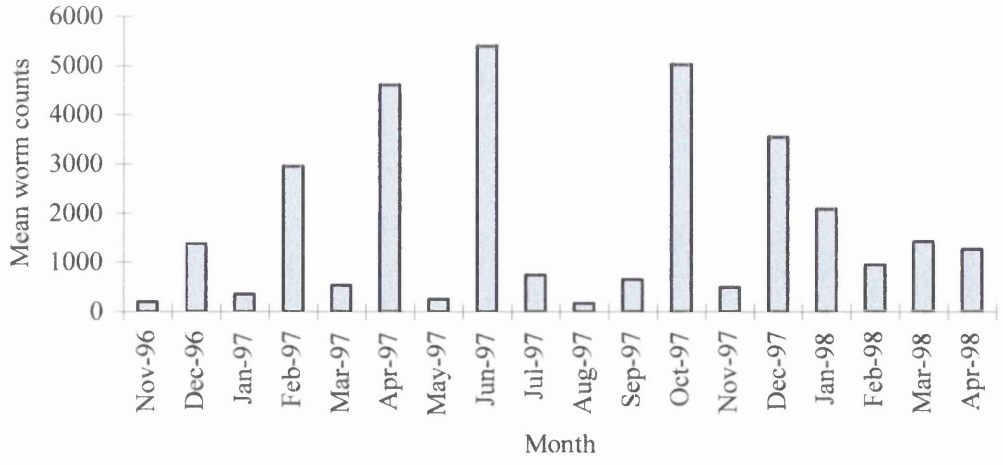

Figure 34: Mean nematode worm counts from the group of permanently grazed sheep each month from November 1996 to April 1998.

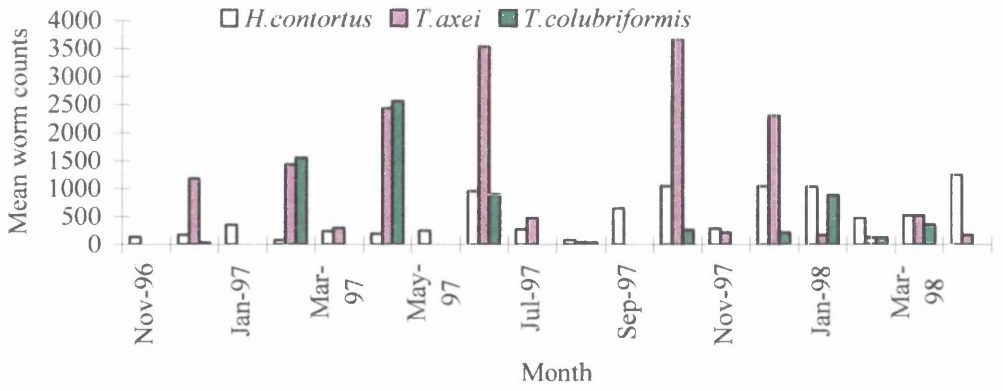

Figure 35: A comparison of *H. contortus, T. axei* and *T. colubriformis* worm burdens in the permanently grazed sheep during the 18 months of the study.

differences in total worm burdens and in *T. colubriformis* and *Cooperia* spp. burdens between the tracer lambs and permanently grazed sheep were not statistically significant ($p > 0.05$).

6.3.2 Evaluation of the intervention trial

6.3.2.1 Farms and animal numbers in the trial

There were initially 40 smallholder farms in each of the trial groups, i.e. the group receiving the trial treatments (treatment group) and the control group which was to continue with the local helminth control practices (control group). The distribution of these farms in the study area is shown in Figure 36. There were three withdrawals within the first two months (2 in the treated and 1 in the control group), while a further 3 farms (all in the treated group) sold all of their sheep in January 1997. The reasons given for the withdrawals were 'lack of benefits from the trial', while one of the farmers did not approve of the faecal sampling technique. All of these farms were not considered in the analyses of the data, leaving a total of 35 farms in the treated group and 39 in the control group. The number of sheep (lambs and adults) sampled each month from the two groups of farms are shown in Table 13 while the number of goats are shown in Table 14. The number of animals sampled each month from these groups of farms averaged 213 sheep and 33 goats in the treated group and 248 sheep and 31 goats in the control group.

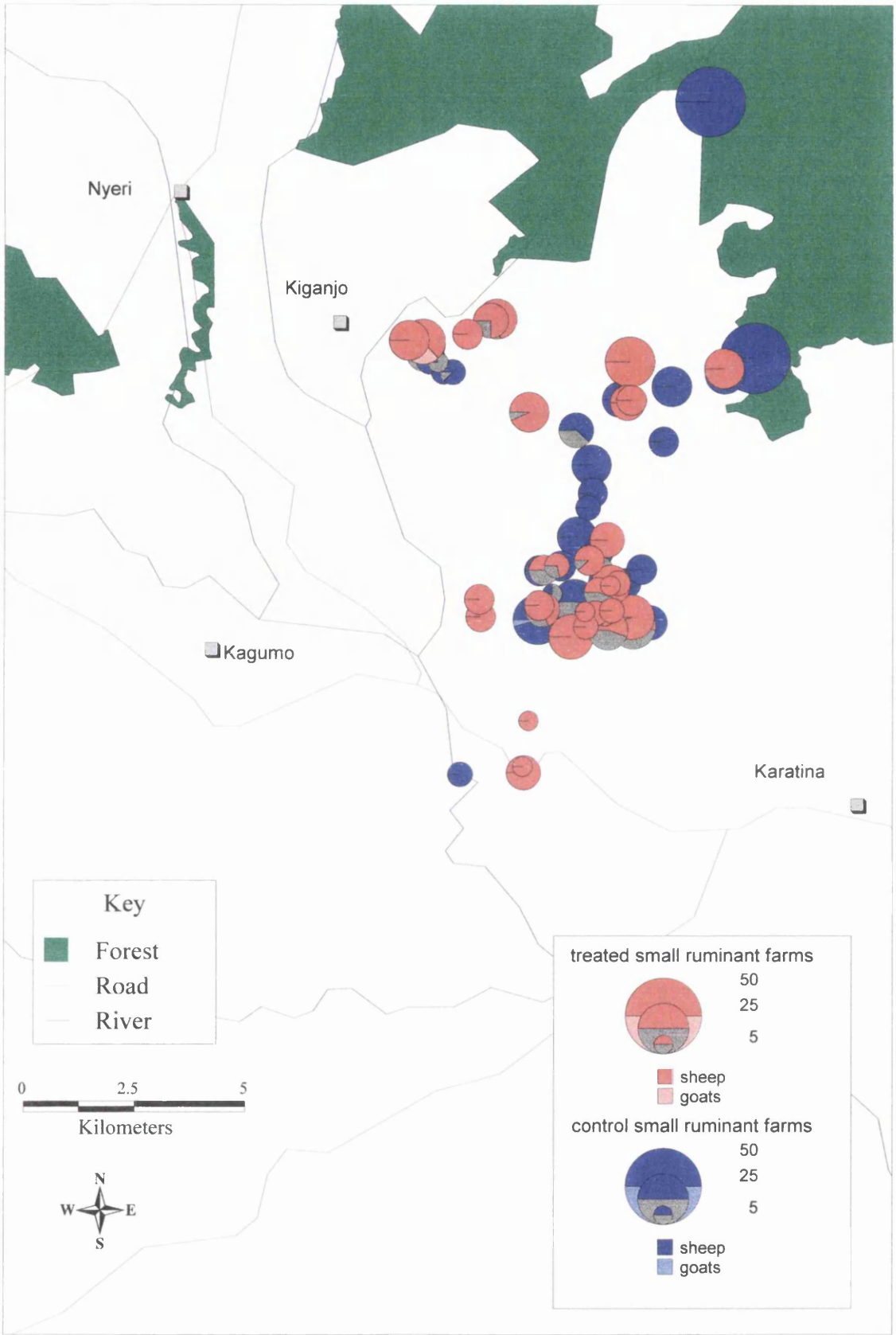

Figure 36: The distribution of small ruminant farms. Treated farms are shown by a red pie, control farms by a blue pie.
Sheep are shown with solid shading, goats diagonal line shading.
Diameter of the pie is proportional to the number of animals on farm.

Time	Treated farms		Control farms	
	Lambs	Adult	Lambs	Adults
1996				
November	46	152	46	173
December	53	159	63	195
1997				
January	54	170	63	202
February	55	160	48	194
March	46	160	42	195
April	32	171	32	196
May	32	183	33	205
June	23	192	27	210
July	33	188	30	207
August	32	189	38	205
September	51	175	58	206
October	49	180	54	219
November	41	166	56	202
December	43	187	54	210
1998				
January	46	182	64	215
February	49	162	63	202
March	34	168	40	213
April	28	162	30	196
Mean ±SD	41.5 ±9.8	172.5 ±12	46.7 ±13.1	202.5 ±10.4

Table 13: Number of lambs and adult sheep sampled every month from the treated and control farms.

Time	Treated farms		Control farms	
	Kids	Adults	Kids	Adults
1996				
November	5	18	5	18
December	6	24	7	22
1997				
January	6	25	7	21
February	6	25	6	19
March	2	27	5	23
April	1	25	5	25
May	1	26	4	26
June	1	31	3	26
July	2	33	2	27
August	1	34	4	34
September	3	34	6	34
October	8	32	6	34
November	7	24	8	31
December	8	31	8	29
1998				
January	10	31	6	26
February	9	31	7	23
March	7	31	2	28
April	4	33	2	27
Mean ±SD	4.8 ±3.0	28.6 ±4.5	5.2 ±2.0	26.3 ±4.9

Table 14: Number of kids and adult goats sampled from the treated and control farms.

6.3.2.2.Anthelmintic treatments and costs

All the treatments were given as scheduled, with levamisole (Wormicid®, Liquid drench, Cosmos Ltd.) in January 1997 and 1998 and closantel (Flukiver®, Jansen Pharmaceutica) in October 1997. Farmers in the control group of farms treated their small ruminants at different times of the year and with different types of anthelmintics as shown in Table 15. Some farmers in the treated group of farms also treated some animals between the scheduled treatments. The number anthelmintic doses used each month and the total cost of the treatments in the two groups of farms are shown in Table 16. Apart from the two types of drenches used in the scheduled treatments in the treated farms, another 5 brands of drenches were used by farmers. These were Fasinex® (10% triclabendazole, Kenya Swiss Ltd.), Valbazen® (2.5% albendazole, Kenya Swiss Ltd.), Levafas® (1.5% levamisole, Norbrook Labs. Ltd.), Wormicid plus® (1.5% levamisole and 8% bithionol, Cosmos Ltd.) and Vetworm® (1.5% levamisole, Lab and Allied Ltd.) respectively, in order of frequency of use.

The cost of anthelmintic treatments were the current prices of commonly used drenches. The average cost of one dose for an adult sheep or goat of average weight of 20 kg or a weaned lamb or kid was estimated at Kenya shillings (Ksh.) 10.00, based on the average purchase price of drenches used commonly by farmers. The total cost of anthelmintic treatments for the sheep in the treated group were higher than the cost of treatment in the control group.

Anthelmintic name	Treated group	Control group
Flukiver	229	6
Fasinex	40	12
Levafas	20	
Nilzan plus		3
Vetworm		5
Valbazen		35
Wormicid	595	470
Wormicid plus		6
Total no. of treatments	884	537

Table 15: The types of anthelmintics and frequency of usage in both treated and control group of farms during the intervention trial. The figures indicate the number of doses of drug used over the entire study period

Time	Treated farms	Control farms
1996		
November	0	0
December	0	0
1997		
January	**227**	6
February	1	59
March	17	89
April	44	1
May	56	10
June	10	9
July	27	65
August	30	2
September	0	55
October	**229**	74
November	0	12
December	17	19
1998		
January	**226**	52
February		18
March	0	66
April	0	0
Total no. of treatments	884	537
Cost of strategic treatment	Ksh. 6,820	nil
Cost of treatment by farmers	Ksh. 2,020	Ksh. 5,370
Total cost of treatments	Ksh. 8,840	Ksh. 5,370

Table 16: Number of anthelmintic doses used each month within the treated and control groups of farms as well as the total cost of the treatments. The scheduled treatments in the treated group of farms are shown in bold.

6.3.2.3. **Comparisons of birth weights of lambs**

During the trial, there were 40 lambs in the treated group and 48 in the control group of farms whose birth weights were recorded. The birth weights in the treated group ranged from 1.0 - 4.5 Kg with a mean of 2.4 ± 0.6 Kg. Those in the control group had birth weights ranging from 1.0 - 5.0 Kg and a mean of 2.5 ± 0.4 Kg. Statistical comparison showed that there were no statistically significant differences between the birth weights of lambs on treated and control farms ($p > 0.05$). The kids born from does in the two groups were too few for any meaningful comparisons.

6.3.2.4 **A comparison of off-take in treated and control farms**

The most frequent cause for exit (other than death) of animals from the flocks in the treated and control farms were sale followed by home slaughter. Animals also left the flocks as gifts or through other reasons such as exchange for breeding stock (Table 17). More animals were slaughtered in the treated than in control farms but the reverse was observed for sales, gifts and other forms of off-take. Overall, the off-take was higher in the control group as compared to the treated group of farms.

Type	Treated group		Control group	
	Sheep	Goats	Sheep	Goats
Slaughter	37	1	30	6
Sale	61	7	86	5
Gifts	2	0	3	0
Others	4	4	11	2
Total	104	12	130	13

Table 17: Comparison of off-take in treated and control groups of farms

6.3.2.5 **Mortality**

The majority of deaths in the treated and control group of farms were attributed to respiratory conditions. The number of sheep and goats that died in the treated farms were fewer than those in the control farms. There were 59 sheep and 5 goat deaths in the treated group as compared to 64 sheep and 8 goat deaths in the control farms.

6.3.2.6 **Growth rate in young sheep and goats**

In sheep, the growth rate was compared between 172 lambs in the treated and 204 lambs in the control group (total = 376). Overall, the growth rate varied from 1.4 - 523.9 gm per day. In the treated group this varied from 10 - 523.9 with a mean of 51.9 gm per day while in the control group it varied from 1.4 - 155 gm per day and a mean of 45.2 gm per day. There was significant variation between farms in terms of growth rate of lambs aged less than one year ($p< 0.05$) but when the variation due to farm was controlled, there was no significant treatment effect ($p> 0.05$). Overall, there was also no significant difference between growth rates between the treated and control farms.

In goats, growth rate of animals less than one year was compared between 24 kids in the treated group and 19 kids in the control group of farms (total = 43). Overall, the growth rate of kids varied from 13.9 - 666 gm per day. In the treated group of farms the growth rate varied from 13.9 - 666 gm per day with a mean of 74.3 gm per day, while in the control group this varied from 15.5 - 128 and with a mean of 43.1 gm per day. Statistical analysis showed that there was no significant variation attributable to either farm or treatment in the growth rates of young goats.

6.3.2.7 **Faecal egg counts in sheep**

The mean monthly faecal egg counts (FEC) for lambs (aged six months and younger) and adults (aged over six months) are shown in Figures 37 and 38 respectively. Prior to the anthelmintic treatments in January 1997, the mean FEC in the two groups were similar both in the adult sheep and in the lambs. The January treatment with levamisole was followed by a sharp drop in mean FEC in February for the sheep (both lambs and adults) in the treated group whilst the mean FEC in the control farms increased in February. The mean FEC increased in March 1997 in the treated group of animals, after which the mean FEC in the two groups declined; this being observed in both lambs and adults. There was a rise in FEC in both lambs and adult sheep in August 1997 which was followed by a gradual decline through to December 1997. The closantel treatment in October 1997 was followed by a less dramatic effect on mean FEC, with very little drop in infection in lambs and adults in November 1997 but

the infection was low between October and December in both groups of farms. The treatment in January 1998 using levamisole resulted in a sharp drop in mean FEC in lambs in the treated group from a mean of 2,359 EPG in January, to 860 EPG in February. There was no apparent effect of the January 1998 treatment in the adult sheep, with the mean FEC actually increasing slightly in both treated and control groups. The levels of infection in both groups remained similar between February and April 1998, being slightly higher in lambs as compared with adult sheep.

In both lambs and adult sheep statistical analyses showed that there was significant variation in faecal egg counts over time and between individual farms ($p< 0.0001$) though no significant difference was detected between treated and control groups of farms ($p> 0.05$). In the adult sheep, there was a highly significant variation in faecal egg counts attributable to treatment and time interaction ($p<0.0001$). This showed that there were significantly higher faecal egg counts in the control group compared with the treated group of sheep at specific time points during the study.

6.3.2.8 **Faecal egg counts in goats**

The mean FEC for the adult goats (older than six months) for the treated and control group of farms are shown in Figures 39. The number of kids examined each month in the two groups of farms was too small for any meaningful comparisons. The mean FEC in adult goats were almost identical between groups prior to the levamisole treatment in January 1997. For the adults in the treated group, the levamisole treatment in January 1997 resulted in a reduction in the mean FEC, the infection in the control group being slightly higher. The mean FEC for both groups remained generally low up to August 1997, when there was an increase in mean FEC from 503 EPG in July to 1,277 EPG in treated and 396 EPG and 797 EPG in control farms respectively. There was a simultaneous drop in mean FEC in both groups in September to 270 EPG and 207 EPG in treated and control groups respectively.

At the time of closantel treatment in the treated farms in October 1997, the mean FEC for both groups had increased. The closantel treatment in goats, unlike in sheep, resulted in a drop in infection from 703 to 75 EPG in October and November respectively. This low level of infection was maintained through to December in the

treated group. In December, the mean FEC in goats in the control group had also dropped to a minimum of 13 EPG. There was a rise in mean FEC in January 1998, at the time of levamisole treatment . This treatment resulted in a less dramatic reduction in mean FEC in February 1998, followed by a further increase in this group in March 1998 which had reached a peak in April 1998, the last sampling date. The mean FEC for goats in the control group were higher than in the treated group in February 1998 and March 1998 but lower than in the treated group at the end of the study in April 1998.

In the adult goats, statistical analyses showed that there was significant variation in faecal egg counts over time and between individual farms ($p < 0.0001$) though no significant difference was detected between treated and control group of farms ($p > 0.05$). There was a highly significant variation in faecal egg counts attributable to treatment and time interaction ($p < 0.0001$), suggesting that there were significant differences between treated and control groups at specific times during the study.

6.3.2.9 **Other parasitological observations**

Infections with *Fasciola* spp. were recorded in sheep throughout the study with the proportion of infected animals varying from 0 - 5.1% and 0.4 - 5.8% in the treated and control groups of farms respectively. The October treatment with closantel, which is also flukicidal, resulted in a reduction in the proportion of animals infected with liver fluke in this group of farms to zero in November and December. These two months were the only times when there were no infections recorded in sheep during the study.

In goats, only a low prevalence of *Fasciola* infections was recorded in December 1996, January 1998, February 1998 and April 1998. All of these infections were recorded in animals within the treated group of farms. As in the sheep, there were no infections detected for two months following treatment with closantel in October 1997.

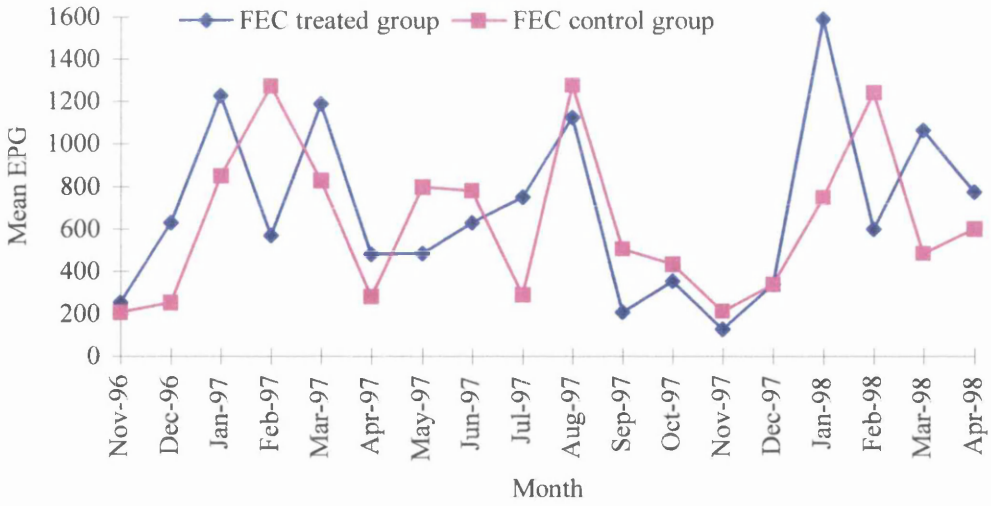

Figure 37: A comparison of mean faecal egg counts for lambs younger than six months in the treated and control groups of farms.

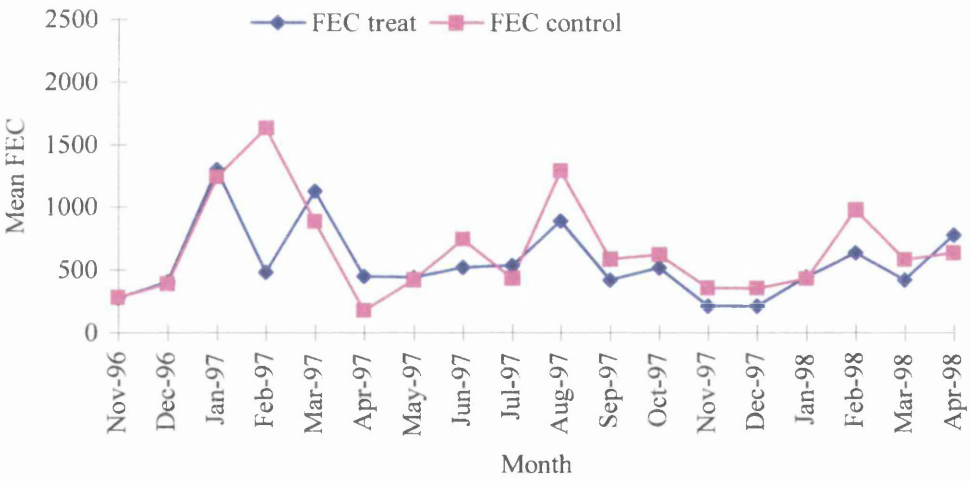

Figure 38: A comparison of mean faecal egg counts for sheep older than six months in the treated and control groups of farms.

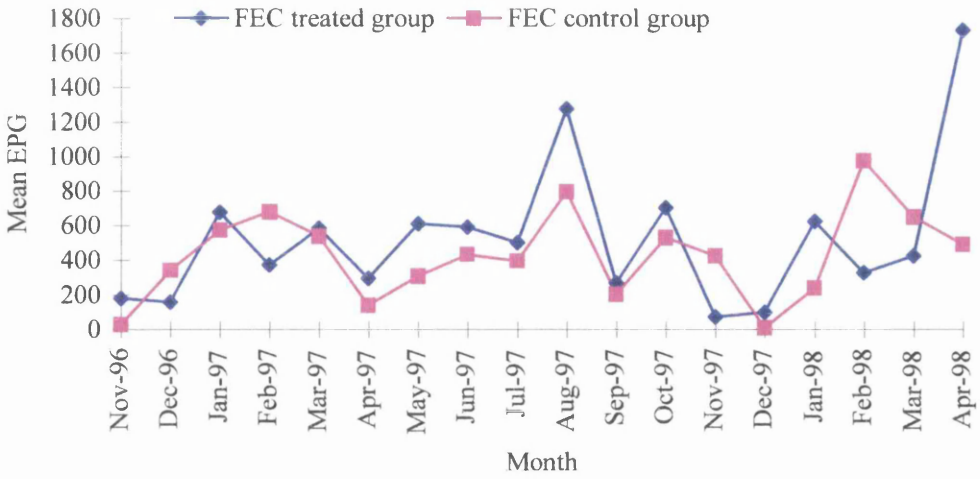

Figure 39: A comparison of mean faecal egg counts for goats older than six months in the treated and control groups of farms.

6.4 DISCUSSION

The additional period of investigation of pasture infectivity with infective nematode larvae and the monitoring of worm burdens in tracer lambs and permanently grazed sheep in this phase of the study, extended the observations reported in Chapter 4. The results from this period of study were similar to those obtained previously and further demonstrated the strong association between the level of infection and rainfall. However, there were some slight differences in the levels of pasture infectivity and levels of infection in the tracer lambs that could be attributed to the unusual weather experienced during certain periods. For example, the early period of the study was characterised by a drought from December 1996 to March 1997. This was reflected in the very low numbers of infective larvae recovered from pasture samples, none being recorded in January 1997 and February 1997. Consequently, the tracer lambs grazing in the area over this period picked up very few parasites. The arrival of the long rains in April 1997 resulted in an increase in both pasture contamination as well as in levels of infection in tracer lambs grazing in the area from April 1997 through to July 1997. The dry period that followed between August 1997 and September 1997 was again reflected in reductions in pasture contamination and infection levels in the tracers. The effects of rainfall on levels of nematode infection was further demonstrated during the unusually extended wet period between November 1997 to April 1998 which was attributed to the *el nino* phenomenon. Over this period higher levels of infection also occurred in the tracer lambs. The slight reduction in pasture larval counts which occurred over the same period can probably be explained by the direct effect of excessive rainfall washing larvae from the herbage. In spite of these slight changes in infection pattern observed in the last months of the study, the results confirmed the general appropriateness of the timing of strategic treatments suggested in Chapter 4.

Worm recoveries from both the tracer lambs and the permanently grazed sheep also confirmed the earlier observations on the relative prevalence of *H. contortus* and *Trichostrongylus* spp. The tracer lambs harboured significantly higher numbers of *H. contortus* than *T. axei* and *T. colubriformis* compared with the situation in the permanently grazed sheep where the reverse was true. The results of earlier studies by Preston and Allonby (1978, 1979) and Mugambi *et al.* (1997) on the resistance of the Red Maasai and susceptibility of the Dorper breeds of sheep to *H. contortus* help to

explain this observation. These results also cast doubt on the suitability of closantel in the strategic treatment in the study area where local sheep harboured more *Trichostrongylus* spp. than *H. contortus*. While the use of closantel has been advocated because of the benefit of its persistence and high efficacy against *H. contortus* (Hall, 1981; Guerrero, 1984; Dash, 1986), the results from the two phases of this study, where local sheep were found to be infected with more *T. axei* and *T. colubriformis* than *H. contortus* showed that closantel might not be an appropriate choice for this area.

The on-farm intervention trial compared the recommended strategic treatment regime with the farmers' normal anthelmintic control practices. Prior to the administration of the first treatment in January 1997, the infection levels in the treated and control groups of farms were similar but this was followed by a reduction in mean FEC in the treated group in February 1997. In this study, sampling of the animals after treatment could not be carried out within 10 - 14 days as recommended to assess the efficacy of the treatment (Coles *et al.*, 1992). As a result, the FEC recorded in February 1997 was not an indication of the efficacy of levamisole treatment as sufficient time had elapsed for the establishment of new infections in the treated animals. The recorded FEC were therefore an indication of new infections acquired after elimination of the previous worm burdens.

Between the first treatment and the next one in October 1997 the mean FEC in the two groups of sheep remained generally low. However, there was a period in March 1997 and April 1997 when the sheep in the control farms had a lower mean FEC than the treated group. This period was associated with treatments of sheep by the majority of the farmers in the control group, probably as a precautionary measure for the anticipated risk of high infections during the long rains. That was the only period where the mean FEC in the treated group of farms was higher than that of the control group prior to the second treatment in October 1997. This observation was made in both lambs and adults. It is also worth noting that some animals in the treated group of farms received treatment during this period, the majority being treated in April and May. These treatments were given by the farmers or extension staff in between the scheduled drenching to treat what they perceived as clinical cases of helminthoses.

Under the study protocol farmers were allowed to have their animals treated for any clinical disease, including helminthoses, when such diagnosis was arrived at by the animal health assistants or by the veterinarians.

The decision to use closantel for the second treatment in October was based on the results of the first phase of the epidemiological study; namely the finding that *H. contortus* were the most prevalent nematode larvae in pasture and the most prevalent parasite in the tracer lambs. The findings from the permanently grazed sheep at that time were not clearly understood and their possible significance in the development of a control programme had not been fully considered. In addition, closantel was considered a good choice due to its ability not only to remove existing *H. contortus* burdens but to prevent re-infection of the host with this parasite for an extended periods of up to two months after treatment (Hall *et al.*, 1981; Guerrero, 1984; Owen, 1988; Barger, Hall and Dash, 1991), and thus to reduce pasture contamination. Since the study area had been identified as a liver fluke area, the use of closantel was expected to give additional benefits in sheep infected with both *F. gigantica* and *H. contortus*. Subsequent analysis of data from the second phase of the epidemiological study confirmed what was observed earlier (Chapter 4), that *Trichostrongylus* spp. were more prevalent than *H. contortus* in local sheep flocks. The use of closantel in October 1997 however was associated with only a slight reduction in mean nematode FEC in both lambs and adult sheep. The implication of this observation was that in the local sheep, which harboured more *Trichostrongylus* spp. than *H. contortus*, the treatment eliminated only a small proportion of the worm burdens. The *Trichostrongylus* spp. and other non-blood feeding nematodes were unaffected by closantel treatment (Guerrero, 1984) and were responsible for the observed FEC over the subsequent month during which the drug would have been protective against haematophagous parasites like *H. contortus*. In this regard it was noteworthy that in the treated group of farms there were no sheep infected with *Fasciola gigantica* for two months following closantel treatment in October. Closantel has flukicidal activity against *F. gigantica*, older than 4-6 weeks (Guerrero, 1984; Anon, 1990; McKellar and Kinabo, 1991). This was the only occasion when there were no sheep of either age group infected with *Fasciola* spp. during this phase of the study. This finding was

a confirmation that closantel treatment ensures a reduction in fluke egg counts for periods of up to nine weeks.

It was expected that the lambs in the smallholder farms could be harbouring more *H. contortus* than *Trichostrongylus* spp. just like the Dorper tracer lambs at the time of treatment. They were at an age when they were expected to be highly susceptible to *H. contortus* (Gamble and Zajac, 1992; Gray *et al.*, 1992; Gray, 1997) prior to development of immunity, hence should have responded better to closantel treatment than the adult sheep. The fact that there was only little change in mean FEC following treatment was an interesting finding. This might suggest that the relative prevalence of their worm burden could be similar to that of the adult sheep or the rate of re-infection with *Trichostrongylus* spp., following expulsion of *H. contortus* by closantel treatment, was very high and accounted for the observed FEC.

Closantel treatment in goats on the other hand was followed by sharp decline in mean nematode FEC from 704 EPG in October to 75 EPG in November. The mean FEC remained low even in December 1997, suggesting that the treatment could have had the effect of preventing re-infection with *H. contortus* over the two month period. It was likely that this difference might be related to goats being relatively more susceptible to *H. contortus* than the local sheep. In this study this possibility was not investigated because there were no goats necropsied for worm recovery. From results reported here, it might be worth investigating in future studies for the benefit of future helminth control recommendations.

At the time of treatment with levamisole in January 1998, the level of infection in the lambs had increased in the two groups, being higher in the treated group than in the control group. The mean FEC in the adult sheep of the two groups were similar. Treatment in the lambs resulted in a reduction in the mean FEC in February 1998 followed by a gradual rise through to April. In the adult sheep, treatment was not associated with any reduction in mean FEC, instead there was a slight rise in February 1998 and a drop in March 1998. During these two months, the mean FEC in the treated group of adult sheep was lower than in the control group. At the end of the

trial in April 1998 the mean FEC in the treated group was similar to that in the control group.

The effect of the third treatment with levamisole in January 1998 was probably masked by the changes in levels of pasture infectivity associated with the extended rainfall period between November 1997 and April 1998. The exposure to high levels of re-infection immediately after anthelmintic treatment are thought to diminish the benefits of treatment (Schroder, 1981). The high rainfall recorded over the extended period from November 1997 to April 1998 was not typical for the area. This rainfall resulted in an increase in the levels of pasture larval infectivity during times of the year normally associated with drought and reduced pasture larval numbers. This was reflected in the worm burdens in tracer lambs that grazed at that time. Also, in the adult sheep in the treated group of farms, treatment in January 1998 led to no observed reduction in mean FEC. Although there was a reduction in mean FEC in February in the lambs, the high challenge led to an increase in the mean FEC in the treated as well as in the control group in the subsequent months of the study. Thus it is likely that re-infection had occurred before the first post-treatment samples were taken because of the four week delay between drenching and next farm visit, as explained earlier.

The apparent failure to detect significant differences in the faecal egg counts in the treated and control groups of animals could partly be explained by the relative composition of different nematode species in the local sheep. Earlier studies by Waller and Thomas (1981) and Courtney (1983) had shown that *Trichostrongylus* spp. have a long adult life span and continue to accumulate with time. In contrast, *H. contortus* has a short adult life span and a rapid generation turnover. This would mean that in the face of constant re-infection, as was the case in the study area, repeated anthelmintic treatment was only beneficial against the effects of the long-lived parasites (Donald and Waller, 1982) such as *T. axei* and *T. colubriformis,* than those with a rapid population turnover (i.e. *H. contortus*). This was probably the reason why statistical analyses showed a highly significant treatment and time interaction in adult sheep but no overall effect of the strategic treatment. It is apparent that the use of closantel in the October treatment was less effective in sheep than anticipated and

that a broad spectrum anthelmintic might have been more effective in reducing worm burdens in the treated group of sheep.

This study had also to contend with the fact that the treated animals were not grazed exclusively in their farms and in most cases they shared communal grazing areas. This meant that the benefits of reduced egg output and thus larval contamination of farm paddocks following anthelmintic treatment were unlikely to be realised. The treated animals were exposed to high challenge as a result of grazing alongside untreated flocks in the roadsides and other communal grazing areas. In addition, the levels of pasture infectivity across farms as well as the type of management including level of nutrition were different. This made the trial unique in that there were no non-anthelmintic treated groups of animals serving as controls. Results from the limited number of studies evaluating the effect of treatments on smallholder sheep production in Kenya had compared groups of sheep on certain treatment regimes with others on no anthelmintic treatment (Muenstermann and Tome, 1989; Maingi *et al.*, 1997b; Peeler and Omore, 1997). It was then easy to demonstrate the benefits of anthelmintic treatments by comparing both parasitological and production parameters. In the studies of Peeler and Omore, (1997), based on a computer model assuming 5 annual anthelmintic treatments, it was concluded that anthelmintic treatment resulted in a decrease in mortality and age at maturity, animals being bred or sold at an earlier age. Studies by Muenstermann and Tome (1989) and Maingi *et al.* (1997b) based on a comparison of treated and control groups of sheep showed that control animals had significantly higher FEC than treated groups. The treated sheep also had higher weight gains and packed cell volumes. The failure to demonstrate a significant effect of strategic treatment in the present study was probably due to the fact that the control group of sheep were also receiving anthelmintic treatment albeit at different times.

The other production parameters considered in this study i.e. off-take, birth weight of lambs and mortality were not significantly different between the two groups of farms. There are very few references to birth weights of local Red Maasai type sheep under smallholder management. The mean birth weights for lambs of 2.4 and 2.5 kg in the treated and control groups respectively were lower than those reported by King'oku,

Thome, Ogutu and Radoczi (1975) of 3.5-3.7 kg for Dorper lambs but higher than 1.9 kg reported for Red Maasai sheep in central Turkana by Njanja (1991). Muensterman and Tome (1989), working with the local Red Maasai sheep in Narok district, recorded growth rates of 9.4 kg and 7.3 kg over an 8 month monitoring period in the treated and control groups respectively. That was equivalent to 39.2 gm and 30.4 gm per day for treated group and control group respectively; which was lower than the growth rates recorded in this study of 51.9 gm and 45.2 gm per day respectively for treated animals and controls (as defined in this study).

The period of monitoring following the administration of the strategic anthelmintic treatments was probably not long enough for the benefits to be reflected in improvements in birth weights of lambs born to ewes in the treated group of farms as well as in improved growth rate in young animals and lowered mortality. Abdala (1989) also failed to demonstrate significant differences in growth rate in treated and untreated Sudanese sheep because of a short monitoring period.

The possible reasons for the failure to demonstrate significant differences between parasitological and production parameters were identified as those concerned with the nature of the farming enterprise, especially the limited land resources, leading to the use of communal grazing, short duration of monitoring and probably the use of a narrow spectrum drug (closantel) in one of the treatments. In spite of all the limitations associated with this kind of trial it is anticipated that the strategic treatment was worthwhile, in view of the epidemiological basis on which it was designed. A re-evaluation of the regime, based on the application of the treatments to all animals in a certain locality, and comparing the performance of small ruminants in this area with those in different locality, in terms of parasitological and production parameters should be carried out. The period of monitoring could also be increased to at least two years so as to allow for the benefits of the treatments to be realised.

CHAPTER SEVEN

COMPARISION OF A RECOMMENDED INTERVENTION STARTEGY WITH EXISTING MEASURES FOR THE CONTROL OF *Fasciola gigantica* INFECTION IN CATTLE ON SMALLHOLDER FARMS IN KENYA.

7.1 INTRODUCTION

Infection with *Fasciola* spp. in domestic ruminants is recognised as a major source of loss to production in many tropical and sub-tropical regions of the world (Hammond and Sewell, 1974; Anon, 1986; Morel and Mahato, 1987; Wamae and Ihiga, 1991). Fasciolosis in ruminants causes economic losses due to mortality, decreased milk, meat and wool production, reduced growth rates in young animals, abortions, treatment costs, condemnations of infected livers and sometimes of whole carcasses due to emaciation or from predisposition to other diseases (Bitakaramire, 1968b; Wamae and Ihiga, 1991; Maingi and Mathenge, 1995; Wamae *et al.*, 1998). Losses from liver fluke infections in Kenya have been estimated at US $8.1 million (Anon, 1986) and from a more recent study at US $14 million (Wanyangu *et al.*, 1996b). In some countries, particularly in Europe and America, the serious effects of liver fluke infections have been reduced, due to the availability of a vast body of epidemiological knowledge that has enabled accurate forecasts of disease outbreaks (Malone, 1997). This has also been combined with the use of more effective fasciolicides and improved farm management (Boray, 1997).

Despite the enormous losses associated with fasciolosis, the patterns of infection in different areas of Kenya have not been adequately studied and consequently there is very little information on which to base regional dosing programmes. Currently, control of liver fluke infections in Kenyan cattle is based on the haphazard use of fasciolicides (Maingi and Mathenge, 1995; Chapter 3), a large proportion of farmers treating every three months. Since it is likely that not all of these treatments are necessary for economic production, there is a need for rational prophylactic programmes based on local epidemiological information to ensure cost-effective control of fasciolosis in Kenya. The objective of this study was to evaluate a strategic anthelmintic treatment regime for cattle in smallholder farms in a *Fasciola* endemic

area of Kenya. The treatment regime was based on the results of an earlier investigation carried out to establish the patterns of *F. gigantica* infections in grazing livestock in the area (Chapter 5). It was intended to use the findings from this trial as a basis for future fasciolosis control recommendations for this and other areas of Kenya where liver fluke infection is endemic.

7.2 MATERIALS AND METHODS

7.2.1 Trial farms

A total of 84 smallholder farms were selected as described in chapter 2.3.1. These were randomly divided into 42 trial and 42 control farms.

7.2.2 Anthelmintic treatments

The choice of drug, frequency and timing of anthelmintic treatment for the treated group of farms was based on the results of the epidemiological study reported in Chapter 5. In the initial trial design, it was proposed to examine the effect of a single annual treatment in October with triclabendazole (Fasinex®, Ciba Geigy). The timing of this treatment was however delayed to the first week of November 1996 because of the time lapse between the end of the epidemiological study and the random selection of farms for this phase of the study. Unfortunately, following this treatment in November 1996 the drug was withdrawn from the Kenyan market by the local agents. An alternative regime was then considered and it was decided to use oxyclozanide (Zanil®, Cooper Animal Health). Because triclabendazole is the only fasciolicide effective against all stages of liver flukes, the effect of three annual treatments with oxyclozanide in October, April and June were examined. The first treatment with oxyclozanide was given in October 1997.

7.2.3 Tracer lambs and permanently grazed sheep

The monthly introduction of tracer lambs and purchase of local permanently grazed sheep to monitor infection patterns with *F. gigantica* in the study area continued during this phase of the study, in the same manner as described previously (Chapter 5).

7.2.4 Trial design

All the cattle in the trial group of farms were treated as described above while those in the control group of farms were treated by the farmers according to their usual routine. A visit was made to all the farms every month and the following data were collected: animal weights, records of calving, anthelmintic usage (names and dosages), sales and other reasons for absence of cattle from the farms. Faecal samples were also taken for examination for liver fluke and nematode eggs. For the duration of the study, the tracer lambs and permanently grazed sheep were used for monitoring the patterns of pasture infectivity with liver fluke metacercariae.

7.2.5 Data collection and storage

Individual animal details and information relating to each individual animal at each visit were recorded in a form similar to that described in Chapter 6. These data were stored in Microsoft Access database, whose design and description are detailed in Chapter 2.3.5.

7.2.6 Parasitological techniques

The parasitological techniques used in this study were as described in Chapter 2.9.

7.2.7 Statistical analyses

The total liver fluke counts from individual sheep (tracer lambs or permanently grazed) were logarithm transformed as $\log_{10}$ (total count +1) before analysis in the General Linear Models procedure of SAS statistical programme as already described in Chapter 5.2.3. Data from cattle in the intervention trial were subjected to simple analyses and transformations in Microsoft Access using specifically designed queries. Further analyses were carried out by first interrogating the data by use of queries to extract parasitological and production data which were exported into worksheets in Microsoft Excel. The visit dates were aggregated by month into sample numbers, 1 for November, 2 for December 1996 and so on up to number 18 for April 1998. Cattle infections with liver fluke were categorised as infected (1) or uninfected (0) and the proportion of infected animals per farm calculated at each sampling point. The

Microsoft Excel worksheets were then exported to Minitab (Minitab for Windows, Release 10.2, Minitab Incorporation) for analyses.

The effect of the intervention status (treated group or control group) on the proportion (percentage) of infected animals in a farm for both young and adult cattle was investigated using the General Linear Models (GLM) programme in the Minitab computer package (Minitab for Windows, Release 10.2, Minitab Incorporation). For the purpose of the analyses, young cattle were defined as those aged 12 months and younger and adults those aged over 12 months. Growth rates were compared between treated and control farms in young cattle. These were calculated as weight difference from the first sampling to the last sampling and dividing this by the total number of days to give the mean growth rate in grams per day.

7.3 RESULTS

7.3.1 Liver fluke epidemiology data

7.3.1.1 Weather data

The weather pattern (rainfall, minimum and maximum temperature) in the study area during the period of the trial has already been described in Chapter 6.3.1.

7.3.1.2 Liver fluke infections in the tracer lambs

During the 18 months of the study, a total of 94 tracers lambs were examined for liver fluke infections after a month's grazing with the local flocks in the study area. The reduction from the total expected of 108 tracers was due to deaths during the early period of grazing mainly as a result of pneumonia. Thus, there were only five tracer lambs examined in January 1997 and July 1997, four in August 1997 and December 1997, three in March 1998 and one in April 1998. The initial number available for the last month of the study, April 1998, was four and of these three died in the first week of grazing.

The livers of infected tracer lambs were enlarged and had necrotic or haemorrhagic tracts, visible on the surface and in the liver tissue. The extent of this change depended on the number of parasites.

The total number of liver flukes recovered from the groups of tracer lambs every month are shown in Figure 40 and the details of the recoveries from individual lambs and monthly means are presented in Appendix 18. There were infected tracer lambs in 10 out of 18 months with monthly total fluke recoveries ranging from one to 24 and counts from individual lambs varying from one to 16 liver flukes. During the 10 months when the tracer lambs were found to have liver fluke infection, the number of infected animals varied from one to three (Figure 41). The highest total number of liver flukes were recorded in September 1997 followed by November 1996 and January 1997, May 1997 and December 1997 respectively. In the months of December 1996 and June, July and August 1997 low liver fluke burdens were found with only one or two tracer lambs infected. Statistical analyses showed that there were significantly more liver flukes recovered in tracer lambs housed for six weeks (Chapter 2.9.4) than those housed for three weeks ($p< 0.0001$). There were also significant variations in fluke burdens attributable to the time of grazing ($p< 0.01$). Other parasites recorded from the livers of the tracer lambs at different times of the study included the sheep liver tapeworm *Stilesia hepatica* and cysts of the dog tapeworm *Taenia hydatigena*.

7.3.1.3 **Liver fluke infections in permanently grazed sheep**

Seventy two permanently grazed sheep were purchased for liver fluke infection: four for each of the months of the study. However, in four months of the study only three sheep were available for examination because of extensive *post mortem* changes to the livers. These months were December 1996, August 1997, November 1997 and March 1998. The livers of infected sheep showed lesions similar to the ones reported for the tracer lambs but some had varying degrees of fibrosis in both the bile ducts and liver tissue. The livers were also pale, firm and of irregular outline in some sheep that had moderate infections. The total number of liver flukes from the four or three sheep examined each month are shown in Figure 42 and the fluke counts from individual sheep as well as the monthly means are presented in Appendix 19. The total fluke burdens varied considerably over the months with infections being recorded in 11 out of 18 months. The liver fluke counts from among the individual infected sheep varied from four to 50. During the 11 months only one sheep was infected each month, with the exception of September 1997 and March 1998 when two were infected (Figure

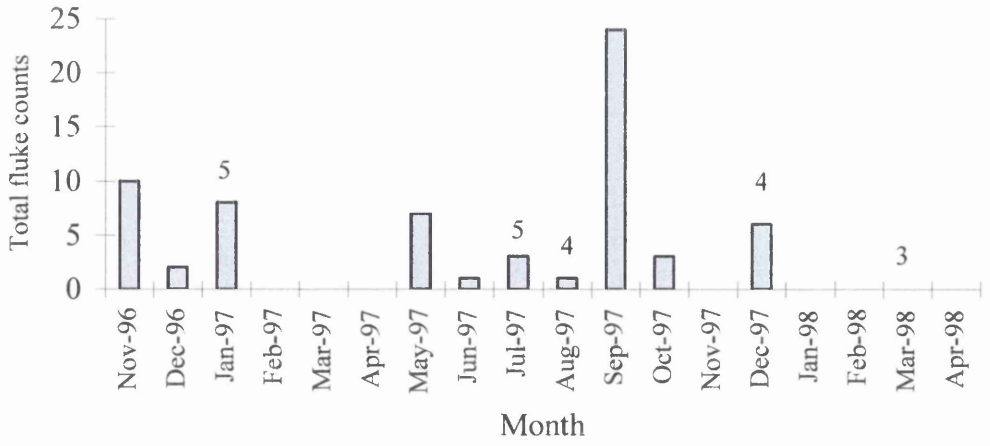

Figure 40: Total fluke recoveries from tracer lambs grazing in the study area during the intervention trial from November 1996 to April 1998. The number of tracer lambs examined, where less than six, are indicated each month.

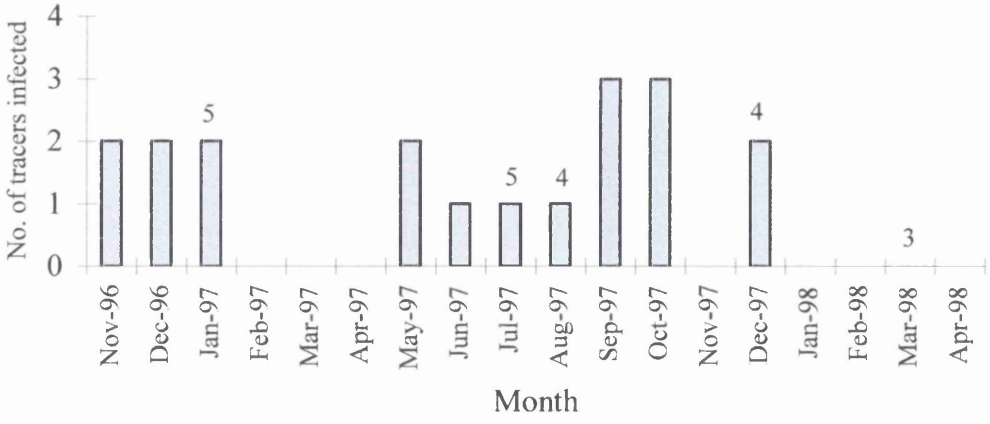

Figure 41: Number of tracer lambs infected with liver fluke out of the six grazing each month in the study area during the intervention trial between November 1996 and April 1998. The number of tracer lambs examined are indicated where less than six per month were available.

43). The infections in the permanently grazed sheep did not show any definite pattern but the months where individual sheep had highest liver fluke burdens were February 1997, March 1998 and September 1997 respectively. Statistical analyses showed that there were significantly more liver flukes recovered in the permanently grazed sheep housed for six weeks than those housed for three weeks ($p< 0.0001$). The reason for this housing protocol was explained in Chapter 2.9.4. There were also significant variations in fluke burdens attributable to the time of purchase ($p< 0.01$). Other parasites recorded in the livers of permanently grazed sheep were *Stilesia hepatica* and cysts of *Taenia hydatigena* and *Echinococus spp.*

7.3.2. **Evaluation of the intervention trial**

7.3.2.1 **Farms and animal numbers in the trial**

There were 84 smallholder farms altogether with 42 in each group. The figure for the number of cattle farms was increased by two from the intended 40 per group because of the fear of withdrawals from those in the control group. In the control group of farms only 35 participated for the entire duration of the trial; two farmers were removed after their animals died whilst a further five farmers withdrew because they felt they were not benefiting from the project. All of these seven farms (8.3% of the initial number selected) were not included in the analyses because they participated for a maximum of only three months. The distribution of the participating farms in the study area is shown in Figure 44. During the monthly visits, the number of cattle sampled varied from 151 - 178 in the treated farms and 143 - 186 in the control farms. The number of cattle of each age category (young or adult) that were sampled each month from the treated and control groups are shown in Table 18.

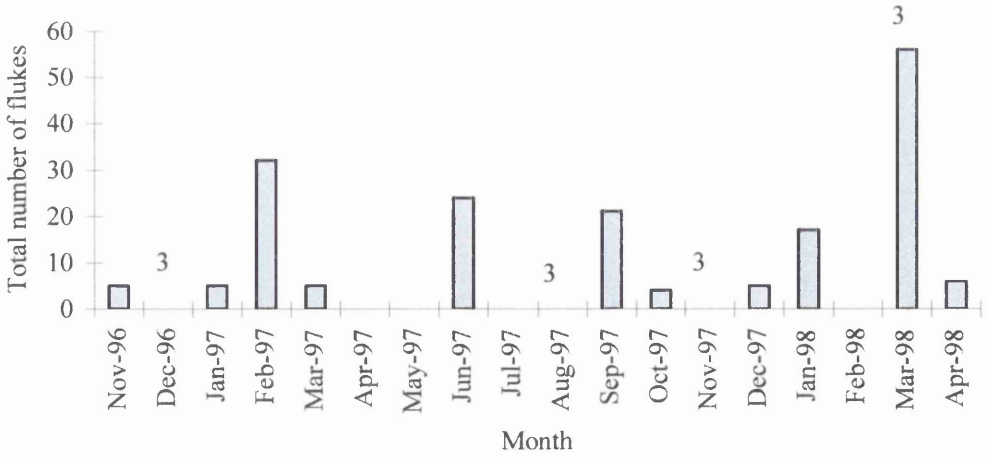

Figure 42: Total fluke recoveries from the permanently grazed sheep purchased from the study area during the intervention trial between November 1996 and April 1998. The number of sheep examined each month is indicated where less than four were available.

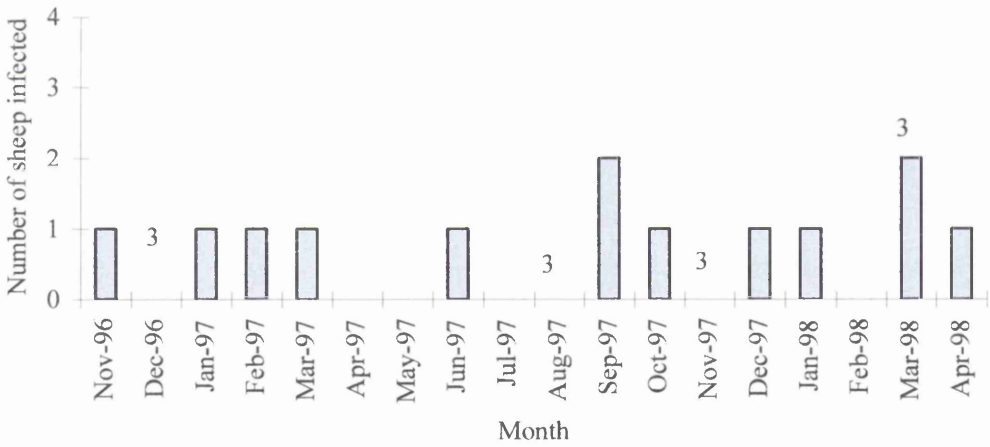

Figure 43: Number of permanently grazed sheep infected with liver fluke out of the four purchased from the study area during the intervention trial between November, 1996 and April, 1998. The number of sheep examined each month is indicated where less than four were available.

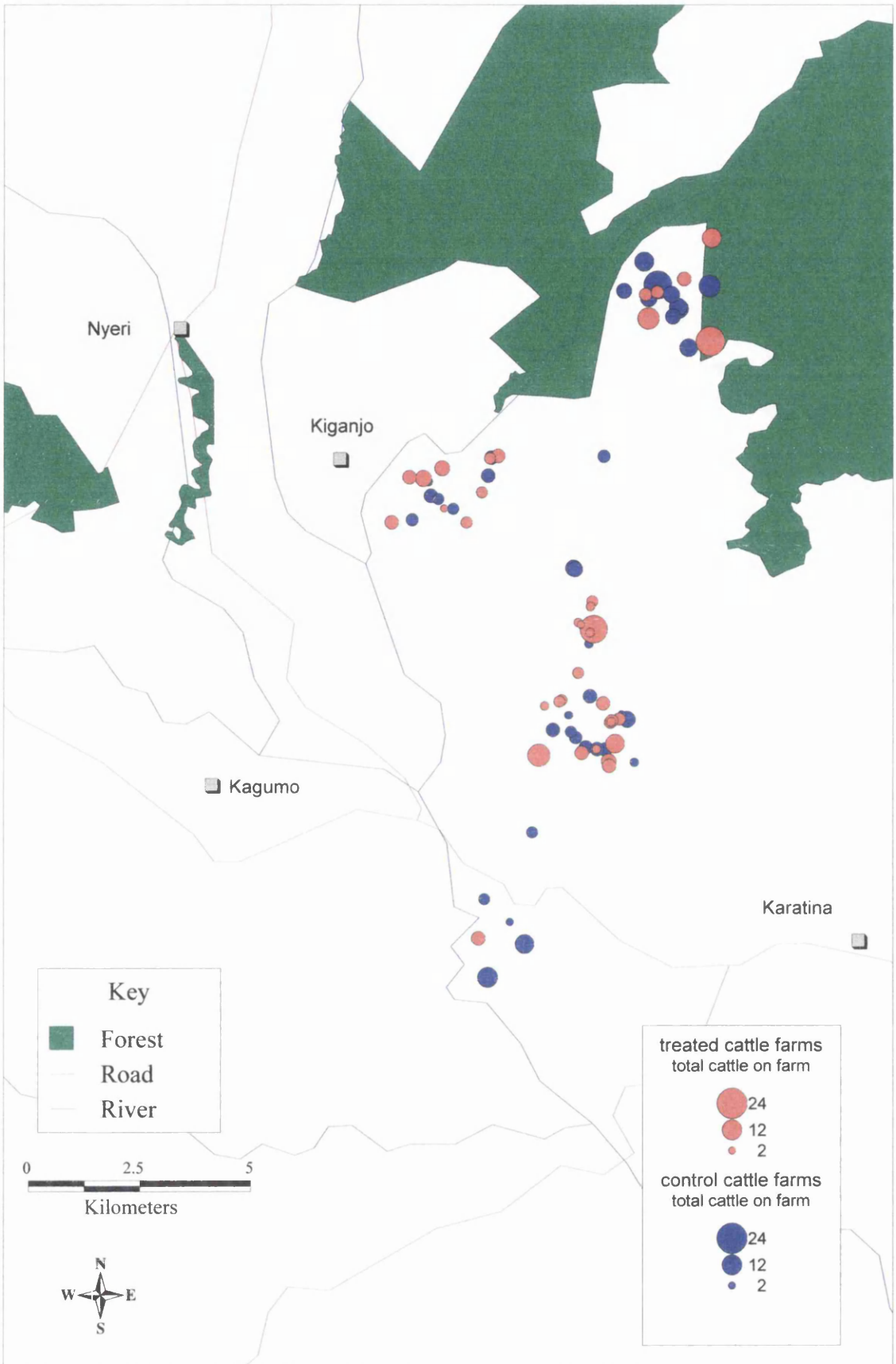

Figure 44: The distribution of cattle farms. Treated farms are shown by a red dot, control farms by a blue dot.
The diameter of the dot is proportional to the number of animals on farm.

Time	Number in treated farms		Number in control farms	
	Young cattle	Adult cattle	Young cattle	Adult cattle
1996				
November	38		37	121
December	41	134	33	110
1997				
January	38	139	35	124
February	41	137	45	136
March	41	128	36	135
April	32	131	36	140
May	32	132	35	142
June	30	134	36	143
July	28	137	31	141
August	26	137	35	149
September	27	132	32	154
October	25	131	28	153
November	24	127	30	149
December	25	131	30	149
1998				
January	26	135	26	149
February	28	128	28	147
March	22	133	28	140
April	24	132	25	137
Mean ± SD	30 ± 6.5	133 ± 3.6	32 ± 4.9	140 ± 11.7

Table 18: The number of young and adult cattle sampled every month from the treated and control farms.

7.3.2.2 Anthelmintic treatments and cost.

The anthelmintic treatments for cattle in the treated group of farms were administered according to the protocol described above in section 7.2.2.

During the monitoring of the animals in the two groups of farms, farmers in the control group continued to treat their cattle according to their usual routine. A few of those in the treated group also treated their animals in between the scheduled treatments. The different brands of anthelmintic used during this period including those used by farmer are shown in Table 19 whilst the timing of anthelmintic medication and total costs in the two categories of farms are shown in Table 20. The costs of treatments were based on the average cost of common drenches used by farmers for adults or weaned young cattle. An average cost of 120 Kenya shillings per dose of anthelmintic was used.

Anthelmintic name	Active ingredient	Number of doses used	
		Treated	Control
Curazole®	1.5% levamisole	1	
Flukiver®	5% closantel		1
Fasinex®	10% triclabendazole	173	78
Levafas®	1.5% levamisole + 3.0% oxyclozanide	2	6
Multidose®	1.5% levamisole +2.25% rafoxanide		5
Nilzan plus®	1.5% levamisole + 3.0% oxyclozanide.		15
Valbazen®	10% albendazole		11
Wormicid®	1.5% levamisole	20	17
Wormicid plus®	1.5% levamisole + 8% bithionol	1	17
Zanil®	3.4% oxyclozanide	268	26
Total number of doses		465	176

Table 19: The different brands of anthelmintics and the number of doses of each that were used in cattle in the treated and control farms during the trial.

Time	Anthelmintic doses in treated farms	Anthelmintic doses in control farms
1996		
November	**131**	1
December	9	1
1997		
January	0	4
February	7	1
March	3	40
April	0	0
May	30	27
June	1	5
July	2	17
August	2	9
September	8	16
October	**134**	11
November	4	9
December	0	14
1998		
January	1	16
February	1	3
March	0	0
April	**132**	2
Total number of doses	465	176
Cost of strategic treatment	Ksh. 47,640	Nil
Cost of treatment by farmers	Ksh. 8,160	Ksh. 21,120
Total cost of treatments	Ksh. 55,800	Ksh. 21,120

Table 20: Number of anthelmintic treatments given to cattle in treated and control groups of farms during the duration of the trial. The time and the treatments for the scheduled drenching for the treated group are shown in bold.

7.3.2.3 Comparison of off-take in the trial farms

The most common cause for exit of animals in both treated and control groups was sale (Table 21). A total of 58 animals left the farms in the treated group of farms whilst 55 left the control farms.

Type	Treated farms	Control farms
Gift	1	1
Sale	53	35
Slaughter	1	3
Other types	3	16
Total	58	55

Table 21: A comparison of off-take in the two groups of farms.

7.3.2.4 Mortality

The majority of deaths amongst cattle in both treated and control farms were caused by tick-borne diseases, mainly bovine theileriosis (East Coast Fever). There were a total of 59 deaths in the treated farms and 64 in the control farms over the monitoring period.

7.3.2.5 Growth rate in young cattle

Growth rate was compared between 86 young cattle in the treated and 98 in the control farms. The growth rate in all the animals varied from 0 - 764 gm per day. In the treated group growth rate varied from 0 - 756 gm per day with a mean of 197 ± 131.5 (SD) and median of 176.7 gm per day, whilst in the control group it varied from 0 - 764 gm per day with a mean of 215 ± 137.1 (SD) and median of 151.9 gm per day. There was a highly significant variation in growth rate of young cattle under one year of age among farms ($p<0.001$) but the strategic treatment had no significant effect ($p>0.05$).

7.3.2.6 Cattle infections with liver fluke among the trial farms

The majority of the infections with *F. gigantica* were recorded in adult cattle and very few in young cattle. The percentages of young and adult cattle infected, based on

faecal examination, are shown in Figure 45 whilst figure 46 shows the timing of the scheduled treatments as well as other treatments administered by farmers in both groups of farms. At the beginning of the trial in November 1996, the proportion of infected cattle (from liver fluke egg counts) in the two groups of farms were similar. There were only 2% of calves infected (all in the treated farms) at that time. The treatment in early November using triclabendazole resulted in the elimination of the infection in calves as shown by the absence of shedding of fluke eggs in the subsequent months. In the adult cattle however, the treatment only resulted in a slight reduction in the proportion of animals shedding *Fasciola* eggs in December. The proportion of infected animals in January 1997 in the treated farms remained almost similar to that in December 1996 and this was followed by a reduction in February 1997 and March 1997 to less than 10%. The anthelmintic treatments administered to cattle by a few farmers in December 1996 and February 1997 might have caused the observed reduction. During the subsequent months an increase in the proportion of infected adult cattle was recorded. During this two month period the proportion of infected cattle in the control farms remained higher than in treated farms. The period from May to the next treatment in October 1997 was characterised by a reduced prevalence of infection in both groups of farms, proportions of infected animals varying from 1.2 - 3.1% in treated and 0 - 4.0% in control farms.

The treatment in October 1997 using oxyclozanide resulted in a very small reduction in the proportion of infected cattle in the treated farms from 1.9% in October to 1.3% in November 1997. The proportion of infected cattle remained the same in December 1997 but increased to 2.5% in January 1998. There were no infected cattle in the treated group in February 1998 but the numbers of infected animals increased through March and April 1998, the time for the final anthelmintic treatment for the treated farms. The infection prevalence during these last two months was similar in both groups. Generally, the prevalence of liver fluke infections during the last 12 months from May 1997 to April 1998 was lower than that recorded during the first six months of the trial. This observation was made in cattle from both treated and control groups of farms.

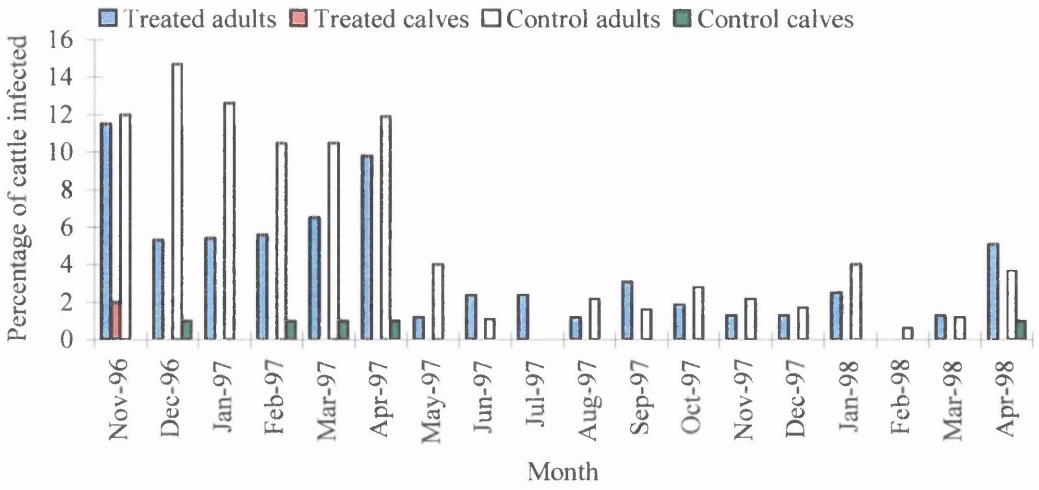

Figure 45: Percentage of calves and adult cattle infected with *Fasciola gigantica* among the treated and control groups of farms.

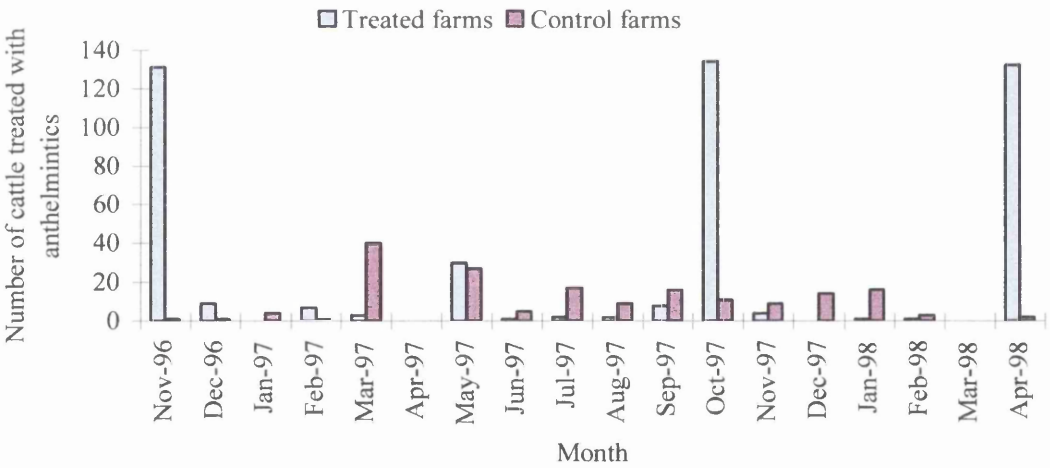

Figure 46: The number of anthelmintic treatments given to cattle in the treated and control group of farms. The scheduled treatments for the treated farms were given in November 1996, October 1997 and April 1998.

Statistical analysis showed that time and farm significantly influenced the proportion of infected cattle ($p<0.0001$) but there was no significant variation in the proportion of infected young and adult cattle attributable to the strategic treatment ($p>0.05$).

7.3.2.7 **Other parasitological observations**

Infections with gastrointestinal nematodes in animals in the trial farms, in terms of mean faecal egg counts are shown in Figure 47 for young and adult cattle. The mean FEC for cattle from both groups remained low throughout the study, being below 500 EPG except on one occasion in calves from the treated farms when the mean FEC of 755 EPG was recorded. Generally, the mean FEC for both age groups were below 200 EPG, but the calves had significantly higher FEC than the adults, those in the treated group of farms having a significantly higher FEC than calves in the control group ($p< 0.05$). In both calves and adult cattle, there was a highly significant variation in FEC attributable to time ($p< 0.0001$).

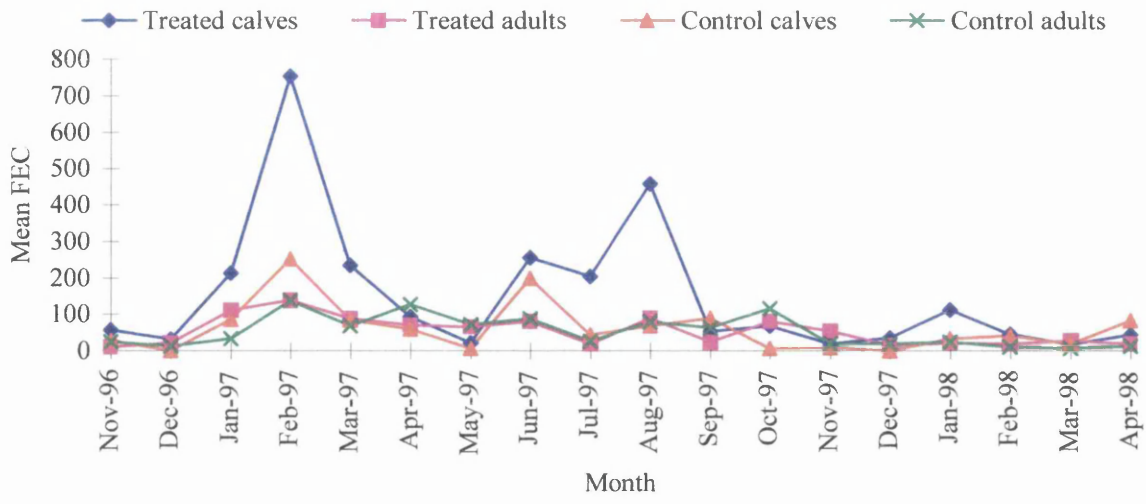

Figure 47: Mean nematode faecal egg counts in calves and adult cattle in the treated and control farms.

7.4 DISCUSSION

The monitoring of infections with *F. gigantica* in this phase of the study provided an opportunity to investigate further the pattern of pasture infectivity with metacercariae and compare this with what was found earlier (Chapter 5). One of the most notable differences was that there was a reduction in the number of parasites that were picked up by the tracer lambs during grazing compared with the previous 18 months. For example, there were more months during which the tracer lambs did not pick up any infections at all and when they did become infected, the number of flukes recovered were fewer. The possible explanations for this occurrence could be either a reduction in pasture contamination with fluke eggs by grazing animals, leading to fewer infected snails shedding metacercariae or a reduction in the snail populations due to adverse conditions. Considering that the tracer lambs were grazing alongside the local sheep flocks as well as cattle, this reduced prevalence of infection might reflect an overall reduction in prevalence of liver fluke infections in all of the animals in this area over this period. The observed reduction in the number of infected sheep among those that were purchased from the area as well as the number of parasites recovered would tend to support this argument.

The reason for this overall reduction in the prevalence of liver fluke infections in animals in the study area was probably related to the weather pattern, particularly the rainfall, which was not typical for the area. There was a severe drought period between June and September 1997 that led to the drying up of some streams and dams used by animals in the area. This probably reduced the snail populations that were previously responsible for parasite transmission which meant that many animals that were treated with fasciolicides at this time were not exposed to further challenge during that drought period. The drought was followed by the short rains which lasted longer than usual; i.e. 5 months from November 1997 instead of the usual six to eight week period. These rains were associated with flooding of streams, rivers and dams which could have had two effects. First this might have washed away the few snails that had survived the drought period. Alternatively, surviving snails could have come out of aestivation (Bitakaramire, 1968a; Cheruiyot and Wamae, 1986) and started to multiply and re-populate the then favourable habitats but this could have taken some time. Whatever the reason the end result was that tracer lambs grazing at that time

picked up very few or no parasites. In the permanently grazed sheep however, there were still some infected animals over this period, though they had small numbers of flukes. These sheep harboured mature infections which might have been picked up three months prior to purchase or earlier. Since liver flukes can survive in sheep for a long period (Haroun and Hillyer, 1986), it was not possible to relate the infections in the permanently grazed sheep with the change in weather pattern in the area. However, this showed that there were still some infected animals in the local farms to perpetuate the life cycle once suitable conditions for the re-establishment of snail intermediate host became available.

In spite of the variation in weather conditions, the results obtained from necropsies of the tracer lambs generally showed that infections were acquired at approximately the same times as those identified during the first phase of the study (Chapter 5.3.4). Infections were mainly recorded in May, September and October-November during both studies but the period of high infection recorded between February and April during the earlier study was not observed in this second phase, probably due to the effects of the prolonged heavy rains at the time. It is likely that with plenty of water and pastures, that is associated with the extended period of rains, grazing animals do not frequent potential transmission sites as much as they do during the dry season.

The levels of infection with gastrointestinal nematodes in calves and adult cattle during this period of the trial confirmed the earlier observations (Chapter 4.3.2). These showed especially in adult animals, that in cattle gastrointestinal nematodes were of less significance than in small ruminants. Calves in the treated group of farms had the highest level of infection over most of the period. This was most likely due to the fact that animals in the *Fasciola* treated group of farms were only receiving fasciolicides whilst farmers in the control group were drenching with combination drugs incorporating both fasciolicides and nematocides. These results confirmed the earlier recommendations to drench only calves in farms where high levels of infection with nematodes were likely. Since nematode parasites are less harmful in mature cattle (Shroder, 1981; Reinemeyer, 1995), there was very little benefit from routine drenching especially in areas where infection with liver fluke does not occur.

The evaluation of the strategic anthelmintic treatment for *Fasciola* infection in cattle, started in November 1996, a month later than the first treatment was proposed. To avoid losing a whole year of monitoring, the treatment with Fasinex® (triclabendazole) was given in early November 1996. Triclabendazole is the best fasciolicide available because of its high efficacy against all stages of *Fasciola* spp. (McKellar and Kinabo, 1991). This high activity against immature stages combined with the relatively long prepatent period of *Fasciola* spp. (Boray, 1997) makes strategic anthelmintic control of fasciolosis an realistic target. In experimental infections in sheep it has been shown to be highly efficacious against *F. hepatica* aged from one day to 12 weeks (Boray *et al.*, 1983) and against immature flukes in goats (Kinabo and Bogan, 1988). Triclabendazole has also been used in control of naturally acquired infections with *F. hepatica* in sheep (Boray, Jackson and Strong, 1985; Fawcett, 1990; Taylor, Langridge and Kenny, 1994). Studies have also confirmed high efficacy of triclabendazole against natural infections with *F. gigantica* in sheep and goats (Ratraparkhi et al., 1994), in cattle (Misra *et al.*, 1987; Suhardono *et al.*, 1991; Ratraparkhi *et al.*, 1994; Waruiru, Weda and Munyua, 1994) and in buffaloes at higher doses (Estungsih *et al.*, 1990; Mahato, Harrison and Hammond, 1994). Success in these studies was probably related to the drug's ability to reduce pasture contamination with fluke eggs over long periods. It was because of these attributes of triclabendazole that it was initially chosen for use in this trial. A single annual treatment for cattle during the time when peak infections with *F. gigantica* were expected, based on the results of the epidemiological study, was expected to give adequate control. The performance of the recommended treatment could only be monitored for one year following the withdrawal of marketing of Fasinex® (triclabendazole) from Kenya. The rest of the trial was therefore based on a revised treatment regime using Zanil® (oxyclozanide), a fasciolicide only effective against mature infections. Oxyclozanide, like the other salicylanilides, is highly protein bound and with an elimination half-life of 6.4 days (Kinabo and Bogan, 1988). The poor activity of oxyclozanide against immature stages of flukes has been thought to be due to this high protein binding in blood. The blood bathes the immature flukes in the liver parenchyma at a stage when they feed on liver cells rather than on blood (McKellar

and Kinabo, 1991). It is only the blood feeding adult flukes in the liver bile ducts that are killed by oxyclozanide.

At the beginning of the trial, the proportions of infected cattle in the treated and control group of farms were similar but only the treated group had a small number of infected calves. The first treatment with triclabendazole eliminated the infection in these calves but did not reduce to zero the number of animals shedding *Fasciola* eggs; this was shown by the presence of a few animals shedding fluke eggs in December 1996. With the reported efficacy against *F. gigantica* of less than 100% (Waruiru, Weda and Munyua, 1994) it is possible that the observed small proportion of cattle in the treated group which remained infected was as a result a lower efficacy of triclabendazole in this parasite as compared to *F. hepatica*. The other possible reason for the absence of a dramatic reduction in infection prevalence following this treatment could be low numbers of infected animals in November 1997. However, the proportion of infected cattle in the treated group of farms continued to be lower than that seen in the control farms. Between this first treatment in November 1996 and October 1997 when the next treatment was due, there was an obvious reduction in the overall prevalence of infection with liver fluke in both groups of cattle. During this period no infected calves were detected on the treated farms whilst in the control farms, infected calves were found in four months (December 1996 and February to April 1997) before the time the next treatment in October 1997 was due. The anthelmintic formulations given to animals by some farmers in the control group in March and May could have resulted in the apparent absence of infected calves in the subsequent months.

Treatment with oxyclozanide in October 1997 only produced a slight reduction in the proportion of infected adult cattle in November 1997. The reason for this could be due to the fact that the efficacy of oxyclozanide against *Fasciola* spp. in cattle is less than 90% for flukes younger than 14 weeks (Boray, 1997). This meant that in cattle incubating pre-patent infections in November 1997, the treatment had little effect and these animals were responsible for the observed fluke egg counts in December 1997. Alternatively, the efficacy of oxyclozanide against adult *F. gigantica* could be lower than 100%, leading to some adult flukes in the treated cattle surviving treatment.

Between this and the final treatment in April 1998, the level of infection in both treated and control group of farms was very low, especially in February when no infected cattle were encountered among the treated farms. Only one animal was found to be infected in the control group of farms at this time. Overall, the last year of the trial was a time when the level of pasture infectivity with *F. gigantica* metacercariae was apparently low as demonstrated by the results from the tracer lambs. It was likely that grazing cattle in the area picked up very few new infections during that period which in turn is reflected in the very low prevalence of the infections during the last 12 months compared with that seen during the first six months of the trial. During the monitoring period cases of clinical fasciolosis in cattle were not encountered amongst animals in the trial farms.

Production losses due to *F. gigantica* in young growing cattle are particularly important since they are more vulnerable to the effects of liver fluke than adult cattle (Wamae *et al.*, 1998) and there is also evidence of acquired resistance in older cattle, both to re-infection and in rejection of an existing infection (Haroun and Hillyer, 1986; Hammond and Sewell, 1990). Growth rate in calves is therefore commonly used to compare the performance of different treatment regimes in cattle (Cawdery *et al.*, 1977; Rowlands *et al.*, 1996) in addition to analyses of parasitological data. The only other report of daily weight gains of calves in smallholder farms in Kenya was that of Gitau *et al.* (1994b) in Kiambu district. The mean daily weight gains recorded in this study of 197.3 gm per day (median = 176.7) for treated and 185 gm per day (median = 151.9) for the control group were lower that that reported in Kiambu district (median =210 gm per day and ranging from -0.400 to 900 gm per day). Both these studies recorded growth rates lower than those reported by Rowlands *et al.* (1996) in Cote d'Ivoire of 243 gm per day, all being below the recommended daily weight gains of between 500 and 750 gms per day for *Bos taurus* (Radostits and Blood, 1985). The results suggested that calf management in the smallholder farms needed improvement in order to increase the productivity of the dairy sector. In this study, comparison of growth rates in young cattle under one year of age among animals in the two groups failed to demonstrate any advantage attributable to the strategic treatment. This was similar to the results from other studies where treated and untreated control calves were compared. In a field trial using triclabendazole

treatment for *F. gigantica* in Indonesian cattle, Suhardono, Widjajani, Stevenson and Carmichael (1991) demonstrated a significant reduction in fluke egg counts in treated animals but there were no differences in weight gain between the treated and control groups. Treatments using oxyclozanide and rafoxanide to treat *F. hepatica* in weaner calves in Papua New Guinea (Owen, 1984) demonstrated no significant differences in weight gains between treated and untreated controls. Other trials in the Gambia by Itty *et al.* (1997) showed that treating cattle twice a year against helminths was only profitable in some herds whilst in others, farmers risked losing money by deworming their cattle. From the results of this study and from the above earlier studies, it might appear like low level liver fluke infections in young and adult cattle do not warrant the current routine drenching that occur in many farms.

Unlike most of the reported trials, this study involved comparing animals on different smallholder farms and there were no untreated control farms because farmers in the control group were treating their cattle according to their usual practices. It was therefore a comparison of the strategic treatment against the farmers' haphazard control practices. The cross-sectional study had also shown that 57% of the farmers practised communal grazing (Chapter 3.3.4.3) indicating that the source of liver fluke infection for animals that were grazed communally could be out with the farm. This combined with the fact that treated animals grazed alongside untreated ones meant that there was very little benefit derived from treatment in terms of reduced pasture contamination with fluke eggs. These factors no doubt contributed to the apparent failure to demonstrate significant differences between animals in farms on the strategic treatment and those that practised their usual control regime. Furthermore, the benefits from strategic anthelmintic might not be realised in any one year (Corwin, 1997) and may require to be evaluated over a longer period. The success of the strategy would also rely on a high adoption rate among farms in any particular locality in order to derive benefits from reduced pasture infectivity associated with the anthelmintic treatment. A better assessment of any regime would require the invariable application of the treatment to all farms in a given locality and comparing production and parasitological parameters for these animals with others from a similar area, far enough away from the first group of farms to avoid any influence on farmers regarding their drenching routine.

CHAPTER EIGHT

CONCLUSIONS AND GENERAL DISCUSSION

The work reported in this thesis was carried out to investigate the infection patterns with parasitic helminths of domestic ruminants on smallholder farms in Nyeri district, which is a high potential area in the Kenya highlands. A protocol similar to that recommended by Hörchner (1990) for the epidemiological survey of helminthoses in tropical countries was followed. Basically, this involved the monitoring of all ruminants in 58 randomly selected smallholder farms for nematode and liver fluke infections, pasture nematode larval counts and *post mortem* nematode and liver fluke burdens in young tracer lambs and permanently grazed sheep. This was carried out over a period of 18 months. This study led to the design of two helminth control strategies: one for the control of gastrointestinal nematodes in small ruminants and another for the control of liver fluke infections in cattle, both of which were based on local epidemiological information. These intervention strategies were then implemented in a group of 40 randomly selected smallholder farms and compared with the current control practices of another 40 randomly selected farms for their effects on faecal egg counts and growth rates of young animals.

The first phase of the study was carried out to provide baseline information on livestock farming in Nyeri district with emphasis on the significance of helminth infections in domestic ruminants and current local control practices. It was intended to give background information on other farm practices such as grazing management and livestock marketing, that were considered relevant to the application and sustainability of potential helminth control programmes. An initial examination of diagnostic records at Karatina Veterinary Investigation Laboratory (VIL) showed that helminth infections were frequently encountered in samples submitted by farmers or by the veterinary extension staff. Cattle faecal samples were more often submitted than sheep samples over the 10 year period investigated which probably reflected their relative value and the concern shown by local farmers for the health of different classes of livestock. In cattle, infections caused by *Fasciola gigantica* were commonly diagnosed whereas in sheep infections with gastrointestinal nematodes were more common, and high faecal egg

counts were recorded. Although the infection levels in both sheep and cattle did not show any correlation with local weather patterns over the same period, the results did show that infections with parasitic gastrointestinal nematodes and liver fluke were common and a source of concern to local farmers in Nyeri district.

The relative value of different classes of livestock to smallholder farmers was assessed during a participatory rural appraisal with the local veterinary extension staff. Whereas dairy cattle were kept as a source of income from milk sales, small ruminants were maintained by many farmers as a form of saving. Small ruminant production in smallholder farms in Kenya is not highly commercial (Stotz, 1983; Peeler and Omore, 1997) but a healthy flock of sheep and goats is viewed as an investment and a form of insurance against crop failure and other domestic emergencies. It was therefore not surprising in this study that the major reasons for the sale of animals were given as cash demands such as school fees or medical expenses. In general, no structured production or marketing strategy, with targets for age and weight at off-take, was followed for either small ruminants or cattle. However, in small ruminants, volumes of sales were related to certain times of the year mainly because of seasonal festivities such as Christmas or seasonal cash demands such as payment of school fees. Young and healthy slaughter animals were worth more than older animals, whilst breeding females were valued more than slaughter animals of similar weight.

It was the view of the local veterinary extension staff that the use of anthelmintic medication was the only helminth control method used by local farmers. This was similar to the situation in other areas, such as Nyandarua (Maingi *et al.*, 1997a) and Nakuru (Mbaria *et al.*, 1995) districts and many others in Kenya (Kinoti *et al.*, 1994). In this area preference was given to lactating cows in the treatment for helminths; other cattle and small ruminants being treated only when it could be afforded or when they were clinically ill.

From the cross-sectional study of farmers, it was apparent that the majority of livestock were either grazed on pasture permanently or in addition to stall feeding with forage in the 'cut-and-carry' practice. This study also confirmed that farm sizes in the area were typical of smallholder farms in other parts of Kenya, such as Kiambu (Gitau *et al.*,

1994a) and Murang'a (Schaik *et al.*, 1996) districts as well as being within the average range of acreage commonly considered to be smallholder in Kenya (Stotz, 1983). The larger portions of the farms were used for cropping with, for example coffee, tea, vegetables and maize, leaving only small portions for pasture and other fodder crops. As a result, off-farm or communal grazing was commonly practised to provide an alternative source of forage. Communal grazing areas included road sides, land reserves adjacent to forests and other public utility land around dams and watering places along rivers. This practice had an obvious influence and impact in transmission of helminth infections especially since overstocking is common and the fact that helminth control in different herds and flocks is not co-ordinated. Furthermore, application of any form of pasture management as an alternative or adjunct to anthelmintic control in smallholder farms practising off-farm grazing was not feasible.

The information obtained from the cross-sectional study largely explained the total reliance on anthelmintics for worm control by local farmers and by many others in Kenya (Kinoti *et al.*, 1994; Wanyangu *et al.*, 1996a). The majority of the farmers reported that they drenched all their animals routinely, and although the common practice was to treat every three months, the farmers were not sure at what time of the year the treatments should be administered. This treatment frequency was similar to that reported in Nakuru (Mbaria *et al.*, 1995) and Nyandarua (Maingi *et al.*, 1997a) districts as well as the commonly recommended regime by extension workers. The source of anthelmintic drugs and advice on helminth control was mainly the veterinarians and animal health assistants but chemists and agro-chemists also provided drenches to a small number of farmers. This study highlighted the fact that dosages were determined on visual appraisal to estimate live weights of animals and this was thought to result in widespread under-dosing. Although the frequency of anthelmintic usage recorded in this study was not high compared with dosing frequencies of up to 26 times a year reported in some large scale sheep and goat farms in Kenya (Wanyangu *et al.*, 1996a), the frequent under-dosing of livestock could lead to selection of anthelmintic resistant nematodes, especially *H. contortus* in small ruminants (Waller, 1997). It was considered that any recommendations on anthelmintic strategy were likely to be more attractive if, in addition to being based on epidemiological information, they took into account the times of the year when livestock were generally marketed. This was important because animals were

sold on the basis of a visual appraisal implying that farmers would be interested in an intervention that had a marked impact on weight and appearance of their animals at the livestock markets. The above background information was taken into consideration in the design of subsequent phases of the study.

The epidemiological investigation of infections with gastrointestinal nematodes in sheep showed that the main species encountered were *H. contortus, T. axei, T. colubriformis, Cooperia* spp. and *Oesophagostomum* spp. The results from both pasture sampling and faecal examinations showed that infections were generally higher during the two main rainy seasons; pasture contamination being very low during the dry months. These findings were similar to results from a number of studies carried out in other areas with distinct rainy and dry seasons, such as in parts of Australia (Fabiyi and Copeman, 1986), South Africa (Reinecke, 1980), Nigeria (Eysker and Ogunsusi, 1980), Mali (Tembely *et al.*, 1997, Tembely, 1998), Cameroon (Ndamukong and Ngone, 1996) and Kenya (Gatongi *et al.*, 1988; Wanyangu *et al.*, 1997). The inclusion of Dorper tracer lambs and permanently grazed adult sheep (Red-Maasai crosses) in this study enabled a further examination of the relationship between infections and weather pattern in different classes and types of sheep. The worm burdens in the local permanently grazed sheep showed less of a relationship with the rainfall pattern than the tracer sheep worm burdens but these results revealed some aspects of parasite dynamics in the adult local sheep that earlier studies, based on pasture and faecal sampling, did not identify (Uriate and Valderrabano, 1989). In this study, permanently grazed sheep were found to harbour higher numbers of *T. axei* than *H. contortus* in their abomasa, in spite of the fact that *Haemonchus* larvae were much more abundant than *Trichostrongylus* larvae on pasture. The resistance of the Red Maasai breed to *H. contortus* has been well documented over the last 20 years (Preston and Allonby, 1978, 1979, Baker, 1993; Mugambi *et al.*, 1997) but the fact that *T. axei* burdens appeared to increase in such resistant sheep was an interesting finding. If resistant sheep such as the Red Maasai and their crosses can control their burdens of *H. contortus,* the influence of *T. axei* as a cause of reduced productivity merits further investigation.

The tracer lambs had parasite burdens which reflected pasture levels of infective larvae during the single months that they were grazing which enabled a more accurate

determination of the pattern of pasture infectivity with nematode larvae. This is considered to be the main advantage of using tracer lambs as opposed to pasture larval counts and permanently grazed animals (Duncan *et al.*, 1979; Uriate and Valderrabano, 1989). The periods which were associated with high worm burdens were November to January and May to July. Both these periods were one month after the onset of the short and long rains respectively. The delay in the build-up of peak infections could be explained by the time lapse between egg deposition on pasture, development through to infective L_3 stage, ingestion by the grazing animals and the 21 day pre-patent period of most gastrointestinal nematodes. This seasonal occurrence of peak infections led to the proposal of two annual treatments for sheep and goats, (in January and October) that were subsequently compared with current helminth control practices in the area.

The epidemiological investigation of *F. gigantica* infections showed that there were similar patterns of infection in sheep and cattle in the smallholder farms. In both, levels of infections were highest during the rainy season, suggesting, as in many studies elsewhere (Ogambo-Ongoma, 1971; Traore, 1989, Wamae, *et al.*, 1990; Tembely *et al.*, 1994, Malone *et al.*, 1998), that most infections were acquired during the dry season. Based on faecal examination of samples from livestock on smallholder farms, overall prevalences of 5.6% and 13.0% for sheep and cattle respectively were recorded. These results indicated that the study area fell within the medium prevalence category for liver fluke infections (less than 40% prevalence) according to the classification of Bitakaramire (1968b). However, a higher infection prevalence of 33.3%, based on *post mortem* liver examinations, was recorded from the permanently grazed sheep purchased from smallholder farms in the area. The fluke burdens in these naturally infected sheep were generally found to be low, ranging from one to 30 flukes per animal, the exception being two sheep from which 155 and 199 flukes were recovered. Although the permanently grazed sheep could not provide detailed information on the pattern of liver fluke infection, the results indicated that infection was widespread amongst local flocks.

The tracer lambs presented the opportunity to establish the levels of pasture infectivity with metacercariae at different times of the year. The results of *post mortem* fluke counts, similar to those from faecal examination of animals in smallholder farms for fluke eggs, showed that most infections were acquired during the dry season or early in the

rainy season. The months associated with high necropsy fluke burdens and hence heavy pasture infectivity with metacercariae, were August to October and February to April. These results enabled the proposal of one annual treatment in October with a fasciolicide effective against all stages of *Fasciola* (i.e. triclabendazole) followed by treatment of individual clinical cases when they occurred. The aim of this treatment was to reduce pasture contamination with fluke eggs by eliminating all stages of liver flukes before the period of high snail activity, in the rainy season. In the absence of triclabendazole from Kenya, three annual anthelmintic treatments using fasciolicides effective against adult fluke stages were subsequently recommended. It was proposed that the treatments be administered in April, June and October in order to coincide with the periods when infected animals were expected to be harbouring adult liver flukes; the stages that fasciolicides other than triclabendazole are effective against.

The seasonality of infections with both gastrointestinal nematodes and liver flukes was further investigated during the second phase of monitoring that continued during the intervention trials subsequently implemented. The results of pasture nematode larval counts showed that months associated with peak infectivity were again those during and towards the end of the two main rainy seasons, with low larval counts recorded during the intervening dry periods. These times were November-January and April- July. However there were slight variations in the levels of pasture infectivity as a result of differences in weather pattern experienced over this period. The drought period early in the study resulted in a failure to recover larvae from any of the sites for two months (January and February 1997) while the extended duration of the short rains from November 1997 to April 1998 led to an increased number of infective larvae over the corresponding period. These changes were subsequently reflected in the worm burdens recorded from tracer lambs that grazed in the study area over that period. The relative prevalence of the different nematode species observed earlier was once again recorded during this phase of the study. *Haemonchus contortus* was more abundant in the tracer lambs compared with *T. axei* and *T. colubriformis;* the reverse being true for the local permanently grazed sheep. One further observation from the tracer lambs was that during certain months, only *H. contortus* and none or very few *T. axei* and *T. colubriformis* were recovered. From the results of this study, it might be possible that in susceptible hosts, *H. contortus* colonises the abomasum and reduces the establishment of *T. axei.*

This would mean that tracer lambs might not truly reflect the levels of *Trichostrongylus* spp. larvae on pasture just as the permanently grazed sheep do not reflect *Haemonchus* levels on pasture.

The second phase of monitoring of liver fluke infections resulted in findings similar to those recorded in the earlier phase. The only marked difference during this phase of the study was that there was a reduction in the number of tracer lambs infected and in the level of infection in those tracer lambs which did become infected after grazing in the study area during this period. The change in weather pattern probably contributed to the observed changes in infection prevalence amongst animals in the smallholder farms and in fluke burdens of the tracer lambs. The severe drought at the beginning of the study resulted in the reduction of suitable snail habitats, through drying up of the streams and dams that acted as transmission sites for liver fluke infection in the area. Similarly, the extended period of the rains at the end of the study was associated with flooding which probably affected the re-establishment of habitats for the snail intermediate hosts. These two factors may have been responsible for reduced levels of infection in the tracer lambs introduced to the study area during this phase of the study. The general reduction in the prevalence of infection in cattle within the trial farms during the last 12 months of the study further supported this explanation, suggesting that grazing animals picked up very few metacercariae over this period.

During the evaluation of the strategic anthelmintic treatment for small ruminants, the results showed that the mean FEC for animals kept on the treated farms were not significantly different from those from the control farms for both sheep and goats. Other studies have shown significant differences between treated and untreated control groups of sheep (Muenstermann and Tome, 1989; Maingi *et al.*, 1997b; Peeler and Omore, 1997) but because of the nature of this study, it was not possible to include untreated controls. The small ruminants in the control farms were being treated by farmers at different times during this phase of the study. Animals from treated farms were grazing alongside animals from untreated flocks in contaminated communal pastures. As a consequence, there was no apparent benefit in terms of lowered pasture contamination with infective nematode larvae which are usually associated with epidemiologically based strategic anthelmintic treatments (Thomas, 1982; Owen; 1988; Itty *et al.*, 1997). The

exposure of treated animals to heavy challenge soon after drenching is recognised as one cause of apparent failure of strategic treatments to reduce infections and increase production (Brunsdon, 1980; Shroder, 1981). The rate of re-infection in some animals in this study, especially those that were communally grazed, was high as evidenced by the FEC monitoring.

The production parameters (birth weight and growth rate) compared between the treated and control groups of small ruminants in this trial did not show any significant variation associated with the strategic treatment. Corwin (1997) recommended that the effect of strategic treatments should be evaluated over several years but in this study, the period of monitoring from the first treatment was probably too short for any significant effects of the treatment regime to have been realised especially given the management difficulties already mentioned. It was also possible that during the short period of monitoring, factors such as nutrition, had a greater influence on growth rate of young sheep and goats than helminth infections. Studies by Coop, Holmes and Gill (1996) demonstrated that harmful effects of helminth parasitism could be reduced by a high plane of nutrition. Poor nutrition, on the other hand, is known to result in reduced weight gains in lambs and kids, both before and after weaning as demonstrated by Inyangala *et al.* (1991) in the case of Dorpers and Red Maasai-Dorper crosses. The type and quality of pasture available for grazing depends on the season when the lambs and kids are born. In the study area, lambing and kidding occurred throughout the year which probably had some influence on the overall growth rates. Lambs and kids born during the rainy season when the pastures were plentiful are more likely to have grown faster since their dams would have had sufficient forage and hence more milk for the young ones. This period is also the time when there was more opportunity for build up of higher burdens of nematode parasites with the growth rate in young animals probably depending on the balance between infection and plane of nutrition. The reverse would be the case for lambs and kids born during the dry months of the year, when the nutrition was poor but with less chance of acquiring heavy nematode infections. It was not surprising then, that there were no significant differences in both birth weight and growth rate, between the lambs and kids born to ewes and does in the two groups.

The strategic treatment for the control of liver fluke infections in cattle resulted in only slight reductions in the prevalence of infection in the treated animals which were not significantly different from the prevalence in the control group. Farmers in the study area were more concerned about the health of their cattle, including helminth control, than the health of their small ruminants. As a result, cattle in the control group of farms also received substantial anthelmintic medication during the trial. It was not surprising therefore that the prevalence of infection with liver fluke in animals between the two groups of farms was not significantly different. A further complicating factor, as in the small ruminant trial, was the fact that some treated cattle grazed communal areas and were thus exposed to challenge soon after anthelmintic treatment. This diminished the desirable long term potential benefits of strategic treatment which would result from a reduction in pasture contamination with fluke eggs.

A notable feature during the trial was the general reduction in prevalence of fluke infection observed in both treated and control groups of cattle. A similar pattern was observed in the tracer lambs grazing the area at this time. The most likely cause of this apparent reduction in pasture infectivity with *F. gigantica* metacercariae was the weather changes discussed earlier in relation to the findings from the tracer lambs, which also reduced the number of animals acquiring new fluke infections. In the absence of new infections, earlier studies by Doyle (1971) and Wamae *et al.* (1990) have shown that cattle are capable of losing mature fluke burdens with time. This could have happened to the cattle in this study in both the treated and control groups.

The analyses of growth rate in young cattle under one year of age demonstrated a significant variation between animals in different smallholder farms but no significant effect of strategic treatment. The only other report on growth rates in calves on smallholder farms in Kenya by Gitau *et al.* (1994b) found that the weight gains in calves were influenced by different management factors among farms including feeding and calf housing. The farm to farm variation recorded in this study served to demonstrate how growth rate in young cattle could be influenced by a wide variety of factors, such as cattle breeds and type of cross-breeds, nutrition and farm management generally which were not specifically considered or controlled for in this study. Both this and the previous study showed that improvements in calf management and other farm level

factors are required to increase calf daily weight gains in smallholder farms. In this study, the effect of the strategic treatment probably required to be monitored over a longer period than was possible in this case. Although it was unlikely for any significant benefits arising from the strategic drenching to be reflected in the growth rate of calves within the short period of time considered in this study, the fact that there were no infected calves after the first treatment in this study suggested that there were some potential long term benefits if the trial had continued over a longer period and communal grazing could have been avoided. Alternatively, it is possible that calves had no opportunity to pick up fluke infections as a result of the weather changes discussed earlier hence the reduced infection pressure.

Overall the objectives of the entire study were achieved through a series of field-based investigations. The epidemiological component was carried out in two phases, i.e. during the initial 18 months and subsequently during the intervention trials. This approach gave the opportunity to study the epidemiology of helminth infections over an extended period and allowed an examination of the potential for strategic anthelmintic treatments to control helminth disease. However, the study was designed to compare current helminth control practices with strategic treatment under existing field/management conditions. Under these circumstances, no parasitological or production advantages of the strategic treatment were demonstrated over the current helminth control practices.

In spite of the failure in this study to demonstrate statistical differences in the treated and control groups of farms in the two trials, it is most likely that if the strategic treatments were applied by the majority of farmers in specific localities, potential benefits in terms of reduced infections in grazing animals and increased production could be realised. The results therefore brought forth the idea of adoption rate for the strategic regime. It was possible that the small number of farms in which the strategic treatments were applied in each locality represented a very small proportion (probably less than 1%) of farmers that shared communal grazing areas. The extent of the benefits realised would certainly be related to the proportion of farmers within a group sharing communal grazing who adopt the strategic treatment, because this will determine the extent of reduction in pasture contamination and infectivity with helminths. Based on the lessons learnt from this study, a change in the study protocol for future studies can be suggested. It would be

worthwhile investigating the impact of the intervention where the majority of farmers in a specific locality have adopted the regime. This could involve first identifying a locality and providing anthelmintic medication for all animals (sheep, goats and cattle) at the recommended times and monitoring both parasitological and production parameters over a period of at least two years. These results could then be compared with those from animals in another locality but in a similar ecological zone, where animals are monitored without strategic drenching. The two localities should be far enough apart to avoid influencing farmers' drenching regimes. The results from such a trial could provide a better assessment of the benefits of epidemiologically based strategic helminth control over the traditional control practices assuming a high adoption rate in an area. In view of the many factors that might affect productivity of animals on smallholder farms, a multi-disciplinary approach (Michel, 1984; Ndiritu and McLeod, 1995) is essential in order to improve the overall productivity of the farming enterprises. This should address other factors such as grazing management, nutrition and preventive veterinary medicine. Farmer education would certainly be crucial in ensuring high adoption rates of strategic helminth control strategies. A combined approach of this nature, if widely adopted may go along way towards improving livestock productivity in smallholder farming wherever they exist and contribute to combating the effects of poverty among the local communities.

Appendix 1

Farm questionnaire used in the cross-sectional study.

KARI/DFID NARP II LIVESTOCK HELMINTHOLOGY PROJECT
STANDARD FARM QUESTIONNAIRE

PART 1

Section A Introduction and location

survey name	
name of interviewer	
contact address	
date	
district	
location	
sub-location	
village name	
GPS reading	latitude longitude
name of household head	
sex of household head	
name of respondent	
sex of respondent	
relationship to the household head	

Section B. Farming Activities

1. Would you characterise your farming activities as

a) mainly livestock□
b) mixed livestock and crops□
c) mainly crops□

2. Do you sell the majority of your livestock products?

a) yes□
b) no□
c) both equally□

3. Do you sell the majority of your crop harvest?

a) yes□
b) no□
c) both equally□

4. What is most important for subsistence?
a) crops□
b) livestock□
c) both equally□

5. What is most important for cash income?

a) crops□
b) livestock□
c) both equally□

6.a. Please complete the table below:

crop enterprise	manure used (tick)	acreage	tick main reason for production	
			sale	consumption
maize				
maize/crop1				
maize/crop2				
sorghum				
millet				
vegetables				
wheat				
barley				
potatoes				
fruit crops				
pasture-natural				
pasture-sown				
napier/other fodder				
coffee				
tea				
multipurpose crops				

Crops grown with maize:

crop1:
crop2:

6.b. What is the total acreage farmed? acres

7. Tick the livestock species kept

Zebu cattle		Sheep		Pigs	
Grade cattle		Goats		Chicken	
Donkeys		Rabbits		Bees	

8. Please give the reasons, in order of importance, for keeping livestock:

	Cattle	Sheep	Goats
Reason 1			
Reason 2			
Reason 3			

9. Is the household sedentary?

yes☐
no☐

10. If sedentary please indicate the main grazing system:

	Zero grazing	Semi-zero grazing	Free grazing
Zebu cattle			
Grade cattle			
Sheep			
Goats			

Zero-grazing- *all fodder cut and carried*
Semi-zero grazing- *majority of fodder cut and carried*
Free-grazing- *majority of fodder by grazing*

11. Please tick the most appropriate answer for **adult** ruminant livestock:

Livestock	**do the livestock graze off-farm:**			
zebu cattle	always	majority of days	minority of days	never
grade cattle	always	majority of days	minority of days	never
sheep	always	majority of days	minority of days	never
goats	always	majority of days	minority of days	never

12. What is the main breeding system used? (tick):

	artificial insemination	natural service
zebu cattle		
grade cattle		

Section C. Livestock Management

1. Which member of the household is mainly responsible for the care, i.e. feeding, watering etc., of the following livestock?

		Member of household
sheep		
goats		
cattle	calves	
	adults	

(1 = male household head, 2 = other adult male household member, 3 = female household head, 4 = adult female household member, 6 = other, specify)

2. Which member of the household is responsible for health care (treatment of sick animals, vaccination, worming etc.) of the following livestock?

		Member of the household
Sheep		
goats		
cattle	calves	
	adults	

(1 = male household head, 2 = other adult male household member, 3 = female household head, 4 = adult female household member, 6 = other, specify)

3. Which member of the household decides whether to sell the following classes of livestock:

	member of household
poultry	
sheep	
goats	
cattle	

(1 = male household head, 2 = other adult male household member, 3 = female household head, 4 = adult female household member, 6 = other, specify)

4. Which member of the household receives the proceeds from the sale of:

	member of household
poultry	
sheep	
goats	
cattle	

(1 = male household head, 2 = other adult male household member, 3 = female household head, 4 = adult female household member, 5 = other, specify)

5. What expenditures are made with the proceeds of the sale of the following livestock:

	expenditures
poultry	
sheep	
goats	
cattle	

(1 = food for the family, 2 = animal feed, 3 = animal health inputs, 4 = school fees, 5 = health care, 6 = other, specify)

6. What source of revenue are used to buy anthelmintics?

a)
b)
c)
(1 = sale of livestock/livestock products, 2 = sale of crops, 3 = cash from employment off-farm, 4 = other, please specify)

7. Are any of the following species slaughtered for consumption on farm:

sheep
goats
cattle
(1 = yes, 2 = no)

8. How many times in the last year did you slaughter:

sheep
goats
cattle

9. On what occasions did you slaughter livestock:
sheep
goats
cattle
(1 = Christmas/Easter, 2 = weddings/christenings/funerals, 3 = circumcision, 4 = birthdays, 5 = visits by friends or relatives, 6 = other, please specify)

Section D: Household Information

1. total number of people in household
2. number of adult males in residence
3. number of adult males working on the farm
4. number of adult females in residence
5. number of adult females working on the farm
6. number of children in residence
7. number of children working on the farm
8. number of adult males working off the farm
9. number of adult females working off the farm
10. number of people in paid employment on the farm
11. for what periods of the year do you employ non-family labour
(1 = all year, 2 = harvest time only, 3 = never, 4 = other, specify)
12. percentage of household income from non-farm sources
(1 = less than 20, 2 = 20-40, 3 = 41=60, 4 = 61-80, 5 = more than 80)

PART 2

ANIMAL HEALTH

Section A Livestock numbers and structure at time of visit

1.a Cattle

	zebu		grade	
	males	females	males	females
suckling				
weaned animals				
breeding				

breeding females have had at least one parturition

1.b For each breeding female please note the following:

cow id/name	date of last calving	is calf suckling (yes or no)	total milk produced yesterday (litres)

(*if day of month of calving is unknown make it the fifteenth - 15*)

2. Sheep

	males	females
suckling		
weaned animals		
breeding		

3. Goats

	males	females
suckling		
weaned animals		
breeding		

4. Pigs

	breeding males	breeding females	suckling and weaners
number			

5. Chickens

	local	exotic	
		layers	broilers
chicks			
adults			

Section B: Constraints to production

1. Constraints to production scored (5-0):

Score the following constraints to livestock production from 5 to 0 (5= very important, 0= completely unimportant). Constraints not listed can be added.

Constraints	cattle	sheep	goats	poultry	pigs
disease					
feed					
water					
low genetic potential					
poor fertility					
labour					
marketing of livestock and livestock products					
lack of access to livestock services (incl. Vet services)					
lack of access to AI					
*					
*					

2. What are the three most important diseases affecting the following livestock (in order of importance):

CATTLE	disease 1	disease 2	disease 3
name			
clinical signs/predisposing factors			
date last case			
age last case			
treatments			
outcome	died□ survived□	died□ survived□	died□ survived□
total no. of cases in the last 12 months			

SHEEP	disease 1	disease 2	disease 3
name			
clinical signs/predisposing factors			
date last case			
age last case			
treatments			
outcome	died□ survived□	died□ survived□	died□ survived□
total no. of cases in the last 12 months			

GOATS	disease 1	disease 2	disease 3
name			
clinical signs/predisposing factors			
date last case			
age last case			
treatments			
outcome	died□ survived□	died□ survived□	died□ survived□
total no. of cases in the last 12 months			

PIGS	disease 1	disease 2	disease 3
name			
clinical signs/predisposing factors			
date last case			
age last case			
treatments			
outcome	died□ survived□	died□ survived□	died□ survived□
total no. of cases in the last 12 months			

CHICKENS	disease 1	disease 2	disease 3
name			
clinical signs/predisposing factors			
date last case			
age last case			
treatments			
outcome	died□ survived□	died□ survived□	died□ survived□
total no. of cases in the last 12 months			

Section C: Helminthology

1. Do you: a) never use anthelmintics (for cattle, sheep/goats)?
   b) use anthelmintics to treat sick animals only (for cattle, sheep/goats)?
   c) routinely use anthelmintics as preventive measure (for cattle, sheep/goats)?
2. If b or c, do you administer anthelmintics yourself?
yes□ no□

3. If no, who does administer anthelmintics?
(1 = vet, 2 = AHA, 3 = neighbour, 4 = family member, 5 = other, please specify)

4. When was the last time the following were dewormed?

zebu cattle
grade cattle
goats
(enumerators - use the 15th of the month as the day of deworming)

5. Please state the number of treatments with anthelmintics in the last 12 months:

	no. of treatments in last 12 months			brand name of anthelmintic last used
	suckling	weaned	adult	
zebu cattle				
grade cattle				
sheep				
goats				

6. Do you ever use herbal cures for helminthoses?
yes☐ no☐

7. How many different brands of anthelmintic have you used in the last one year?

8. Where do you obtain your anthelmintics from?

vet/AHA ☐
pharmacy ☐
other (please specify) ☐

9. How do you decide which anthelmintic to use?

Price ☐
advice from AHA/vet ☐
advice from vendor ☐
other (please specify) ☐

10. Do you think that the anthelmintic you are currently using is effective?
yes☐ no☐

11a. Have any of your livestock died of worms in the last 12 months?
yes☐ no☐

11b. If yes, which class of livestock died?

	suckling	weaned	adult
zebu cattle			
grade cattle			
sheep			
goats			

Section D: Other animal health practices

1. Have any of the following classes of livestock been vaccinated against any disease in the last 12 months?

zebu cattle
grade cattle
sheep
goats
pigs
poultry
(Use 1 = yes, 2 = no)

2. If yes, against which disease were they vaccinated?

	disease 1	disease 2	do not know (tick)
zebu cattle			
grade cattle			
sheep			
goats			
pigs			
poultry			

(1 = FMD, 2 = LSD, 3 = anthrax,4 = rinderpest, 5 = blackquarter, 6 = haemorrhagic septicaemia, 7 = capripox, 8 = CCPP, 9 = CBPP, 10 = other, 11 = don't know)

3. What tick control practices are used? Please tick appropriate box.

	none	acaricide	grazing restriction	hand picking	traditional treatments
zebu cattle					
grade cattle					
sheep					
goats					
poultry					

4. If acaricide is used what brand was last purchased?

5. If acaricide is used please indicate the method of application by ticking the appropriate box.

	Dip	hand spray	hand wash	pour-on	other
zebu cattle					
grade cattle					
sheep					
goats					

6. Please note the number of acaricide treatments against ticks for each age group in the last one month:

	zebu cattle	grade cattle
suckling		
weaned		
adult		

7. At what age do you first treat calves with acaricide?

IS THIS FARM PART OF THE ORIGINAL TRIAL GROUP?

yes☐ no☐

Appendix 2

Data collection form for individual animal details and visits record.

KARI/DFID NARP II HELMINTHOLOGY PROJECT
INTERVENTION TRIAL RECORDS

Farmer's name
Farm No.

Species	Entry date		
Ear tag No.	Bought☐	gift☐	born on farm☐
Ear tag colour	Birth date		
Sex[1]	estimate ☐	exact ☐	

[1] *male, female, castrate*

Visit date	weight (kg)	Anthelmintic use		Events[2] and date of event	FEC	Fluke EC
		name	dose (ml)			

[2] *partutition, weaning, disease, injury, treatment, vaccination, etc.*

If animal not present, reason for absence: death☐ slaughter☐ gift☐ sale☐
If sold, sold to: Butcher☐ trader☐ market☐ neighbour☐ relative☐
If sold or slaughtered, reason:

Appendix 3

List of subjects covered during the rapid epidemiological appraisal with animal health assistants and veterinarians.

RAPID EPIDEMIOLOGICAL APPRAISSAL WITH ANIMAL HEALTH ASSISTANTS AND FIELD VETERINARIANS

SUBJECTS TO BE COVERED

A) Livestock marketing
B) Perceptions of AHAs and veterinarians to helminth control
   -Recommended methods
   -What farmers do
C) Price fluctuations

NB: The vets and AHAs to be interviewed separately

A) LIVESTOCK MARKETING AND PRICE FLUCTUATIONS

NB: For cattle differentiate between Zebu and exotic cattle. Also differentiate between breeding and other animal categories.

SHEEP, GOATS AND CATTLE

Which type of animals do farmers sell?
Male
female
At what age are they sold

When are they sold (time of the year)

What would the price of male/female animal cost?

Which times of the year do they fetch good price?

Which times of the year are peak sales?

NB: A chart showing pictorially the relative changes in sales volume could be of help

At what time of the day would you have the highest and the lowest price?

Which is highly priced animals bought from the market ?

What determines the price of the animal (visual appraisal, weight, etc.)

NB: Check with county council records for trade volumes.

B) HELMINTH CONTROL PRACTICES

What preventive measures do farmers take against diseases?

What practices do farmers exercise to control helminths

What proportion of farmers use anthelmintics and other forms of control
-Anthelmintics:
-Other forms of control:

Which anthelmintics do they use
-Brands:
-When:
-Doses:

What brands do you AHA/Vets use
-Why:
-When:
-Doses:

Do farmers differentially treat livestock based on age, season of the year, selectively or on a herd basis:

When do you AHA/vets recommend

Would farmers be prepared to change the strategies (i.e. adopt new drenching regime)

Would you AHA/vets be prepared to change the strategies (i.e. adopt new drenching regime)

What is the source of drugs that farmers use
-Chemist
-Agro-chemists
-Co-operatives
-AHA/vets

What is the source of the drugs that you use
-Chemist
-Agro-chemists
-Co-operatives
-Other sources

How does the AHA/vet know about a helminth clinical case?
-Called
-Reminds the farmer, etc.
-Both

How often do you take samples for confirmation of helminth infections?

What kind of farmers are most likely to use anthelmintics?
-Poor
-Rich
-Educated
-Illiterate

What prices per dose of anthelmintic is charged per animal?
-Lamb
-Calf
-Adult, etc.

In your opinion do you or other colleagues give a recommended dose per animal?

What do you recommend?
-For young animals
-For adults

Do the anthelmintic you use work?

Appendix 4

Pasture larval counts from individual sites sampled at the study area showing the monthly differential and mean counts (*Haem* = *Haemonchus sp.*, *Trich* = *Trichostrongylus spp.*, *Coop* = *Cooperia spp).*

Year	Month	Site	*Haem*	*Trich*	*Oesop*	*Coop*	Total
1995	March	A	260	55	0	0	350
1995	April	A	150	35	0	0	185
1995	May	A	400	0	0	10	410
1995	June	A	160	140	0	20	320
1995	July	B	0	0	0	0	0
		C	670	224	0	0	914
		D	125	0	0	0	125
		E	83	0	0	0	83
		F	122	122	0	0	244
		G	2500	100	0	100	4500
	Mean		**583**	**78**	**0**	**17**	**978**
1995	Aug.	B	76	0	0	763	839
		C	520	0	104	104	728
		E	160	0	80	319	559
		F	543	217	0	0	760
		G	1403	0	0	0	1403
	Mean		**540**	**27**	**23**	**237**	**858**
1995	Sept.	A	0	0	0	517	517
		B	156	0	0	0	156
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
	Mean		**22**	**0**	**0**	**74**	**96**
1995	Oct.	A	0	0	0	145	145
		B	78	0	78	0	156
		C	0	0	0	0	0
		D	0	0	75	75	150
		E	0	0	0	0	0
		F	95	0	0	0	95
		G	356	89	0	0	445
		H	0	260	0	130	390
	Mean		**66**	**44**	**9**	**43**	**172**
1995	Nov.	A	0	0	0	0	0
		B	244	122	122	0	488
		C	88	0	0	0	88
		D	86	43	0	0	129
		E	86	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	65	0	0	65
	Mean		**52**	**29**	**15**	**0**	**96**

Year	Month	Site	*Haem*	*Trich*	*Oesop*	*Coop*	Total
1995	Dec.	A	0	306	0	0	306
		B	87	87	0	0	174
		C	0	0	0	0	0
		D	0	259	346	0	605
		E	117	0	117	117	351
		F	5875	443	0	0	6318
		G	0	0	0	0	0
		H	0	0	0	0	0
	Mean		**760**	**137**	**58**	**15**	**969**
1996	Jan.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	91	91	91	0	273
		D	0	120	0	0	120
		E	0	0	0	0	0
		F	236	236	0	0	472
		G	58	115	0	231	404
		H	0	0	0	0	0
	Mean		**48**	**70**	**11**	**29**	**159**
1996	Feb.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	5564	78	0	78	5720
		D	1199	0	0	0	1199
		E	0	0	0	0	0
		G	0	0	0	0	0
		H	1044	0	0	0	1044
	Mean		**976**	**11**	**0**	**11**	**995**
1996	March	A	282	0	0	0	282
		B	217	0	0	0	217
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	127	0	0	0	127
		F	175	0	0	0	175
		G	0	417	0	0	417
		H	2623	0	0	0	2623
	Mean		**428**	**52**	**0**	**0**	**480**
1996	April	A	299	149	0	149	597
		B	74	0	74	0	148
		C	0	0	0	0	0
		D	233	349	0	0	582
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	120	120	0	0	240
		H	0	0	0	0	0
	Mean		**91**	**77**	**9**	**19**	**196**

Year	Month	Site	*Haem*	*Trich*	*Oesop*	*Coop*	Total
1996	May	A	0	0	154	0	154
		B	0	0	0	0	0
		C	0	179	0	179	358
		D	0	0	147	0	147
		E	1765	0	0	294	2059
		F	0	0	0	0	0
		G	125	0	0	375	500
		H	0	408	204	0	612
	Mean		**236**	**73**	**63**	**106**	**479**
1996	June	A	282	1130	0	282	1694
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	457	0	0	0	457
		E	0	0	0	0	0
		F	385	0	0	0	385
		G	109	0	0	0	109
		H	381	0	127	0	508
	Mean		**201**	**141**	**16**	**35**	**394**
1996	July	A	156	0	0	0	156
		B	0	0	0	0	0
		C	119	0	0	0	119
		D	0	90	0	0	90
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	222	222	0	444	888
		H	0	0	0	0	0
	Mean		**62**	**39**	**0**	**56**	**157**
1996	Aug.	A	0	0	0	0	0
		B	396	49	0	0	445
		C	0	0	0	0	0
		D	182	91	0	0	373
		E	0	0	0	0	0
		F	213	0	0	0	213
		G	0	0	0	0	0
		H	0	0	0	0	0
	Mean		**99**	**18**	**0**	**0**	**129**
1996	Sept.	A	132	0	0	132	264
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	204	0	0	204
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
	Mean		**17**	**26**	**0**	**17**	**59**

Year	**Month**	**Site**	***Haem***	***Trich***	***Oesop***	***Coop***	**Total**
1996	Oct.	A	0	88	88	0	176
		B	0	0	0	0	0
		C	0	102	0	0	102
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	0	76	0	0	76
		G	0	0	0	0	0
		H	370	0	0	0	370
	Mean		**46**	**33**	**11**	**0**	**91**

Appendix 5

Mean differential larval counts from sheep faecal culture for the period between March 1995 and October 1996.The cultures were from pooled faecal samples for the animals with a positive egg count for nematodes.

Months/Year	Mean percentage larval counts for the different nematode genera				
	Haemonchus	*Trichostrong-ylus*	*Oesophagosto-mum*	*Strongyloides*	*Cooperia*
1995					
March	56.5	8.7	4.3	30.4	0.0
April	38.0	60.2	0	0	0.8
May	17.7	58.8	10.7	20.8	0
June	26.3	36.8	15.8	0	21.1
July	66.3	18.4	5.3	10.0	0
August	56.5	8.7	4.3	30.4	0
September	60.0	24.4	14.6	0	0
October	41.1	23.5	5.9	11.8	23.5
November	57.0	14.3	28.6	0	0
December	11.8	70.5	11.8	5.9	0
1996					
January	54.5	43.8	1.7	0	0
February	28.4	30.7	32.7	8.2	0
March	30.3	16.9	27.3	25.5	0
April	16.7	50.0	33.3	0	0
May	38.2	45.0	13.2	3.6	0
June	83.7	7.1	2.8	6.4	0
July	37.2	33.1	22.3	3.8	3.6
August	19.5	72.2	0	0	8.3
September	0	33.3	66.7	0	0
October	8.3	4.2	6.7	68.3	12.5
MEAN	**37.3**	**33.1**	**22.3**	**3.8**	**3.5**

Appendix 6

Mean differential larval counts from cattle faecal cultures for the period from March 1995 to October 1996. The cultures were from pooled faecal samples for animals with a positive egg count for nematodes.

Month/Year	Mean percentage larval counts for different nematode genera				
	Haemonchus	*Trichostrongy -lus*	*Oesophagosto -mum*	*Strongyloides*	*Cooperia*
1995					
March	27.4	21.1	26.5	16.8	8.2
April	55.1	22.7	6.1	2.0	10.9
May	9.9	47.3	15.9	0	6.9
June	34.3	28.1	9.4	6.3	22.0
July	44.4	44.4	6.1	0	5.0
August	48.3	27.4	8.2	0	16.1
September	43.6	28.4	23.0	5.0	0
October	75.0	12.5	12.5	0	0
November	22.2	11.1	50.0	0	16.7
December	10.7	72.2	10.0	0	7.1
1996					
January	17.7	70.6	11.8	0	0
February	20.0	66.7	6.7	0	6.7
March	21.2	6.1	33.3	0	39.4
April	33.3	33.3	16.7	0	16.7
May	31.0	16.7	45.2	0	7.1
June	20.6	28.6	23.4	6.3	21.1
July	42.3	18.0	15.6	0	24.1
August	27.0	38.1	10.4	3.1	21.4
September	43.8	20.8	35.4	0	0
October	55.6	16.7	27.7	0	0
MEAN	**34.1**	**31.5**	**19.7**	**1.9**	**12.8**

Appendix 7

Total and differential nematode counts from the individual tracer lambs grazed at the study area every month.

Year	Month	Animal no	wk indoor	*H.cont*	*T. axei*	*T. colum*	*Cooperia*	*Oe.*	*Trichuris*	Total
1995	May	751	3	300	0	0	0	0	0	300
		767	3	250	100	350	50	93	1	844
		759	3	350	0	200	0	14	2	566
		799	6	350	50	50	0	35	2	487
		754	6	1550	0	150	50	149	4	1903
		777	6	450	0	0	0	18	4	472
		Mean		**541**	**25**	**125**	**17**	**52**	**2**	**821**
1995	June	778	3	100	0	0	0	9	1	110
		792	3	250	0	0	0	11	1	262
		784	3	1150	0	0	0	10	1	1166
		764	6	600	0	0	0	13	0	613
		784	6	350	0	0	0	2	4	356
		793	6	850	0	0	0	4	2	856
		Mean		**550**	**0**	**0**	**0**	**8**	**2**	**560**
1995	July	770	3	150	0	0	0	3	4	157
		790	3	300	0	0	0	0	0	300
		776	3	700	400	150	0	0	0	1250
		760	6	450	0	200	0	4	4	658
		761	6	500	250	0	0	5	0	755
		Mean		**420**	**130**	**70**	**0**	**2**	**2**	**624**
1995	August	4365	3	750	100	200	0	0	0	1050
		4363	3	1100	900	1300	0	46	0	3346
		774	3	250	450	400	0	0	0	1100
		405	6	700	750	1000	0	22	9	2481
		4336	6	450	250	100	0	12	3	815
		4399	6	1050	550	1250	100	31	2	2983
		Mean		**717**	**500**	**708**	**17**	**19**	**2**	**1963**
1995	Sept.	4385	3	500	350	850	0	6	10	1716
		4367	3	0	0	150	0	0	0	150
		4337	3	500	450	200	0	0	0	1150
		4396	6	550	900	900	50	0	0	2400
		4374	6	200	150	550	100	0	0	1000
		3397	6	500	100	0	0	0	0	600
		Mean		**375**	**325**	**442**	**25**	**1**	**2**	**1170**

Year	Month	Animal no	wk indoor	*H.cont*	*T. axei*	*T. colum*	*Cooperia*	*Oe.*	*Trichuris*	Total
1995	October	399	3	450	150	50	0	0	0	650
		574	3	200	100	200	0	0	0	500
		559	3	250	100	250	0	0	0	600
		592	6	350	250	50	0	19	13	682
		578	6	350	300	600	0	0	0	1250
		571	6	450	850	650	50	0	0	2000
		Mean		**342**	**292**	**300**	**8**	**3**	**2**	**947**
1995	Nov.	2658	3	600	0	0	0	0	0	600
		2645	3	2400	1000	1600	450	0	0	5450
		2659	3	750	500	350	650	0	0	2250
		2656	6	2450	1850	0	0	28	3	4331
		2660	6	8750	2300	2600	1900	60	0	15610
		Mean		**2990**	**1130**	**910**	**600**	**18**	**1**	**5649**
1995	Dec.	248	3	200	0	0	0	0	0	200
		208	3	600	0	1650	0	0	0	2250
		232	3	400	0	0	0	0	0	400
		205	6	200	250	0	0	0	0	450
		214	6	1350	600	0	0	0	0	1950
		552	6	1350	250	650	0	0	0	2250
		Mean		**683**	**183**	**383**	**0**	**0**	**0**	**1250**
1996	Jan.	246	3	4650	0	650	100	0	0	5400
		202	3	300	350	0	0	18	0	668
		229	3	4250	650	1500	400	0	0	6800
		241	6	700	1350	2350	0	0	0	4400
		219	6	800	0	1900	0	0	0	2700
		269	6	1600	50	550	250	39	0	1489
		Mean		**2050**	**400**	**1158**	**125**	**10**	**0**	**3776**
1996	Feb.	233	3	450	50	0	0	0	0	500
		228	3	450	0	0	0	0	0	450
		216	3	750	500	500	0	0	0	1750
		243	6	950	0	0	0	0	0	950
		266	6	200	200	0	0	0	0	400
		Mean		**560**	**150**	**100**	**0**	**0**	**0**	**810**

Year	Month	Animal no	wk indoor	*H.cont*	*T. axei*	*T. colum*	*Cooperia*	*Oe.*	*Trichuris*	Total
1996	March	348	3	2150	0	100	0	0	0	2250
		328	3	1300	600	0	0	0	0	1900
		314	3	650	0	0	0	0	0	650
		353	6	750	0	1250	0	0	0	2000
		320	6	600	350	0	0	0	0	950
		306	6	1650	800	600	0	0	0	3050
		Mean		**1183**	**292**	**325**	**0**	**0**	**0**	**1800**
1996	April	354	3	1350	350	100	50	0	0	1850
		350	3	450	0	0	0	0	0	450
		312	3	1550	0	600	0	0	0	2150
		338	6	1900	100	100	0	0	0	2100
		329	6	450	0	0	0	0	0	450
		365	6	150	300	0	0	0	0	450
		Mean		**975**	**125**	**133**	**8**	**0**	**0**	**1241**
1996	May	784	3	6250	0	950	0	0	0	7200
		780	3	2400	200	400	0	0	0	3000
		785	3	450	0	0	0	0	0	450
		786	6	2300	850	0	350	0	0	3500
		791	6	250	0	0	0	0	0	250
		783	6	1450	200	50	0	0	0	1700
		Mean		**2183**	**208**	**233**	**58**	**0**	**0**	**2683**
1996	June	939	3	700	250	350	0	0	0	1300
		961	3	2250	1850	1050	450	0	0	5600
		976	3	900	0	650	0	123	10	1603
		981	6	250	50	0	300	0	0	600
		977	6	2850	300	1350	0	0	0	4500
		923	6	1150	50	1800	0	56	0	3056
		Mean		**1350**	**417**	**867**	**125**	**30**	**2**	**2777**
1996	July	912	3	1200	200	500	350	0	0	2250
		968	3	700	0	0	100	0	0	800
		906	3	1250	1150	0	0	9	0	2400
		972	6	2200	1400	100	50	0	0	3750
		787	6	900	800	0	0	0	0	1700
		922	6	1350	300	0	0	0	0	1650
		Mean		**1267**	**642**	**100**	**83**	**2**	**0**	**2092**

Year	Month	Animal no	wk indoor	*H.cont*	*T. axei*	*T. colum*	*Cooperia*	*Oe.*	*Trichuris*	Total
1996	August	957	3	200	0	0	0	0	0	200
		984	3	200	0	0	0	0	0	200
		990	3	200	50	0	50	0	0	400
		917	6	100	0	0	0	0	0	100
		949	6	250	200	0	0	0	0	450
		Mean		**210**	**50**	**0**	**10**	**0**	**0**	**270**
1996	Sept.	315	3	0	0	0	0	0	0	0
		309	3	0	0	0	0	0	0	0
		308	3	0	0	0	0	0	0	0
		321	6	400	300	0	0	0	0	700
		Mean		**100**	**75**	**0**	**0**	**0**	**0**	**175**
1996	October	375	3	50	0	0	0	0	0	50
		364	3	0	0	0	0	0	0	0
		325	3	50	0	0	0	0	0	50
		Mean		**33**	**0**	**0**	**0**	**0**	**0**	**33**

Appendix 8

Total and differential nematode counts from the individual permanently grazed sheep purchased from farms in the study area every month.

Year	Month	Animal no	Wk	*H. cont*	*T.axei*	*T.colum*	*Cooperia*	*Oesoph*	*Trichuris*	Total
1995	July	500	3	650	350	0	0	0	0	1000
		501	3	0	0	50	0	3	0	53
		3908	6	450	1100	350	0	27	0	1927
		3906	6	200	500	0	0	0	0	700
		Mean		**325**	**488**	**100**	**0**	**7**	**0**	**920**
1995	Aug.	3954	3	550	350	900	0	26	3	1829
		3951	3	150	250	950	0	0	0	1350
		3952	6	500	100	50	0	20	1	671
		3953	6	50	450	1950	100	0	0	2550
		Mean		**313**	**288**	**963**	**25**	**11**	**1**	**1600**
1995	Sept.	3890	3	0	100	0	0	0	0	100
		3891	3	0	2950	6850	0	0	0	9800
		3889	6	50	1000	500	50	0	0	1600
		3892	6	50	750	3000	50	0	0	3850
		Mean		**25**	**1200**	**2588**	**25**	**0**	**0**	**3838**
1995	Oct.	3872	3	200	1500	500	50	0	0	2250
		3871	6	100	450	200	50	11	0	811
		3861	6	150	650	50	0	0	0	850
		Mean		**150**	**867**	**250**	**33**	**4**	**0**	**1304**
1995	Nov.	553	3	100	100	0	0	0	0	200
		2646	3	3200	300	1100	150	0	0	4750
		551	6	150	1300	4600	0	242	300	6592
		Mean		**1150**	**567**	**1900**	**50**	**80**	**100**	**3847**
1995	Dec.	101	3	200	650	0	0	0	0	850
		103	3	0	0	0	0	0	0	0
		104	6	50	2250	0	0	0	0	2300
		102	6	0	100	0	0	0	0	100
		Mean		**63**	**750**	**0**	**0**	**0**	**0**	**813**
1996	Jan.	808	3	150	6700	12400	1800	0	0	21050
		500	3	0	0	0	0	0	0	0
		534	6	100	2850	1500	350	0	0	4800
		822	6	50	500	1350	100	0	0	2000
		Mean		**75**	**2513**	**3813**	**563**	**0**	**0**	**6963**

Year	Month	Animal no	Wk	*H. cont*	*T.axei*	*T.colum*	*Cooperia*	*Oesoph*	*Trichuris*	Total
1996	Feb.	386	3	450	1900	0	0	0	0	2350
		387	3	50	7800	4950	300	0	0	13100
		388	6	550	1350	0	0	0	0	1900
		389	6	500	1500	850	2500	0	0	5350
		Mean		**388**	**3138**	**1450**	**700**	**0**	**0**	**5675**
1996	March	777	3	100	400	0	0	0	0	500
		776	3	0	0	0	0	0	0	0
		779	6	0	300	1750	1250	0	0	3300
		Mean		**33**	**233**	**583**	**417**	**0**	**0**	**1267**
1996	April	635	3	1350	1450	1050	0	0	0	3850
		633	6	0	150	0	0		0	150
		632	6	200	0	50	0	0	0	250
		Mean		**517**	**525**	**367**	**0**	**0**	**0**	**1417**
1996	May	636	3	2600	300	50	50	0	0	3000
		3617	3	3800	3050	1050	150	0	0	8050
		671	6	1300	50	0	0	0	0	1350
		637	6	1250	950	0	0	0	0	2200
		Mean		**2238**	**1088**	**275**	**50**	**0**	**0**	**3650**
1996	June	225	3	700	100	0		45	0	845
		226	3	550	0	650	50	0	0	1250
		227	6	1100	300	0	0	0	0	1400
		228	6	150	450	0	0	0	0	600
		Mean		**625**	**213**	**163**	**12**	**11**	**0**	**1024**
1996	July	801	3	250	0	100	50	0	0	400
		4117	3	50	800	450	0	0	0	1300
		267	6	800	950	100	0	0	0	1850
		266	6	550	850	1050	0	22	1	2473
		Mean		**413**	**650**	**425**	**12**	**6**	**0.25**	**1506**
1996	Aug.	3613	3	800	1800	0	0	0	0	2600
		236	3	50	300	0	0	0	0	350
		801	6	0	250	0	0	0	0	250
		802	6	2800	2250	1550	0	0	0	6600
		Mean		**913**	**1150**	**387**	**0**	**0**	**0**	**2450**

Year	Month	Animal no	Wk	*H. cont*	*T.axei*	*T.colum*	*Cooperia*	*Oesoph*	*Trichuris*	Total
1996	Sept.	285	3	100	0	0	0	0	0	100
		284	3	250	0	0	0	0	0	250
		3978	6	0	0	0	0	0	0	0
		Mean		**117**	**0**	**0**	**0**	**0**	**0**	**117**
1996	Oct.	449	3	300	950	2200	0	0	0	3450
		435	3	50	0	100	0	0	0	150
		456	6	0	0	0	0	0	0	0
		Mean		**117**	**317**	**766**	**0**	**0**	**0**	**1200**

Appendix 9

Monthly infection prevalence of sheep in smallholder farms with the liver fluke, *Fasciola gigantica*, based on faecal examinations.

Time	No. of sheep examined	No. with liver fluke eggs	Percentage positive
1995			
March	120	4	3.3
April	122	8	6.6
May	83	11	13.2
June	85	6	7.1
July	71	5	7.0
August	93	5	5.4
September	93	2	2.1
October	87	3	3.4
November	88	10	11.4
December	105	3	2.9
1996			
January	120	4	3.3
February	142	5	3.5
March	129	*	*
April	147	1	0.7
May	146	14	9.6
June	129	6	4.7
July	122	5	4.1
August	155	9	5.8
September	130	8	6.2
October	130	10	7.7

* Samples were not examined for Fasciola eggs in March 1996.

Appendix 10

Monthly infection prevalence of cattle with the liver fluke, *Fasciola gigantica*, in smallholder farms based on faecal examinations

Time	No. of cattle examined	No. with liver fluke eggs	Percentage infected
1995			
March	168	13	7.7
April	190	25	13.2
May	185	41	22.2
June	176	27	15.3
July	145	20	14.0
August	179	34	19.1
September	190	9	5.2
October	171	20	11.7
November	151	29	19.2
December	171	9	5.3
1996			
January	179	10	5.6
February	211	5	2.4
March	177	*	*
April	192	8	4.2
May	207	30	14.5
June	196	32	16.3
July	188	25	13.3
August	206	42	20.4
September	197	34	17.3
October	195	38	19.5

* Samples were not examined for Fasciola eggs in March 1996.

Appendix 11

Monthly infection prevalence of sheep with paramphistomes in smallholder farms in the study area based on faecal examinations.

Month/Year	No. of sheep examined	No. infected with paramphistomes	Percentage infected
1995			
March	120	15	12
April	122	22	18
May	83	10	12
June	85	9	11
July	71	10	14
August	93	19	20
September	93	19	20
October	87	16	18
November	88	17	19
December	105	23	22
1996			
January	120	21	17
February	142	24	17
March	129	15	11
April	147	25	17
May	146	16	11
June	129	13	10
July	122	19	14
August	155	18	11
September	130	22	17
October	130	11	8.5

Appendix 12

Monthly infection prevalence of cattle with paramphistomes in smallholder farms in the study area based on faecal examinations.

Month/Year	No. of samples examined	No. infected with paramphistomes	Percentage infected
1995			
March	168	40	24
April	190	65	34
May	185	67	36
June	176	70	40
July	145	56	38
August	179	58	32
September	190	58	30
October	171	37	22
November	151	64	42
December	171	54	32
1996			
January	179	44	25
February	211	71	33
March	177	45	25
April	192	69	35
May	207	75	36
June	196	82	41
July	188	66	35
August	206	68	197
September	197	70	36
October	195	73	37

Appendix 13

Liver fluke recoveries from tracer lambs every month showing the individual counts as well as the monthly mean and total fluke burdens.

Year	Month	Animal no.	Wk indoors	Fluke count
1995	May	751	3	6
		767	3	3
		759	3	2
		799	6	1
		754	6	1
		777	6	14
		Total		**27**
		Mean		**4.5**
1995	June	778	3	0
		792	3	0
		794	3	0
		764	6	0
		784	6	0
		793	6	0
		Total		**0**
		Mean		**0**
1995	July	770	3	0
		790	3	0
		776	3	0
		760	6	0
		761	6	5
		Total		**5**
		Mean		**1**
1995	August	4365	3	5
		4363	3	0
		774	3	3
		405	6	0
		4336	6	0
		4399	6	3
		Total		**11**
		Mean		**1.8**
1995	September	4385	3	10
		4367	3	3
		4337	3	2
		4396	6	20
		4374	6	0
		3397	6	0
		Total		**35**
		Mean		**5.8**

Year	Month	Animal no.	Wk indoors	Fluke count
1995	October	399	3	23
		574	3	26
		559	3	17
		592	6	0
		578	6	30
		571	6	28
Total				**124**
Mean				**20.7**
1995	November	2658	3	0
		2645	3	2
		2659	3	0
		2656	6	0
		2660	6	0
		Total		**2**
		Mean		**0.4**
1995	December	248	3	0
		208	3	0
		232	3	0
		205	6	4
		214	6	0
		552	6	0
		Total		**4**
		Mean		**0.7**
1996	January	246	3	0
		202	3	1
		229	3	0
		241	6	4
		219	6	0
		269	6	3
		Total		**8**
		Mean		**1.3**
1996	February	233	3	2
		228	3	3
		216	3	0
		243	6	79
		266	6	0
		Total		**84**
		Mean		**16.8**

Year	Month	Animal no.	Wk indoors	Fluke count
1996	March	348	3	11
		328	3	0
		314	3	0
		353	6	4
		320	6	16
		306	6	12
		Total		**43**
		Mean		**7.2**
1996	April	354	3	2
		350	3	1
		312	3	0
		338	6	3
		329	6	32
		365	6	2
		Total		**40**
		Mean		**6.7**
1996	May	784	3	0
		780	3	1
		785	3	0
		786	6	0
		791	6	0
		783	6	0
		Total		**1**
		Mean		**0.2**
1996	June	939	3	0
		961	3	0
		976	3	0
		981	6	0
		977	6	0
		923	6	0
		Total		**0**
		Mean		**0**
1996	July	912	3	0
		968	3	0
		906	3	0
		972	6	0
		787	6	6
		922	6	0
		Total		**6**
		Mean		**1**

Year	Month	Animal no.	Wk indoors	Fluke count
1996	August	957	3	0
		984	3	0
		990	3	0
		917	6	3
		949	6	0
		Total		**3**
		Mean		**0.6**
1996	September	315	3	0
		309	3	0
		308	3	0
		321	6	0
		Total		**0**
		Mean		**0**
1996	October	375	3	0
		364	3	0
		325	3	0
		Total		**0**
		Mean		**0**

Appendix 14

Liver fluke recoveries from the permanently grazed sheep every month showing the individual counts as well as the monthly mean and total fluke burdens.

Year	Month	Animal no.	Wk indoor	Fluke count
		501	3	0
1995	July	500	3	3
		3908	6	2
		3906	6	3
		Total		**8**
		Mean		**2**
1995	August	3954	3	0
		3951	3	0
		3952	6	0
		3953	6	0
		Total		**0**
		Mean		**0**
1995	September	3890	3	3
		3891	3	0
		3889	6	1
		3892	6	0
		Total		**4**
		Mean		**1**
1995	October	3872	3	0
		3871	6	30
		3861	6	0
		Total		**30**
		Mean		**10**
1995	November	553	3	1
		2646	3	0
		551	6	0
		Total		**1**
		Mean		**0.3**
1995	December	101	3	0
		103	3	0
		104	6	11
		102	6	0
		Total		**11**
		Mean		**2.8**

Year	Month	Animal no.	Wk indoor	Fluke count
1996	January	808	3	0
		500	3	4
		534	6	0
		822	6	0
		Total		**4**
		Mean		**1**
1996	February	386	3	0
		387	3	0
		388	6	0
		389	6	0
		Total		**0**
		Mean		**0**
1996	March	777	3	0
		776	3	0
		779	6	26
		Total		**26**
		Mean		**8.7**
1996	April	635	3	18
		633	6	23
		632	6	0
		Total		**41**
		Mean		**13.7**
1996	May	636	3	0
		3617	3	0
		671	6	8
		637	6	0
		Total		**8**
		Mean		**2**
1996	June	225	3	0
		226	3	0
		227	6	6
		228	6	0
		Total		**6**
		Mean		**1.5**

Year	Month	Animal no.	Wk indoor	Fluke count
1996	July	801	3	3
		4117	3	0
		267	6	199
		266	6	115
		Total		**317**
		Mean		**79.3**
1996	August	3613	3	4
		236	3	1
		801	6	0
		802	6	0
		Total		**5**
		Mean		**1.3**
1996	September	285	3	0
		284	3	3
		3978	6	0
		Total		**3**
		Mean		**1**
1996	October	449	3	0
		435	3	0
		465	6	6
		456	3	0
		Total		**6**
		Mean		**1.5**

Appendix 15

Total and differential larval counts from herbage samples collected from individual sites as well as the monthly means for the duration of the intervention trial between November, 1996 and April, 1998.

Haem. = *Haemonchus* spp.
Trich. = *Trichostrongylus* spp
Oe. = *Oesophagostomum* spp.

Year	Month	Site	*Haem.*	*Trich.*	*Oe.*	*Cooperia*	Total
1996	Nov.	A	0	0	0	312	312
		B	2128	106	0	0	2234
		C	0	82	0	0	82
		D	0	0	0	0	0
		E	0	0	0	135	135
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	403	80	80	80	643
Mean			**316**	**34**	**10**	**66**	**426**
1996	Dec.	A	280	0	0	0	280
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	92	0	0	0	92
		E	0	126	0	0	126
		F	0	0	0	0	0
		G	97	0	0	0	97
		H	0	0	0	0	0
Mean			**59**	**16**	**0**	**0**	**74**
1997	Jan.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**0**	**0**	**0**	**0**	**0**
1997	Feb.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**0**	**0**	**0**	**0**	**0**

Year	Month	Site	*Haem.*	*Trich.*	*Oe.*	*Cooperia*	Total
1997	Mar.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	60	60	241	0	361
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**8**	**8**	**30**	**0**	**45**
1997	Apr.	A	129	258	711	129	1227
		B	0	116	0	0	116
		C	0	0	0	0	0
		D	0	83	0	250	333
		E	91	91	0	91	273
		F	685	411	1164	685	2945
		G	0	368	0	147	515
		H	0	91	229	229	549
Mean			**113**	**149**	**263**	**191**	**745**
1997	May	A	0	0	0	82	82
		B	75	0	0	224	299
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	90	90
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**9**	**0**	**0**	**50**	**59**
1997	June	A	0	0	0	757	757
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	135	0	0	135	270
		E	128	0	0	128	256
		F	105	0	0	0	105
		G	93	0	0	0	93
		H	0	0	0	0	0
Mean			**58**	**0**	**0**	**128**	**185**
1997	July	A	0	260	0	0	260
		B	0	0	0	1370	1370
		C	0	0	0	109	109
		D	118	0	0	118	236
		E	0	0	0	339	339
		F	244	0	0	0	244
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**45**	**33**	**0**	**242**	**320**

Year	Month	Site	*Haem.*	*Trich.*	*Oe.*	*Cooperia*	Total
1997	Aug.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**0**	**0**	**0**	**0**	**0**
	Sept.	A	0	0	0	0	0
		B	0	66	0	0	66
		C	0	0	0	0	0
		D	0	49	0	0	49
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	58	0	0	58
		H	0	0	0	0	0
Mean			**0**	**22**	**0**	**0**	**22**
1997	Oct.	A	0	0	0	349	349
		B	0	305	0	0	305
		C	296	0	148	0	444
		D	0	0	0	0	0
		E	200	200	300	100	800
		F	0	0	0	90	90
		G	169	0	0	0	169
		H	117	117	0	0	234
Mean			**97**	**73**	**56**	**68**	**289**
1997	Nov.	A	109	435	109	0	653
		B	0	0	0	0	0
		C	0	0	0	83	83
		D	113	0	0	0	113
		E	0	0	0	0	0
		F	0	278	0	0	278
		G	455	113	0	0	568
		H	139	0	0	69	208
Mean			**102**	**103**	**14**	**19**	**272**
1997	Dec.	A	726	1855	0	0	2501
		B	152	76	0	758	986
		C	0	0	0	139	139
		D	0	80	0	0	80
		E	454	226	0	113	793
		F	113	0	0	0	113
		G	0	0	0	0	0
		H	370	0	0	93	463
Mean			227	279	**0**	**138**	**634**

Year	Month	Site	*Haem.*	*Trich.*	*Oe.*	*Cooperia*	Total
1998	Jan.	A	1886	1730	314	0	3930
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	0	0	51	254	305
		E	0	0	0	0	0
		F	121	0	0	0	121
		G	0	142	74	74	284
		H	0	0	0	0	0
Mean			**251**	**234**	**55**	**41**	**580**
1998	Feb.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	96	96
		D	0	0	0	579	579
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	0
		H	0	0	0	0	0
Mean			**0**	**0**	**0**	**84**	**84**
1998	Mar.	A	0	0	0	0	0
		B	246	246	0	0	492
		C	0	0	0	0	0
		D	0	0	0	0	0
		E	0	0	0	0	0
		F	132	264	0	0	396
		G	0	0	0	0	0
		H	0	102	0	0	102
Mean			**47**	**76**	**0**	**0**	**124**
1998	Apr.	A	0	0	0	0	0
		B	0	0	0	0	0
		C	0	0	0	0	0
		D	333	167	0	167	667
		E	0	0	0	0	0
		F	0	0	0	0	0
		G	0	0	0	0	
		H	0	0	0	0	0
Mean			**42**	**21**	**0**	**21**	**83**

Appendix 16

Total and differential nematode counts from tracer lambs grazing in the study area during the intervention trial between November, 1996 and April, 1998. The monthly means are also shown for individual nematode species and total recoveries.

H. co. = *Haemonchus contortus*
T. axei. = *Trichostrongylus axei*
T.col. =*Trichostrongylus colubriformis*
Coop. = *Cooperia* spp.
Oe. = *Oesophagostomum* spp.
Trich. =*Trichuris* spp.

Year	Month	An. no	Wk	*H.co..*	*T. axei*	*T. col.*	*Coop.*	*Oe.*	*Trich.*	Total
1996	Nov.	360	3	550	0	0	0	0	0	550
		326	3	600	50	0	50	0	0	700
		365	3	0	0	0	0	0	0	0
		318	6	250	0	0	0	0	0	250
		316	6	500	0	0	0	0	0	500
		358	6	0	0	0	0	0	0	0
Mean				**317**	**8**	**0**	**8**	**0**	**0**	**333**
1996	Dec.	332	3	1150	0	0	0	0	0	1150
		313	3	300	0	0	0	0	0	300
		353	3	200	0	0	0	0	0	200
		361	6	300	0	0	0	0	0	300
		376	6	0	2000	0	0	0	0	2000
		400	6	350	0	0	0	0	0	350
Mean				**383**	**333**	**0**	**0**	**0**	**0**	**716**
1997	Jan.	340	3	1700	750	0	0	0	0	2450
		343	3	100	0	0	0	0	0	100
		344	3	0	0	0	0	0	0	0
		376	6	0	0	0	0	0	0	0
		365	6	0	0	0	0	0	0	0
Mean				**450**	**188**	**0**	**0**	**0**	**0**	**638**
1997	Feb.	196	3	0	0	0	0	0	0	0
		109	3	0	0	0	0	0	0	0
		168	3	0	0	0	0	0	0	0
		179	6	0	0	0	0	0	0	0
		142	6	0	0	0	0	0	0	0
		189	6	0	0	0	0	0	0	0
Mean				**0**	**0**	**0**	**0**	**0**	**0**	**0**
1997	Mar.	102	3	500	150	0	0	0	0	650
		123	3	0	0	0	0	0	0	0
		186	6	150	0	0	0	0	0	150
		115	6	200	0	0	0	0	0	200
		152	6	0	0	0	0	0	0	0
Mean				**170**	**30**	**0**	**0**	**0**	**0**	**200**

Year	Month	An. no	Wk	*H.con*	*T.axei*	*T.col*	*Coop*	*Oe.*	*Coop*	Total
1997	Apr.	174	3	950	900	0	0	0	0	1850
		197	3	1000	2100	0	0	0	0	3100
		185	3	150	1050	0	0	0	0	1200
		104	6	0	0	0	0	0	0	0
		169	6	850	450	0	0	0	0	1300
Mean				**590**	**900**	**0**	**0**	**0**	**0**	**1490**
1997	May	119	3	550	0	0	0	0	0	550
		128	3	800	550	650	250	0	0	2250
		134	3	800	0	0	0	0	0	800
		171	6	850	0	0	0	0	0	850
		116	6	600	0	0	0	0	0	600
		140	6	650	0	0	0	0	0	650
Mean				**708**	**118**	**108**	**42**	**0**	**0**	**950**
1997	June	511	3	700	350	0	0	0	0	1050
		591	3	300	0	0	0	0	0	300
		571	3	700	50	0	0	0	0	750
		576	6	800	0	300	0	0	0	1100
		592	6	450	0	0	0	0	0	450
		558	6	800	0	0	0	0	0	800
Mean				**625**	**67**	**50**	**0**	**0**	**0**	**742**
1997	July	533	3	1050	0	250	0	0	0	1300
		557	3	250	0	0	0	0	0	250
		520	6	0	4100	0	0	0	0	4100
		510	6	550	0	0	0	0	0	550
		529	6	1050	400	0	0	0	0	1450
Mean				**500**	**900**	**50**	**0**	**0**	**0**	**1530**
1997	Aug.	543	3	300	0	0	0	0	0	300
		530	3	1050	0	0	0	0	0	1050
		542	6	300	0	0	0	0	0	300
		586	6	0	0	0	0	0	0	0
Mean				**413**	**0**	**0**	**0**	**0**	**0**	**413**
1997	Sept.	566	3	650	0	0	0	0	0	650
		538	3	500	0	0	0	0	0	500
		540	3	350	0	0	0	0	0	350
		527	6	450	0	0	0	0	0	450
		565	6	400	0	0	0	0	0	400
		553	6	200	0	0	0	0	0	200
Mean				**425**	**0**	**0**	**0**	**0**	**0**	**425**

Year	Month	An.no	Wk	*H.con*	*T.axei*	*T.col.*	*Coop.*	*Oe.*	*Trich.*	Total
1997	Oct.	509	3	750	0	0	0	0	0	750
		595	3	250	0	0	0	0	0	250
		525	3	1450	550	1700	0	0	0	3700
		543	6	1200	0	0	0	0	0	1200
		583	6	2350	0	650	0	0	0	3000
		584	6	1600	650	950	0	0	0	3200
Mean				**1267**	**200**	**550**	**0**	**0**	**0**	**2017**
1997	Nov.	508	3	750	0	550	150	0	0	1450
		579	3	0	7400	0	0	0	0	7400
		586	6	1950	0	0	0	0	0	1950
Mean				**900**	**2467**	**183**	**50**	**0**	**0**	**3600**
1997	Dec.	517	3	1800	650	1550	0	0	0	4000
		558	3	3850	3400	0	0	0	0	7250
		581	3	900	0	0	0	0	0	900
		585	6	750	0	0	0	0	0	750
Mean				**1825**	**1013**	**388**	**0**	**0**	**0**	**3225**
1998	Jan.	536	3	0	0	300	300	0	0	600
		600	6	600	0	0	0	0	0	600
		541	6	2000	0	200	0	0	0	2200
Mean				**1300**	**0**	**167**	**100**	**0**	**0**	**1133**
1998	Feb.	608	3	4150	600	0	0	0	0	4750
		601	3	250	0	5650	0	0	0	5900
		603	6	2450	400	0	0	0	0	2850
		606	6	700	1200	0	0	0	0	1900
		602	6	1500	0	0	0	0	0	1500
Mean				**1810**	**440**	**1130**	**0**	**0**	**0**	**3300**
1998	Mar.	243	3	1300	0	0	0	0	0	1300
		226	3	5050	1600	0	300	0	0	6950
Mean				**3175**	**800**	**0**	**150**	**0**	**0**	**4125**
1998	Apr.	240	3	2850	1050	350	0	0	0	4250

Appendix 17

Total and differential nematode counts from the permanently grazed sheep purchased from the study area during the intervention trial between November, 1996 and April, 1998. The monthly means are also shown for individual nematode species and total recoveries.

H. co. = *Haemonchus contortus*
T. axei. = *Trichostrongylus axei*
T. col. =*Trichostrongylus colubriformis*
Coop. = *Cooperia* spp.
Oe. = *Oesophagostomum* spp.
Trich. =*Trichuris* spp.

Year	Month	An.no	Wk	*H.con*	*T.axei*	*T.col*	*Coop*	*Oe.*	*Trich*	Total
1996	Nov.	374	3	350	0	0	250	0	0	600
		315	3	200	0	0	0	0	0	200
		312	6	0	0	0	0	0	0	0
		375	6	0	0	0	0	0	0	0
Mean				**138**	**0**	**0**	**63**	**0**	**0**	**201**
1996	Dec.	545	3	200	200	0	0	0	0	400
		549	3	250	0	0	0	0	0	250
		312	6	50	3350	100	0	0	0	3500
Mean				**167**	**1183**	**33**	**0**	**0**	**0**	**1383**
1997	Jan.	310	3	550	0	0	0	0	0	550
		311	3	100	0	0	0	0	0	100
		326	6	750	0	0	0	0	0	750
		312	6	0	0	0	0	0	0	0
Mean				**350**	**0**	**0**	**0**	**0**	**0**	**350**
1997	Feb.	346	3	0	0	0	0	0	0	0
		347	3	0	5550	4650	0	0	0	10200
		348	6	0	0	0	0	0	0	0
		312	6	300	150	1150	0	0	0	1600
Mean				**75**	**1425**	**1450**	**0**	**0**	**0**	**2950**
1997	Mar.	444	3	700	300	0	0	0	0	1000
		445	3	0	0	0	0	0	0	0
		443	6	0	600	0	0	0	0	600
Mean				**233**	**300**	**0**	**0**	**0**	**0**	**533**
1997	Apr.	216	3	0	4200	0	0	0	0	4200
		217	3	0	1000	1300	100	0	0	2400
		218	6	400	2100	8950	0	0	0	11450
		219	6	350	0	0	0	0	0	350
Mean				**188**	**2433**	**2563**	**25**	**0**	**0**	**4600**
1997	May	264	3	0	0	0	0	6	0	6
		265	3	200	0	0	0	0	0	200
		266	6	250	0	0	0	0	0	250
		267	6	550	0	0	0	0	0	550
Mean				**250**	**0**	**0**	**0**	**1.5**	**0**	**252**

Year	Month	An.no	Wk	*H.con*	*T.axei*	*T.col*	*Coop*	*Oe.*	*Trich*	Total
1997	June	702	3	850	450	150	0	8	0	1458
		701	3	2900	1250	3450	0	20	0	7620
		703	6	50	0	0	0	2	0	52
		704	6	0	12450	0	0	0	0	12450
Mean				**950**	**3538**	**900**	**0**	**8**	**0**	**5396**
1997	July	455	3	550	1900	0	0	3	0	2453
		458	3	200	0	0	0	1	0	201
		457	6	200	0	0	0	0	0	200
		456	6	150	0	0	0	0	0	150
Mean				**275**	**475**	**0**	**0**	**1**	**0**	**751**
1997	Aug.	485	3	0	0	0	0	2	0	2
		486	3	200	0	100	0	0	0	300
		354	6	50	150	0	0	0	0	200
Mean				**83**	**50**	**33**	**0**	**0.7**	**0**	**168**
1997	Sept.	608	3	100	0	0	0	0	0	100
		609	6	1650	0	0	0	0	0	1650
		500	6	200	0	0	0	0	0	200
Mean				**650**	**0**	**0**	**0**	**0**	**0**	**650**
1997	Oct.	608	3	2300	2050	0	0	0	0	4350
		609	3	200	2400	0	0	0	0	2600
		606	6	1650	300	1050	200	0	0	3200
		607	6	0	9950	0	0	0	0	9950
Mean				**1038**	**3675**	**263**	**50**	**0**	**0**	**5025**
1997	Nov.	357	3	100	250	0	0	0	0	350
		359	3	350	0	0	0	0	0	350
		358	6	400	400	0	0	0	0	800
Mean				**283**	**217**	**0**	**0**	**0**	**0**	**500**
1997	Dec.	365	3	350	3450	0	0	0	0	3800
		366	3	2900	800	850	0	0	0	4550
		367	6	900	0	0	0	0	0	900
		3612	6	4950	0	0	0	0	0	4950
Mean				**1038**	**2300**	**213**	**0**	**0**	**0**	**3550**

Year	Month	An.no	Wk	*H.con*	*T.axei*	*T.col*	*Coop*	*Oe.*	*Trich*	Total
1998	Jan.	611	3	1950	0	0	0	0	0	1950
		613	6	750	0	250	0	0	0	1000
		614	6	400	500	2400	0	0	0	3300
Mean				**1033**	**167**	**883**	**0**	**0**	**0**	**2086**
1998	Feb.	436	3	800	0	0	0	7	0	807
		437	3	300	0	0	0	15	0	315
		438	6	360	0	200	800	0	0	1360
		439	6	450	550	350	0	0	0	1350
Mean				**478**	**138**	**138**	**200**	**5.5**	**0**	**959**
1998	Mar.	196	3	1350	1450	1050	0	0	0	3850
		197	3	0	150	0	0	0	0	150
		199	6	200	0	50	0	0	0	250
Mean				**517**	**533**	**367**	**0**	**0**	**0**	**1417**
1998	Apr.	184	3	1850	0	0	0	0	0	1850
		185	3	650	50	0	0	0	0	700
		186	3	1250	0	0	0	0	0	1250
Mean				**1250**	**16.7**	**0**	**0**	**0**	**0**	**1267**

Appendix 18

Individual and monthly mean and total liver fluke recoveries from tracer lambs that grazed in the study area during the intervention trial between November,1996 and April, 1998.

Year	Month	Animal no.	Wk indoors	Fluke count
1996	Nov.	360	3	8
		326	3	0
		365	3	0
		318	6	0
		316	6	2
		358	6	0
Total				**10**
Mean				**1.7**
1996	Dec.	313	3	1
		353	3	0
		332	3	0
		361	6	0
		376	6	1
		400	6	0
Total				**2**
Mean				**0.3**
1997	Jan.	340	3	0
		343	3	0
		344	3	0
		376	6	1
		365	6	7
Total				**8**
Mean				**1.6**
1997	Feb.	196	3	0
		109	3	0
		168	3	0
		142	6	0
		189	6	0
		179	6	0
Total				**0**
Mean				**0**
1997	Mar.	102	3	0
		123	3	0
		186	3	0
		186	6	0
		115	6	0
		152	6	0
Total				**0**
Mean				**0**

Year	Month	Animal no.	Wk indoors	Fluke count
1997	Apr.	174	3	0
		197	3	0
		185	3	0
		104	6	0
		188	6	0
		169	6	0
Total				**0**
Mean				**0**
1997	May	119	3	2
		128	3	0
		134	3	0
		171	6	5
		116	6	0
		140	6	0
Total				**7**
Mean				**1.2**
1997	June	511	3	0
		591	3	0
		571	3	0
		576	6	0
		592	6	1
		558	6	0
Total				**1**
Mean				**0.2**
1997	July	533	3	0
		557	3	0
		520	6	0
		510	6	3
		529	6	0
Total				**3**
Mean				**0.6**
1997	Aug.	543	3	0
		530	3	0
		542	6	1
		586	6	0
Total				**1**
Mean				**0.3**

Year	Month	Animal no.	Wk indoors	Fluke count
1997	Sept.	566	3	5
		538	3	0
		540	3	0
		565	6	16
		527	6	0
		553	6	3
Total				**24**
Mean				**4**
1997	Oct.	509	3	1
		595	3	0
		525	3	0
		543	6	0
		583	6	1
		584	6	1
Total				**3**
Mean				**0.5**
1997	Nov.	575	3	0
		508	3	0
		553	3	0
		579	6	0
		563	6	0
		586	6	0
Total				**0**
Mean				**0**
1997	Dec.	517	3	1
		558	3	0
		581	3	0
		585	6	5
Total				**6**
Mean				**1.5**
1998	Jan.	536	3	0
		593	3	0
		528	3	0
		591	6	0
		541	6	0
		578	6	0
Total				**0**
Mean				**0**

Year	Month	Animal no.	Wk indoors	Fluke count
1998	Feb.	604	3	0
		608	3	0
		601	3	0
		603	6	0
		606	6	0
		602	6	0
Total				**0**
Mean				**0**
1998	Mar.	243	3	0
		226	3	0
Total				**0**
Mean				**0**
1998	Apr.	240	3	0
Total				**0**
Mean				**0**

Appendix 19

Individual and monthly mean and total liver fluke recoveries from permanently grazed sheep purchased from the study area during the intervention trial between November,1996 and April, 1998.

Year	Month	Animal no.	Wk indoors	Fluke count
1996	Nov.	374	3	0
		315	3	0
		312	6	5
		375	6	0
Total				**5**
Mean				**1.3**
1996	Dec.	545	3	0
		549	3	0
		312	6	0
Total				**0**
Mean				**0**
1997	Jan.	310	3	0
		311	3	0
		326	6	0
		312	6	5
Total				**5**
Mean				**1.3**
1997	Feb.	346	3	0
		347	3	0
		348	6	32
		312	6	0
Total				**32**
Mean				**8**
1997	Mar.	444	3	5
		445	3	0
		442	6	0
		443	6	0
Total				**5**
Mean				**1.3**
1997	Apr.	216	3	0
		217	3	0
		218	6	0
		219	6	0
Total				**0**
Mean				**0**

Year	Month	Animal no.	Wk indoors	Fluke count
1997	May	264	3	0
		265	3	0
		266	6	0
		267	6	0
Total				**0**
Mean				**0**
1997	June	702	3	0
		701	3	0
		703	6	24
		704	6	0
Total				**24**
Mean				**6**
1997	July	455	3	0
		458	3	0
		457	6	0
		456	6	0
Total				**0**
Mean				**0**
1997	Aug.	485	3	0
		486	3	0
		354	6	0
Total				**0**
Mean				**0**
1997	Sept.	607	3	0
		608	3	4
		609	6	0
		500	6	17
Total				**21**
Mean				**5.3**
1997	Oct.	608	3	0
		609	3	4
		606	6	0
		607	6	0
Total				**4**
Mean				**1**

Year	Month	Animal no.	Wk indoors	Fluke count
1997	Nov.	357	3	0
		359	3	0
		358	6	0
Total				**0**
Mean				**0**
1997	Dec.	365	3	0
		366	3	0
		367	6	0
		3612	6	5
Total				**5**
Mean				**1.3**
1998	Jan.	611	3	0
		612	3	0
		613	6	17
		614	6	0
Total				**17**
Mean				**4.3**
1998	Feb.	436	3	0
		437	3	0
		438	6	0
		439	6	0
Total				**0**
Mean				**0**
1998	Mar.	196	3	0
		197	3	6
		199	6	50
Total				**56**
Mean				**18.7**
1998	Apr.	184	3	6
		183	3	0
		185	6	0
		186	6	0
Total				**6**
Mean				**1.5**

Appendix 20

List of suppliers

A. McCaskie Ltd., Stirling, Scotland.

Ciba-Geigy, Switzerland.

Cooper Animal Health, Nairobi, Kenya.

Cosmos Ltd., Nairobi, Kenya.

Dalton Supplies Ltd., England

Garmin Corporation, Lenexa, Kansas, USA.

Janssen Pharmaceutica (Animal Health), B-2340 Beerse, Belgium

Kenya Swiss Ltd., Nairobi, Kenya.

Leec Ltd., Nottingham, England

MapInfo Corporation, One Global View, Troy, New York 12180-8399, USA.

Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399, USA.

Minitab Incorporation, 3081 Enterprise Drive, State College, PA 16801-3008, 814-238-3280.

Stanhope-Seta Ltd., Surrey, England.

Statistical Analysis Systems Institute, Cary, North Carolina, USA.

Tru-test Ltd., Auckland, New Zealand.

Weber Scientific Instruments, Middlesex, England.

Whirlmixer Scientific Industries.

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