The integration of grazing management with anthelmintic treatment to control Trichostrongylid infection in sheep

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ABSTRACT OF THESIS

A review of the relevant literature showed that worm control in sheep in the high rainfall areas of southern Australia is based almost exclusively on the use of anthelmintic chemicals. There are a number of potential strategies that can be integrated into worm control programs to reduce the reliance on anthelmintics. Grazing management is one that requires further investigation. The primary aim of grazing management is to optimise pasture utilisation and only a few grazing practices offer additional benefits for parasite control.

A new worm control strategy was developed that incorporates periods of intensive grazing with strategic anthelmintic treatment. The aim of this strategy was to reliably prepare pastures that are parasitologically 'safe' for grazing by spring-born Merino sheep during their first winter. In addition, the strategy also aimed to efficiently utilise available herbage during this period. The new strategy was designed to take advantage of the pre-patent period of the parasites to ensure minimal worm egg deposition onto the pasture during the preparation period. If sheep are treated with an effective anthelmintic, there is a three-week period in which no worm egg contamination can occur regardless of the number of sheep that graze the paddock or the amount of re-infection the sheep acquire.

A replicated field experiment was conducted over two years to compare the new strategy with the current standard strategy. In the new strategy, paddocks were prepared during the summer by intensively grazing them at about 2.5 times the standard stocking rate for one month (slightly longer than the pre-patent period of the parasite) after each of the two summer anthelmintic treatments. In the standard strategy, paddocks were continuously stocked at 15 wethers/ha for the entire preparation period, and the sheep received anthelmintic treatments at the same time as those wethers grazing the new strategy paddocks.
Results from the experiment showed that the new strategy almost eliminated worm egg deposition on the pasture from November to April, whereas mean worm egg counts reached 250 eggs per gram for wethers grazing the paddocks prepared in the standard way. There were significantly fewer *Trichostrongylus vitrinus* in ‘tracer’ sheep grazing paddocks prepared using the ‘new’ strategy during June, July and August in both years. These counts were between 50 and 90% lower than for ‘tracers’ grazing the paddocks prepared using the standard strategy. *Ostertagia circumcincta* burdens of ‘tracer’ sheep grazing the paddocks prepared using the new strategy were reduced by between 20 and 75% for most ‘tracer’ grazing periods, when compared with ‘tracers’ grazing the standard paddocks. From April to November, the worm egg output from weaners that grazed paddocks prepared using the new strategy were significantly reduced to about half that of similar weaners grazing paddocks prepared using the standard strategy. The weaners grazing the new strategy paddocks grew significantly more clean wool (12%) and were significantly heavier (7%) at the end of the winter grazing period than the weaners grazing paddocks prepared in the standard way.

The new strategy is a simple, reliable and effective way to prepare parasite ‘safe’ pastures for grazing by susceptible sheep in regions where two summer anthelmintic treatments are used to control *O. circumcincta* and *Trichostrongylus* spp.
DECLARATION

This is to certify that:

(i)  *this thesis comprises only my original work*

(ii) *due acknowledgement has been made in the text to all other material used*

(iii) *no part of this thesis has been submitted for any other degree*

Paul G Niven
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Chapter 1 Introduction and Literature review

Introduction

Internal parasite infections cause major losses for sheep production in Australia. Most obviously, internal parasites reduce the efficiency of wool and meat production directly, through the effect of the parasites on the individual animal. Production losses in the animal occur primarily as a result of reduced food intake, but are also due to poor nutrient utilisation and redistribution of endogenous protein for tissue repair (Sykes 1982). Less obviously, there may be substantial indirect costs associated with internal parasites. The stocking rate, flock structure and grazing management on farms in high rainfall areas of Australia are often influenced by the producer’s attitude to internal parasites (Lean et al 1997). In the many flocks whose owners’ have failed to adopt an appropriate worm control program, worms regularly cause disease at low stocking rates. Controlling internal parasites allows farmers to increase their profits by raising stocking rates and making better use of pastures. The indirect costs are often overlooked, but, overall, may be greater than the direct production losses associated with parasitic infections.

The class of stock most susceptible to the effects of internal parasitic infections are young sheep. Uncontrolled clinical infections in young sheep can lead to a mortality approaching 100%. However, losses as severe as this are rare, because most producers in Australia have adopted some form of parasite control. In contrast, sub-clinical infections are common and may reduce liveweight gains by about 20% and wool growth by up to 30% in both young and adult sheep (Barger 1982).

The cost of internal parasites to the Australian wool industry has been estimated by Beck et al (1985) and by McLeod (1995). Beck et al (1985) used surveys of farmers and sheep extension officers to estimate the cost of treatment and lost production due to blowflies, other external parasites and internal parasites. McLeod (1995) used a model to estimate the cost of treatment and lost production with blowflies, lice and gastrointestinal
worms. Both authors estimated the cost to the Australian sheep industry of internal parasites to be almost twice that of blowfly strike, the second most costly disease. They also found that most of the costs associated with internal parasites were attributable to production losses, rather than to treatment costs.

McLeod (1995) estimated sheep nematode infections to cost the Australian grazing industry about $222 million per annum. Such an estimate is of little practical value because it is not known how much of this cost can be recovered. A more useful estimate of the economic impact of nematode infection may be obtained by measuring the effect of control measures (Morris and Meek 1980). A number of studies (Anderson et al 1976; Morris et al 1977; Johnson et al 1979; Thompson and Callinan 1981, Brown et al 1985) have concluded that the optimum economic control strategy produced dramatic improvements in profit when compared to untreated controls. For example, Morris et al (1977) showed a return on funds invested in anthelmintic treatment of over 1000% for ewes and lambs.

Long before any estimates of the cost of parasitism were made, methods for the control of internal parasites were being investigated. Initial work investigated the kinds and numbers of parasites present, the epidemiology of parasitic infections and chemicals with anthelmintic properties. Advances in the control of helminth parasites from the mid 1950s until the early 1990s have been summarised by Soulsby (1994) and Armour (1994).

The 1960s saw the beginning of a new era in the control of nematode infections, with the introduction of the first broad-spectrum anthelmintics. The forerunner was thiabendazole, released in the early 1960s. This product was safe and easy to use, and highly efficacious. The advantages of this new drug were progressively adapted, and widespread and frequent use became common. Other chemicals were soon developed, and enjoyed similar success in the field. Currently the three major classes of broad-spectrum anthelmintic chemicals used in Australia are the benzimidazoles, levamisole, and the macrocyclic lactones.
Anthelmintics were initially used therapeutically, in response to the signs of clinical parasitism. Once more was learnt about the epidemiology of parasitic infections, control programs based on the strategic use of anthelmintics were developed for the different regions of Australia. These regional recommendations have been reviewed by Anderson (1990) and Waller et al (1995).

At present, the control of nematode infections in sheep in Australia relies heavily on the use of anthelmintics. Although these control strategies are generally very effective, there are three reasons why control programs based exclusively on anthelmintics are not preferred. The first is financial. The preferred control program is one that maximises profit. Integrating other control strategies with anthelmintic treatment may result in control programs that are more profitable, through an increase in productivity, a reduction in costs or both.

Secondly, frequent and regular use of anthelmintics causes selection of parasites with resistance to the effects of the drug. Anthelmintic resistance has been found in all the major nematode parasites of sheep and to all classes of anthelmintics currently available. Waller et al (1995) reported that resistance to both benzimidazoles and levamisole was widespread in Australia, with about 50% of flocks in the high rainfall areas (greater than 500mm annual rainfall) having nematodes resistant to both anthelmintics. These findings are consistent with other surveys. The macrocyclic lactones were first introduced to Australia in 1988, and resistance was first reported in 1993 (Le Jambre 1993). With increasing anthelmintic resistance, the degree of control achieved by anthelmintic use will be less. Integrating anthelmintic use with other procedures to control nematode infections may reduce selection pressure for resistance and thus increase the expected life of the anthelmintic. However, such procedures need to be applied in the light of knowledge about the parasite’s biology. For reviews of anthelmintic resistance see Prichard (1994) and Waller (1997a).
Thirdly, consumer demand for 'organically' grown produce may encourage sheep production without the use of anthelmintics. The growth of niche markets, and the desire for some producers to cater for this market may result in research to determine if systems for animal production can be developed that substantially reduce or eliminate the use of anthelmintics. However, even if systems requiring no anthelmintics are developed, they may not be widely adopted and may not be financially beneficial for large-scale sheep producing enterprises.

For these reasons, options for parasite control that are not based exclusively on anthelmintics need to be explored further. These are called integrated control programs. All integrated control programs should be soundly based on the epidemiology of parasitic infection and be cost effective. Although there are a number of possible options for control, those that have been investigated include breeding sheep resistant to parasitic infection, biological control of nematodes and vaccination of sheep against parasites. The current situation of these methods of control will be briefly reviewed. There are some pasture management practices that are already used in integrated nematode control programs, and these will be reviewed also.

**Epidemiology of Trichostrongylid infections in sheep in a winter rainfall region**

Australia can be roughly divided into three distinct rainfall regions, namely the winter, uniform and summer rainfall zones. In each of these zones the species of parasitic nematodes that are of particular importance differ, although all are Trichostronglyids. In the winter rainfall areas of southern Australia, Ostertagia circumcincta and Trichostrongylus spp predominate. In those regions of Australia with summer rainfall patterns, Haemonchus contortus is the major parasite. In areas of uniform rainfall, all three genera are present and can cause disease. This review will focus on the winter rainfall area of southeast Australia.
In 1953, Pullar reported on cases of parasitic gastroenteritis presented to the Veterinary Research Institute, Melbourne, for the decade January 1943 to December 1952. He found Ostertagia and Trichostrongylus to be present in 98% of cases. The next most prevalent species was H. contortus, which showed a particular geographical distribution, namely in the north-east of Victoria and on the open plains around Port Phillip Bay. Nematodirus spp, Oesophagostomum venulosum and Chabertia ovina were also present

Pullar (1953) also reported the seasonal occurrence of outbreaks and found Ostertagia and Trichostrongylus infections showed a diphasic pattern with a peak in January-February-March and a slightly larger peak in July-August-September. This was the first report of the seasonal variation in clinical disease in untreated sheep in Victoria. However, this study did not provide information as to when the parasites were acquired. In his explanation for the seasonal occurrence of disease, Pullar suggested the winter peak resulted from inadequate nutrition, climatic conditions and mass exposure to larval parasites, whereas the summer peak reflected the effect of a falling plane of nutrition on hosts with existing infections. Pullar was unable to analyse the influence of age on the occurrence of disease because of incomplete records.

A more detailed description of the seasonal Trichostrongylid patterns in a winter rainfall area of Victoria was made by Anderson (1972; 1973). In field studies conducted near Nerrin Nerrin, faecal egg counts and worm counts from 'tracer' sheep were used to determine parasite species, seasonal fluctuations in available larvae, and seasonal variations in pasture contamination with worm eggs.

The species of parasites found by Anderson (1972; 1973) were consistent with previous findings (Pullar 1953). In Anderson’s study, the major parasite species present were O. circumcincta and Trichostrongylus vitrinus. Nematodirus spp were also present, but in relatively small numbers. H. contortus was absent in these studies.

Anderson (1972; 1973) found the seasonal fluctuations of infective larvae of O. circumcincta and Trichostrongylus spp were almost identical in both years of the study.
Availability of larvae on the pasture increased rapidly after the onset of autumn rains. Larvae were most abundant from June until October. From October to December, numbers decreased rapidly, with very low numbers present during the hot, dry summer months.

One major difference observed between the years was the numbers of available infective larvae. Comparison of ‘tracer’ worm counts showed the numbers were more than tenfold greater in the first year than the second. The lower availability occurred after a drier than usual autumn. The worm burdens of weaner sheep that grazed continuously were estimated from serial total worm counts on groups killed at intervals of about six weeks. In the second year when numbers of available larvae were low, there was a very high correlation (r = 0.97) between cumulative mean worm counts from ‘tracer’ sheep and mean worm counts of weaner sheep. In the first year worm burdens of the set-stocked weaner sheep began to decrease after October. These observations are consistent with the development of immunity in the immature sheep due to many weeks of exposure to large numbers of infective larvae. The development of immunity was also reflected in decreased worm egg counts.

The seasonal variation in worm egg counts was similar in both years, with counts of less than 100 eggs per gram (epg) in both immature and adult sheep during the autumn and winter when the sheep were exposed to high numbers of infective larvae. During spring and summer, counts began to rise, and remained above 300 epg until mid March when the observations ceased. In the second year, when numbers of available larvae were comparatively less, egg counts in the immature sheep began to rise in September, six months earlier than in the previous year. However, maximum egg counts were similar in both years. This provided further evidence that the patterns of worm egg counts and the availability of infective larvae on pasture are inversely related.

From the combined seasonal variations in worm egg counts and numbers of available larvae present, Anderson (1972; 1973) deduced that the majority of larvae that are
available on the pasture during winter are derived from eggs deposited in the late summer and autumn, rather than the winter itself.

Later, Anderson (1983) undertook a series of experiments near Caramut to investigate the contribution that worm eggs deposited at different times of the year had on subsequent numbers of infective larvae. This study showed that the majority of *Ostertagia* and *Trichostrongylus* infective larvae available on the pasture during winter resulted from eggs deposited in the period December to March. Eggs deposited before December contributed only small numbers to the winter larval population. This observation provided the basis for a control strategy based on limiting summer worm egg deposition to reduce the numbers of infective larvae during the winter.

The ecology of the free-living stages of *O. circumcincta, T. vitrinius* and *Trichostrongyulus axei* was investigated by Callinan (1978a; 1978b; 1979) at Hamilton. In a plot study, faeces containing eggs of one of the parasite species were deposited manually onto 0.5m$^2$ plots. Afterwards, the numbers of free-living parasites in the faeces, soil and herbage were estimated every second or third day for two weeks and weekly or fortnightly thereafter until they were no longer recovered. From these observations, the development rates for these parasites, from egg to infective stage, were determined.

In these studies, Callinan observed no species to survive over summer, or develop to infective larvae during the summer. This finding is different from those of Anderson (1972; 1973; 1983). There are several possible reasons for this inconsistency. Callinan used single point deposition of faeces in uniform amounts followed by single point observations for determining numbers of the free-living stages. In contrast, Anderson used natural worm egg contamination by sheep, which resulted in varying volumes and densities of worm egg deposition during the contamination period. Anderson then used ‘tracer’ sheep to determine numbers of infective larvae. ‘Tracer’ sheep that graze over a 14-day period are more sensitive in determining the numbers of available larvae than single point observations. In summary, the methodology used by Callinan for deposition and recovery of infective larvae was not as sensitive as that of Anderson, and therefore
was unable to detect low numbers of larvae that may have been present over the summer period.

One important observation made by both Anderson (1972; 1973; 1983) and Callinan (1978a; 1978b; 1979) was the long time lags between egg deposition and recovery of infective larvae. Anderson (1983) found eggs that developed into larvae before the summer, but remained within the faeces, could survive over summer and become available to sheep after the autumn rains, some five to seven months after deposition. Callinan (1978a) retrieved *O. circumcincta* larvae up to 183 days after eggs were deposited in May. Infective larvae of *O. circumcincta* were first detected on herbage 14 days after the deposition of eggs (Callinan 1978a). These observations also supported those of Donald (1968) who proposed a time lag of five weeks or more between the deposition of faeces and the first appearance of infective *Trichostrongylus colubriformis* larvae. The time lag from egg deposition until larvae become available to the grazing animal is often overlooked, but is essential knowledge for any control strategy.

The findings of Beveridge *et al* (1985) at Kybybolite, in the winter rainfall area of South Australia are similar to those of Anderson (1972; 1973; 1983). Mortalities occurred in untreated sheep during winter, and were directly attributed to gastrointestinal nematode parasitism. Infective larvae were acquired after the onset of autumn rains, and reached a peak during the winter months July and August, coinciding with the peak in mortalities.

From the general pattern of larval availability, Anderson (1972) concluded that a control strategy based on summer anthelmintic treatments to reduce summer egg deposition would be successful at reducing numbers of available larvae over the winter period. Anderson (1972) proposed the first summer treatment should be given when pastures begin to dry off, usually between mid October and December. This coincided with the rapid decline in the number of available larvae on pastures. The period of low contamination can be extended by giving a second summer treatment in mid-summer. This system limits summer contamination to minimal amounts, and therefore minimises the numbers of available larvae during the winter (Anderson 1973).
The production and financial advantages of this control strategy have been compared with untreated animals and traditional treatment programs for ewes, lambs, and weaner sheep (Anderson et al 1976, Morris et al 1977). Both these studies showed significant benefits for the summer treatment program. For example, weaner sheep receiving two strategic treatments experienced a mortality rate of 12%, compared with 22% in the traditional treatment group and 26% in the untreated group. The resulting production benefits for these weaners represented a return on funds invested in anthelmintic treatment of 538%.

However, a major limitation of the two summer treatment strategy is that sheep can become re-infected after treatment. Re-infection commonly occurs after two events. Firstly, if the first summer treatment is given before the numbers of available infective larvae have decreased to low numbers, sheep will become re-infected after treatment. Secondly, environmental conditions such as summer rainfall which results in infective larvae being available on the pasture will lead to re-infection. If re-infection occurs, there will be a substantial reduction in the period when worm egg contamination of pastures is minimised, and therefore more infective larvae may be available during autumn and winter.

The effects of summer rain on parasite transmission is best demonstrated in the studies of Southcott et al (1976), Donald et al (1978) and Anderson (1983). These studies compared the epidemiology of Trichostrongylid parasites of sheep in different regions during the same years (1970/71 and 1971/72). Southcott et al (1976) conducted studies in the summer rainfall region of New South Wales and Donald et al (1978) conducted studies in the evenly distributed, but highly variable rainfall pattern of Canberra, Australian Capital Territory. Donald et al (1978) found pastures contaminated in any month of a wet summer were likely to be infective within one month and remain so for the rest of the summer. In the summer rainfall area, numbers of infective larvae remain high throughout the summer (Southcott et al 1976).
Therefore, if there was substantial rainfall in the late spring and summer, animals treated during November or December will be exposed to immediate re-infection. As a result, pasture contamination with worm eggs would be expected during January. This could result in substantial larval populations on the pasture during February and March if there were further rains. A second summer treatment in February could be followed by immediate re-infection, depending on the environmental conditions, but on average is less likely because the weather is hotter during this period. In summary, control strategies based on two anthelmintic treatments in summer are unlikely to be as successful following a wet summer as they would in a dry one.

**Breeding sheep resistant to parasitic infection**

The characteristics of animal populations can be altered by genetic selection. The response to selection for a single characteristic depends upon the heritability of the trait, the intensity of selection, the variation in breeding value, the generation interval and the accuracy of selection. Although many characteristics are heritable, there is little benefit in selecting for a trait that does not have a profitable outcome for the farmer. Selection must therefore be directed to improve those characteristics that improve the profitability of the enterprise. The combination of characteristics that a producer wishes to improve is called the breeding objective. Within Australian Merino flocks, different producers place different emphases on a variety of traits, and consequently a variety of breeding objectives exist (James 1987).

Both resistance and resilience to internal parasites have been proposed as possible breeding objectives for sheep. Resistance may be defined as the ability of a host to reduce the number of parasites that establish, reproduce or survive. Resilience is defined as the ability of the host to thrive in the presence of parasites. Most Australian research has concentrated on resistance as the preferred breeding objective, largely based on the work of Albers and Gray (1987) which indicated that resilience appeared to be less heritable and more difficult to measure than resistance.
For any breeding objective, there must be selection criteria that allow the producer to achieve his or her objective. The selection criteria are defined as the combination of characters that are used to make selection decisions. For some selection objectives, such as increased fleece weight or reduced fibre diameter, direct measurement is the obvious and preferred selection criterion. There is however, no direct measure for selecting sheep that are less susceptible to the effects of parasitism and the choice of selection criteria is not obvious.

The preferred selection criteria for a flock being bred for resistance to gastrointestinal nematodes have not been comprehensively studied. Despite this, faecal worm egg counts have been used almost exclusively as the sole selection criterion. Worm egg counts have been used because it is assumed that sheep with lower worm egg counts will have lower worm burdens. In addition, low worm egg counts will result in lower worm egg contamination of the pasture, which over time should result in lower numbers of available larvae on the pasture.

Some limitations of using low worm egg counts as the sole selection criterion have been elucidated. For example, a major cost associated with internal parasitic infection of sheep is dag formation (Larsen et al 1995). Because there is a very low correlation between egg counts and the formation of dag on sheep (Morley et al 1976, Pullman et al 1991, Larsen et al 1995), selection for low worm egg counts is unlikely to reduce the susceptibility of sheep to dag formation. Selection criteria other than low worm egg count, such as the immune response or the use of multiple criteria probably deserve further investigation.

In general, there is considerable variation in susceptibility to worm parasites both within and between breeds of sheep. Heritability estimates for faecal worm egg counts in Australian Merino lines have ranged from 0.21 to 0.47 (Woolaston and Eady, 1995), indicating the potential to breed sheep that have reduced faecal worm egg counts.
Experiments to determine the success of selecting sheep for reduced faecal egg counts have been underway for just over 20 years, and slow but obvious progress has been made. Single trait selection for low faecal worm egg count has been shown to decrease the counts in successive generations by between 50 and 95% over 20 years (Woolaston and Eady, 1995). There are now a number of flocks in Australia and New Zealand that have been subjected to selection for low worm egg counts. For a review of these projects refer to Woolaston and Eady (1995) and Morris et al (1995).

Most estimates of the genetic correlation between faecal egg count and other traits, such as clean fleece weight, are close to zero, indicating that moderate selection pressure can be applied to reduce faecal worm egg counts without substantially reducing the rate of gain in other important traits.

It is difficult to determine the financial benefit that may accrue from breeding sheep with reduced faecal worm egg counts. In practical terms, the number of anthelmintic treatments that a flock requires per year is a useful measure of the economic effectiveness of a control strategy. Eady et al (1997) used a model to show the reductions in anthelmintic treatment resulting from selecting sheep for reduced H. contortus egg counts. Within the constraints of their assumptions they found no anthelmintic treatments would be required after 20 years. Monitoring worm egg counts within flocks, in which selection for resistance is practised, will provide data to validate the predictions of the model.

In summary, although progress is slow, and the financial benefit is uncertain, selecting sheep for resistance to internal parasites has been successful. Selecting sheep for parasite resistance does not appear to strongly favour the selection of undesirable traits. Bearing these ideas in mind, the sheep industry could adopt this technology as part of an integrated control strategy for internal parasites. The implementation of this technology is not particularly difficult and is practically feasible, as shown by the Nemesis extension program in Australia (Anon 1997).
Biological control

Biological control may be defined as the role that natural enemies play in the regulation of a species. Applied biological control is achieved by human intervention when natural control methods are manipulated to enhance the degree of control achieved.

A number of organisms have been identified that use the free-living stages of nematode parasites as a food source, and so may be useful for controlling their numbers. These include fungi, bacteria, viruses, arthropods, protozoa and predacious nematodes (Waller and Faedo 1996). Of these, considerable effort has been focused on the identification and characterisation of fungi that trap the free-living stages of nematode parasites. These fungi are now widely referred to as Nematophagous fungi.

Nematophagous fungi belong to a group characterised by their ability to capture and use nematode larvae either as their main source of nutrients, or supplementary to a saprophytic existence. Barron (1977) classified these fungi into two groups, predacious and endoparasitic, according to their morphology and the structural characteristics used for nematode capture. Predacious fungi produce nematode trapping structures such as adhesive knobs and rings on the mycelium to trap nematodes. Endoparasitic fungi invade the nematodes either by penetration from sticky spores that adhere to the cuticle, or from spores that are ingested during development.

Efficacy trials of nematophagous fungi have been conducted for parasites of the horse, cow, sheep and pig (Larsen et al 1997) and have shown significant reductions in the numbers of available larvae on pasture and subsequent lower worm burdens in animals grazing the pasture. Studies with sheep conducted overseas have provided encouraging results. For example, Larsen et al (1997) showed ‘tracer’ sheep grazing paddocks that had been grazed with sheep fed daily with Duddingtonia flagrans for three months had approximately 90% less parasites when compared with untreated controls (P < 0.05). It can therefore be concluded that nematophagous fungi could have potential for the biological control of sheep parasites in Australia.
In Australia, Waller and Faedo (1993) tested 94 species of fungi with known nematophagous activity to determine their ability to destroy the free-living stages of sheep nematodes. Although many fungi were capable of destroying nematodes, only a few showed efficient activity in sheep faeces. For this reason, most of the work has concentrated on fungi that are effective at trapping free-living nematode larvae and have spores capable of surviving passage through the ruminant digestive tract. The two genera with the greatest potential for biological control are *Arthrobotrys* and *Duddingtonia*.

How effective this biological control strategy will be depends upon the ability of the fungus to survive in different environmental conditions. Survey work by Larsen *et al* (1994) has shown that *Arthrobotrys* and *Duddingtonia* species were found in approximately 3.5% of faecal samples taken from grazing livestock in Australia.

The growth rate and trapping efficacy of these nematode trapping fungi has been shown to vary significantly at different temperatures (Fernandez 1999). These laboratory experiments have shown that the reduction of nematode larvae was greatest at 15 degrees centigrade, but if temperatures fluctuated between 10 and 35 degrees, the reduction ranged between 0 and 25%. Temperatures in Australia fluctuate markedly and therefore the efficacy of nematophagous fungi at controlling the free-living stages of nematode parasites may be questionable, and further research is needed to address this issue.

If fungi were identified that could survive the ruminant digestive tract and readily colonise and survive in faeces under Australian conditions, a suitable method of administration would be required. The delivery system would have to be both practical and cost effective. In Australia, grazing sheep are rarely supplemented every day, and therefore it may be impractical for sheep to receive a daily ‘dose’ of the fungal spores in supplementary feed. Control release capsules and supplement blocks are being investigated as possible delivery vehicles. Commercial partners are now involved in both Australian and Danish research, so further information regarding these issues is difficult to obtain.
Production of large quantities of nematophagous fungi will also be required for commercialisation of a product. Repeated laboratory passage of these fungi may result in the loss of various attributes, which may include nematode trapping capacities (Waller 1997b).

Biological control, involving nematode trapping fungi has the potential to play an important role in future integrated control strategies against parasitic nematodes in grazing sheep. One key feature of this strategy is the potential benefits for other grazing animals that become infected with nematode parasites. However, it is extremely unlikely that biological control will completely replace other control strategies.

**Vaccination against Trichostrongylid infections**

Vaccination involves administering a specific antigen or antigens that are capable of promoting a protective immunological response in the animal. Sheep slowly develop an acquired immunity against the major gastrointestinal nematodes present in Australia. Therefore, vaccination should be possible against these parasites once appropriate antigens have been identified.

The mechanisms by which sheep express immunity to gastrointestinal nematodes are complex. Rothwell (1989) reviewed the immune expulsion of parasitic nematodes from the alimentary tract. He found evidence to suggest that the immune response of the host results in the delivery of pharmacologically active substances into the parasitic environment and these substances interfere with processes crucial for their survival, and results in their expulsion. However, analysis of the mechanisms of this process is at a very early stage.

The exact timing of the development of immunity to Trichostrongylid parasites of sheep depends on the species of parasite and host factors. Immunity develops faster in adult sheep than in immature sheep (Gibson and Parfitt 1972). In addition, the nature of the immune response changes with time. For example, Dobson et al (1990) showed that
immunity to *T. colubriformis* progressively intensifies from the expulsion of incoming L3 around 5 to 7 weeks after the start of infection, then suppression of fecundity in established worms around 8 to 12 weeks, and ultimately to the expulsion of established adult worms after 16 to 20 weeks.

The first attempts to develop vaccines against gut parasites in ruminants used crude antigens from homogenised parasites but were not successful. Following the success of the irradiated larval vaccine for *Dictyocaulis viviparus*, the lung worm of cattle, research was undertaken to determine if irradiated larvae could be used to vaccinate sheep against gastrointestinal parasites. This vaccination strategy did show some promising results for *H. contortus* and *T. colubriformis* (Smith and Angus 1980) and *O. circumcincta* (Smith et al 1982). However, the logistical problems of producing the number of parasites needed and the limited shelf life of the vaccine have discouraged commercialisation of such a product.

Vaccine research then focused on the use of structural or excreted/secreted proteins as antigens. Two types of molecules have been investigated, termed ‘natural’ and ‘hidden’ antigens. ‘Natural’ antigens are those molecules identified by the host during infection and stimulate the development of naturally acquired immunity. Most of the research has concentrated on ‘natural’ antigens, but thus far success has been limited.

‘Hidden’ antigens are those that are not recognised by the host during natural infection but have been identified as producing antibodies that affect the viability of the parasite. They are usually associated with the gut epithelium of the parasite.

Most of the work with ‘hidden’ antigens has focused on antigens of the intestine of the blood sucking parasite *H. contortus*. Smith (1993), for example, was able to induce protection against *H. contortus* in seven-month-old sheep by immunizing them with an extract from the cell membrane of the gut of the adult worm. The worm burdens of the ‘vaccinated’ sheep were reduced about 14 fold compared with unvaccinated sheep after infection with 5000 infective larvae. This study also identified that no cross protection
was induced for *O. circumcincta* or *Nematodirus battus*. The challenge is now to identify similar substances that are effective against non-blood sucking parasites such as *O. circumcincta* and *Trichostrongylus* spp.

To determine the potential benefits of vaccination, computer modeling simulations were conducted by Barnes *et al.* (1995). Their model suggests that a control program using a vaccine incorporating a 'natural' antigen given to 80% of the flock with an efficacy of 60% would result in less lamb deaths than a standard control program based on anthelmintic treatment alone. 'Hidden' vaccines gave better worm control than did the standard control program if they achieved 80% efficacy or protected more than 80% of the flock. Further research and field trials are needed to find the efficacy that will be required for cost-effective reduction of parasitism and the role of vaccines in integrated worm control strategies.

In summary, attempts to control parasites by vaccination have been a long-term goal of parasitologists, but to date has not resulted in any commercially available vaccines for sheep Trichostrongylids. The search for a single antigen that is capable of inducing protective immunity for the gut dwelling parasites of sheep continues.

**Grazing Management**

Grazing management is the manipulation of animal grazing in an attempt to optimise pasture utilisation and hence animal production. This is the primary goal of all grazing management practices.

Some grazing management practices have other beneficial effects in addition to their primary goal. Grazing management can provide parasite 'safe' pastures. A parasite 'safe' pasture is one on which the numbers of infective larvae are below the number that produce disease and loss of production.
There are certain management practices that are used on farms throughout southeastern Australia to improve the utilisation of pastures. Their effects on parasite numbers and thus usefulness in the control of internal parasites are discussed under the headings pasture spelling, cropping, fodder conservation and alternate grazing, between species and classes of stock.

**Pasture Spelling**

A pasture is spelled when not grazed by stock. The primary aim of this strategy is to allow the growth of pasture so that it will be of a higher nutritional value for the stock. Rotational grazing schemes allow for spelling of pastures for varying periods at different times of the year.

When a paddock is not grazed by sheep, contamination with worm eggs stops, and residual populations of infective larvae will decrease over time, especially during periods unfavorable to the survival of infective larvae. Therefore, management practices that leave a paddock destocked have the potential to provide parasite ‘safe’ pastures if the period of spelling is of sufficient duration.

Short-term pasture spelling is when sheep are removed from a pasture for periods of two to eight weeks. When short-term pasture spelling was first proposed as a parasite control option, little was known about the epidemiology of the free-living parasites on the pasture in Australia. Donald (1967) investigated the common belief of the time, that pasture spelling for a period of three or four weeks was all that was required for the death of a high proportion of parasites on the pasture. In this study, conducted at Badgery's Creek near Sydney, two paddocks were contaminated by infected lambs from 3 October 1961 until 13 February 1962 or 13 March 1962. Measurements of pasture growth and available larvae were made weekly for 9 weeks on each paddock after sheep were removed. Donald found there was no significant reduction in the number of larvae per square yard of herbage on either paddock. This study clearly showed spelling a pasture
for nine weeks during late summer and autumn at Sydney did not reduce numbers of *Trichostrongylus* spp and *H. contortus*.

Donald (1968) further investigated population dynamics of free living *T. colubriformis* and *H. contortus*. In his preliminary conclusions, he proposed a time lag of five weeks or more between deposition of faeces and the first appearance of infective larvae on the herbage for *T. colubriformis*. This study gave further evidence to support his previous work that short-term pasture spelling was not an effective strategy to produce 'safe' pastures.

Since the studies of Donald (1967, 1968) studies in the winter rainfall areas of Victoria have given further evidence that short-term pasture spelling is not effective for preparing 'safe' pastures for this region. Anderson (1972) found larval numbers on pasture remained high from the onset of the autumn rains until temperatures began to rise in the spring. In addition, studies by Callinan (1978 a) found long time lags between worm egg deposition and recovery of infective larvae from herbage. From these studies it is clear that short-term pasture spelling does not give rise to parasite safe pastures.

Rotational grazing is the frequent movement of animals between paddocks with the aim of increasing animal production per hectare. Promoters of rotational grazing claim it enhances pasture growth, improves pasture composition, improves disease control and ultimately increases farm profitability. Although the details of the agronomic advantages and disadvantages of various grazing systems are beyond the scope of this review, only a small number of papers have been published that provide sound scientific evidence for any of these arguments. In one notable study, Morley *et al* (1969) showed that subdivision, and especially intense subdivision did not offer any great expansion in plant or animal productivity on phalaris and sub clover pastures. More research is required to determine the agronomic and nutritional advantages of these systems.

Rotational grazing is unlikely to be successful as a control strategy for Trichostrongylids in southern Australia. Rotational grazing usually involves periods of pasture spelling of
six to nine weeks. As explained above, pasture spelling for periods from one to three months during the late autumn, winter and early spring period will not greatly reduce the numbers of available larvae on the pasture. Considering autumn, winter and early spring are the times when rotational grazing is used the system provides minimal parasitological advantages.

In summary, pasture spelling alone, in any of its various forms, is unlikely to be useful for parasite control because the periods of pasture spelling can only be three to six weeks for efficient pasture utilisation. These periods are too short to diminish the numbers of infective larvae present. If longer periods are used to achieve parasite control, then the primary aim of better pasture utilisation may not be achieved.

**Cropping**

In the winter rainfall areas of Australia, summer and winter cropping is practised by some graziers. Summer cropping is now not common, and will not be discussed. There is a rise in the popularity of winter cropping because of improved technology for cropping in this region, and improved profitability of cropping compared with grazing enterprises. In this region, cereal crops are most common, with canola and legumes becoming more common.

Winter crops are planted from early autumn until late winter. These crops are harvested during summer. Winter cropping provides sufficient time and conditions to greatly reduce numbers of infective larvae from the pasture because there is usually no contamination during the growth of the crop.

The nutritional value of crop aftermath is derived from two sources: grain and weeds. Improved harvesting techniques mean more seed heads are harvested and less grain is lost during harvesting. This results in only very small amounts of grain being left in a crop paddock. The improved use of herbicides results in most crop stubbles being free of
weeds. These two factors mean most cereal crop stubbles have limited nutritional value for young stock. In addition, canola and lupin stubbles often have little nutritional value, and in the case of the latter, may be infected with a fungus that can cause poisoning when eaten. Therefore, although crop stubbles are often parasite 'safe', they may not be suitable for grazing by sheep.

Paddocks are usually cropped consecutively for a number of years. At the end of this 'cropping phase' the paddocks are sown down to pasture. These paddocks will be parasite 'safe', and will have pasture that is of good nutritional value.

The technology that has extended cropping to many areas in southern Australia is 'raised beds'. They improve the drainage of the soil to minimise the effects of waterlogging, which is commonly experienced in this region. If adopted widely, there would be more crop stubbles for sheep to graze. However, the beds are expensive to form, and are damaged by grazing stock. Therefore, the small nutritional benefit that is achieved by grazing the stubble is outweighed by the cost of reforming beds after they are grazed. It follows that in areas of southern Australia where raised bed cropping is used there will be little scope to use these areas as parasite 'safe' pastures.

Despite the potential parasitological advantages, crop stubbles are rarely appropriate 'safe' pastures because of the generally poor nutritional value of the stubbles. Crop stubbles can be used for short term grazing by some classes of adult stock, but are almost never suitable to meet the nutritional requirements of spring born sheep during their first summer. However, new pastures that are sown down at the end of a cropping phase will be parasite 'safe' in the following autumn and winter and paddocks prepared in this way can be integrated into a parasite control program.
Fodder conservation

Pasture grown during the spring can be conserved as hay or silage. Stock are usually removed from pastures to be conserved in September for a period of between four and ten weeks, allowing pasture to grow. Paddocks are usually cut in November, when the pasture begins to dry off. The cut pasture is raked and then baled over a period of one week. This effectively means the paddock is destocked for two to three months during September, October and November. The exact timing of events varies between seasons and regions.

No studies have been conducted to determine the number of infective larvae present on aftermath following hay or silage production. However, it is fair to extrapolate results of epidemiological studies in this region to estimate what the numbers of infective larvae may be. Anderson (1972, 1973) showed a rapid decrease in numbers of available larvae during September and October. If this event is coupled with cutting and removing pasture to a short length and hence exposing the remaining larvae to sunlight and heat, then their numbers are likely to be very low. Therefore, from a parasitological perspective, hay aftermath will often be parasite 'safe'.

Hay or silage aftermath is often of high nutritional value. The pasture cut for hay or silage usually consists of perennial grasses and pasture legumes. After cutting in the spring, these species usually continue to grow, resulting in pastures that are highly nutritious for all classes of stock. Therefore, the nutritional requirements of spring born sheep weaned onto these paddocks will be met.

Hay cutting is widely practised in Victoria. As with any other enterprise on a farm, hay making needs to be profitable in its own right, otherwise it is economically irrational to undertake it. Any potential advantage of hay making, including parasite 'safe' pastures, must be compared to the specific unavoidable costs of hay making, such as machinery or contract costs, and the opportunity costs of stored fodder. For instance, if stocking rates
are actually reduced to enable hay making to occur, as happens on many farms, hay
making may reduce total farm profitability.

When hay and silage aftermath is available, it should be used as a 'safe' pasture because
it fulfils both parasitological and nutritional requirements. However, all managers should
consider the real cost of hay making including the opportunity costs because it may not
be a cost effective practice.

**Alternate grazing with different species**

Alternate grazing is the sequential stocking of a pasture with different livestock species to
prepare parasite 'safe' pastures. This procedure takes advantage of the fact that different
animal species are infected with different parasites and that infective larvae decrease in
number over long time periods. Possible options for alternate grazing with sheep are
cattle, horses and pigs. Such systems have the potential to produce parasite 'safe'
pastures when animal rotations are of sufficient duration for the reduction in numbers of
available parasites.

The concept that cattle could be used to cleanse sheep pastures was investigated in
Australia by Roberts (1942). He concluded that cattle could be used to control sheep
helminths in Queensland, for all parasite species except *H. contortus*. The control of *H.
contortus* was different because lambs, calves and adult cattle were all susceptible to the
parasite. It is important to point out that at the time of this study, *H. contortus* and
*Haemonchus placei* were not differentiated, and this may explain his conclusion. *T. axei*
was acknowledged to be infective to both cattle and sheep, but lambs used in the
experiment only had small burdens of *T. axei*, and consequently numbers of available
larvae to cattle were assumed to be low.

Recent Australian research has focused on the alternate grazing of sheep and beef cattle.
In their preliminary work, Barger and Southcott (1975 a) found there were considerable
benefits for parasite control in young cattle that graze pastures that are intermittently
grazed by sheep. Southcott and Barger (1975) also investigated the effect of different
periods of grazing with the alternate species on subsequent parasite availability for both sheep and cattle. These experiments produced encouraging results, and provided information to design a more detailed investigation of alternate grazing with sheep and cattle.

Barger and Southcott (1978) investigated the parasitological effects of the cattle-sheep interchange over several seasons in an experimental situation more closely related to a commercial enterprise. Over three years, they compared six monthly interchange in January and July, twelve monthly interchange in July and no interchange. Six monthly interchange was the most successful system, with significant weight gain advantages for spring born Merino sheep that grazed the pastures from January onwards. Sheep in this system grew more wool, and there were fewer mortalities than in any other system. These differences were attributed to the lower worm burdens of the sheep in this treatment. In the third year of the experiment, weaner sheep were drenched monthly from January until July to compare bodyweights with sheep in the six monthly rotation. Although the sheep receiving monthly treatments were slightly heavier (1.5kg), the difference was not statistically significant. It was concluded that the six monthly interchange had a similar effect to monthly treatments for spring born Merino weaners from January until July. Barger and Southcott (1978) did suggest that better worm control might be achieved if the twelve monthly rotation occurred in January, so that lambs could be weaned onto pastures grazed solely by cattle for the previous twelve months.

There are limitations for the extrapolation of this work to the winter rainfall areas of Victoria. The work of Barger and Southcott (1975 a), Southcott and Barger (1975) and Barger and Southcott (1978) was conducted on the Northern Tablelands of New South Wales, which experiences a summer dominant rainfall pattern. They found large comparative reduction in *H. contortus* and *T. colubriformis* on sheep pastures that were grazed by cattle for 6, 12 or 24 weeks. *H. contortus* is rarely found in Western Victoria, and *T. vitrinus* is far more prevalent than *T. colubriformis* in this environment (Anderson 1972, 1973, Callinan 1979).
Research conducted by Donald et al (1987) in Canberra can be more easily applied to the Victorian situation. They investigated two kinds of management systems and four drenching frequencies to determine the best system of worm control for spring born sheep after weaning in December. The lambs were either set stocked from weaning, or alternated with cattle in December, February and July. Both management systems were investigated under four drenching treatments; December alone, December and February, December, February and July, and fortnightly treatments until the following December. They found there were fewer deaths among lambs given a single drench at weaning and interchanged with cattle in December, February and July and they gained as much liveweight and produced as much wool as the fortnightly drenched set stocked sheep. No production benefits were recorded as a result of additional anthelmintic treatments given to these sheep. They concluded the superiority of the alternate grazing system was entirely attributable to a high degree of parasite control, and was achieved with a reduced use of anthelmintics.

The major drawback of the cattle-sheep interchange is the availability of cattle on sheep farms. Equivalent stocking rates of cattle and sheep are rarely encountered on sheep producing farms in Victoria but, often, sufficient cattle are available to prepare pastures for weaners that need only about 20% of the area required for the sheep flock. Furthermore, the profitability of beef cattle production in Victoria is often less than either meat or wool production from sheep (Beattie 1999). As a consequence, the number of cattle on sheep farms has decreased over recent years.

Another problem is the transmission of parasites in cattle to sheep. Generally the trichostrongylid species of sheep and cattle are monospecific, however, T. axei has been reported from many hosts including sheep, cattle, deer, rabbits and horses (Levine 1968). Consequently, care is needed when paddocks destined for grazing by sheep are being grazed by cattle that have not been treated for T. axei infection. Abbott and McFarland (1991) reported four cases in which T. axei was the principal cause of diarrhoea, weight loss and death in young sheep or lambing ewes grazing alternately with cattle. In all cases, paddocks were grazed by cattle until April or May, when sheep were put into the
paddock. The report by O’Callaghan et al. (1992) of Ostertagia ostertagi causing clinical disease in sheep is a rare observation, but needs to be considered.

A final problem is the grazing of cattle on pastures that have been grazed by sheep. Sheep graze pastures shorter than cattle, and unless pastures are spelled after the sheep grazing period finishes, the pastures will be too short for cattle.

Horses and free-range pigs are other potential species to alternatively graze with sheep to produce safe pasture. However, few if any sheep farmers have enough horses or free-range pigs to prepare a safe paddock. Therefore, although this practice is sound in principle, it is of little practical importance.

Alternate Grazing with Resistant Sheep

Adult sheep, except for lactating ewes, tend to be more resistant to worm infections than young sheep. Alternate grazing with resistant sheep has been recommended as a means of providing parasite ‘safe’ pastures. For example, Waller et al (1987) found that parasite ‘safe’ pastures could be prepared for August lambing ewes by grazing the paddock with either adult sheep or cattle in the preceding March to July period. Donald et al (1976) compared the effect of moving lambs at weaning in December to pastures grazed for three months by both ewes and lambs or wether sheep. Lower pasture contamination was observed when adult sheep were grazing, and lambs grazing these pastures subsequently had lower worm burdens and slightly greater liveweight gains over the summer. However, these advantages were not as great as when lambs were weaned onto pastures grazed by cattle for the previous three months.
**Conclusion: Grazing Management**

The primary aim of grazing management is to optimise pasture utilisation. Pastures need to be destocked for a long time period to reduce the number of infective larvae so a pasture can be considered parasite 'safe'. Unless the pasture is utilised in some way during the spelling period, very inefficient pasture utilisation will occur. Grazing strategies that allow for long spells between sheep grazing periods and maintain efficient use of the pasture resource can cost-effectively provide parasite 'safe' pastures that can be used in parasite control programs. Paddocks that have been cropped and pastures that have been harvested for hay or silage or alternatively grazed with cattle are usually destocked for enough time for the numbers of infective larvae to decrease to low numbers, whilst utilising the pasture. There are however limitations to these systems. In addition, the options for parasite control from grazing management practices on properties that only graze sheep and do not harvest pasture are very limited.

**General conclusion**

Trichostrongylid control strategies based solely on anthelmintic use may not be preferred for reasons of productivity, sustainability and consumer demand. Control strategies that integrate anthelmintic use with other options for control have the potential to profitably improve parasite control. Many potential control options have been investigated, but only breeding sheep for resistance to parasitic infection and some grazing management strategies are currently available to sheep producers in Australia. Biological control appears to be an option if an appropriate organism can be found and a suitable delivery system developed. Currently there are no vaccines for sheep Trichostrongylids in Australia. There is the opportunity to develop new grazing management strategies that incorporate efficient pasture utilisation whilst preparing parasite 'safe' pastures.
Chapter 2 An evaluation of a strategy incorporating grazing management with anthelmintic treatment to control Trichostrongylid infection in sheep

Introduction

Trichostrongylid infections continue to be a major problem for sheep flocks in the high rainfall areas of southern Australia with young sheep most susceptible to the effects of parasitism. Farm managers exert considerable effort trying to control infections in spring-born sheep from weaning until they are one year of age. The effects of Trichostrongylid parasitism are most commonly seen during the winter, with production losses and even death occurring when the sheep are exposed to large numbers of infective larvae. To minimise these problems, parasite ‘safe’ pastures can be used.

The currently recommended strategy used to prepare parasite ‘safe’ pastures for weaner sheep for the winter grazing period is to combine anthelmintic treatments with the grazing of mature sheep during the summer, (Anderson 1990). In this strategy, a paddock is selected in November for grazing by weaner sheep during the late autumn, winter and spring period. During the summer and early autumn, mature sheep that are treated with anthelmintic in November and February continuously graze the selected paddock. This strategy reduces the deposition of worm eggs onto the pasture during the summer period, whilst maintaining efficient utilisation of available herbage. As a result of reducing worm egg deposition on the pasture during summer and autumn, there should be reduced numbers of available larvae on the pasture during the winter, when the weaners graze the paddock.

This strategy to prepare ‘safe’ pastures is not successful in all years because mature sheep can become re-infected with Trichostrongylids immediately after anthelmintic treatment and have the opportunity to contaminate the pasture being prepared. Re-infection of mature sheep occurs when the first anthelmintic treatment is given before the numbers of available infective larvae have fallen to low numbers or when infective larvae become
available on the pasture as a result of summer rainfall. In these years, the preparation of ‘safe’ pastures will be less successful because of the deposition of worm eggs by the mature sheep, and weaner sheep may be exposed to amounts of infective larvae during the late autumn and winter sufficient to cause production losses or even death.

To ensure that a pasture is parasite ‘safe’ during the winter, the selected paddock could be destocked for the entire summer and autumn period. This would completely remove the risk of contamination during the entire summer period. However, it would also result in very poor utilisation of available herbage and would therefore be a costly way of preparing a parasite ‘safe’ pasture.

To combat these problems, a new strategy to prepare parasite ‘safe’ pastures was developed. This new strategy integrates anthelmintic treatment with grazing management with the aim of reliably preparing parasite ‘safe’ pastures for winter grazing whilst efficiently utilising available herbage during the preparation period.

This new strategy is designed around the pre-patent period of the Trichostrongyloid parasites, which is about 21 days. If sheep are treated with an effective anthelmintic, there is a three-week period in which no worm egg contamination can occur regardless of the number of sheep that graze the paddock or the amount of re-infection the sheep acquire. In the ‘new’ strategy, parasite ‘safe’ pastures are prepared by restricting grazing of the paddock to a period of four weeks after each of the two summer anthelmintic treatments. To enable efficient utilisation of pasture, the paddock is heavily stocked during each of the grazing periods.
Materials and Methods

2.1 Experimental design

A replicated field experiment was conducted at Gnarwarre, near Geelong, Victoria, to estimate the effectiveness of a new system of parasite control for weaner sheep in the winter rainfall area of southern Australia. A strategy, termed the 'new' strategy, integrating grazing management with anthelmintic treatment was compared with the current recommended strategy, termed the 'standard' strategy. Both strategies were used to prepare parasite ‘safe’ pastures to be grazed by spring-born Merino weaner sheep from the autumn until the end of spring. Three replicates of the two treatments were compared over two years, year one: November 1997 until October 1998, and year two: November 1998 until October 1999. Each year was divided into two phases, a period of pasture preparation (November to mid-April) and a grazing period for weaner sheep (mid-April to October).

2.2 Experimental site

Six one hectare paddocks on 'South Roxby', a wool producing farm 15 km west of Geelong in the Western District of Victoria, were used for this experiment. Pasture on these paddocks consisted of cocksfoot (*Dactylis glomerata*), phalaris (*Phalaris aquatica*) and subterranean clover (*Trifolium subterraneum*), with cape weed (*Arctotheca calendula*), onion grass (*Romulea rosea*) and barley grass (*Hordeum leporinum*) the major weed species. The pastures received an annual fertiliser application of approximately 14 kg of phosphorus per hectare.

The six experimental paddocks were fenced in July 1997 and 20 weaners with naturally acquired Trichostrongylid infections were put into each one. Mean strongyle egg counts from 10 sheep in each paddock ranged from 50 to 200 eggs per gram during the period August to October inclusive. In addition, groups with higher mean egg counts were
interchanged with lower ones to provide uniform contamination to all paddocks before the start of the experiment.

In November 1997, paddocks were systematically allocated to the treatment under which they were to remain until the end of the experiment. Paddocks were allocated alternatively to each treatment to reduce the effect of a possible confounding factor of slight changes in soil type across the hill transect.

2.3 Preparation Period

The preparation period began in November, when the first anthelmintic treatment was given. The preparation period finished after the onset of the autumn rains, which in this environment usually occurs in mid April.

In both treatments, the paddocks were grazed by mature fine-wool Merino wethers that were given anthelmintic treatments at the beginning of November and February. In the 'new' strategy, the paddocks were grazed at 37 wethers/ha for four weeks after each anthelmintic treatment. This was a stocking rate of about 2.5 times that on the 'standard' strategy paddocks. After these intensive grazing periods, the 'new' strategy paddocks were destocked. The treatments and periods of intensive grazing are shown in Figure 2.1.
Figure 2.1. The two ‘preparation’ strategies used to prepare parasite ‘safe’ pastures during the November to April period. The ‘new’ strategy incorporates two periods of intensive grazing at 37 wethers/ha for November and February following each anthelmintic treatments (A). The ‘standard’ strategy maintains the stocking rate of 15 dse/ha for the entire period, with the two anthelmintic treatments (A) given at the same time as for the ‘new’ strategy.
In the ‘standard’ strategy, paddocks were continually stocked at 15 wethers/ha for the entire period. The wethers received two anthelmintic treatments at the same time as those wethers grazing the ‘new’ strategy (Figure 2.1). Both strategies had the same average stocking rate of 15 wethers/ha per month over the entire preparation period.

2.4 Weaner Grazing Period

The weaner grazing period began after the onset of autumn rains, once green pasture availability reached about 500kg/DM/ha. The grazing period finished in November in both years.

In both treatments, 15 five-month-old fine-wool Merino weaners grazed each replicate for the entire weaner-grazing period. Before entering the paddocks, the weaners were treated with ivermectin (Ivomec™, Merial Australia, Parramatta, NSW) at recommended dose rates.

Supplementary feeding of all the weaners with grain was to be given to the stock in all replicates if mean bodyweights of any replicate began to decrease.

2.5 Parasitology

2.5.1 Worm egg counts
Worm egg counts were obtained every two weeks throughout the experiment, from November to October each year. For each observation, faecal samples were collected from the rectum of ten of the fifteen animals in each paddock. A modified McMaster slide technique (described below) was used to estimate faecal worm egg counts.
From each sample, three grams of faeces was weighed out into another container, and 42 ml of clean tap water added. After homogenising with an electric mixer, the samples were passed through a 9 cm 100 mesh sieve and the liquid was collected. After a few swirls to mix the liquid, 15 ml was poured into a 15 ml test tube, and left to settle in the fridge for at least one hour. Washing of the mixer, mixing container, sieve and collecting bowl was done after each sample was processed.

After settling, the supernatant was poured off, leaving a plug of debris containing the eggs. Saturated salt solution was added to the test tube and the plug was re-suspended by repeatedly inverting the ¾ full tube. The tube was filled with salt solution, and a sample was removed using a pasteur pipette and put into two chambers of a Universal McMaster Slide (0.5 ml in each chamber). The sum of the two chambers was multiplied by 15 (the dilution factor) to give the number of eggs per gram of faeces.

2.5.2 Estimates of larval availability
'Tracer' sheep were used to estimate the number and species of worm larvae available on the pasture during the weaner grazing period of both years and the summer preparation period of the second year. Groups of spring-born Merino weaner wethers were selected to be used as 'tracer' sheep. At weaning, they were treated with an anthelmintic and grazed together in a paddock nearby the trial site until required. The tracers were treated with anthelmintics, Combi™ (Novartis Animal Health, Pendle Hill, NSW) and Ivomec™ (Merial Australia, Parramatta, NSW) before being put into the experimental paddocks.

(i) Weaner Grazing period
In both years, three tracer sheep grazed each paddock for a period of one month on four sequential occasions, from June to September. At the end of their grazing period, 'tracer' sheep were housed and fed pasture hay for one week. The sheep were then killed for total worm counts.
Preparation Period
During the summer of 1998/99 additional ‘tracer’ sheep were used to estimate the numbers of larvae available during the summer period. From 8 December, 1998 to 1 March, 1999, six sequential groups of three ‘tracers’ were put onto each of the three ‘standard’ paddocks for a period of two weeks. At the end of each grazing period, the nine sheep were housed and fed pasture hay. Worm egg counts were monitored weekly for either five or six weeks for all six groups. To relate worm egg counts to worm counts, two groups were killed for total worm counts.

Worm burdens of weaner sheep during the weaner grazing period
On 18 August 1999, two weaners from each paddock were selected from all replicates of both treatments. The two weaners selected had worm egg counts of about the mean of the replicate, using worm egg counts collected on the 10 August 1999. The sheep were housed at Werribee and fed pasture hay for one week before being killed for worm counts.

2.5.3 Procedure and method for worm counts
The sheep were killed and the gastrointestinal tracts were removed. The reticulum was separated from the omasum, and the pylorus was tied off, effectively containing the contents of the abomasum. The first third of the small intestines was separated from the omentum and related structures. The caecum and colon was separated from their omental attachments and opened along the line of attachment. The contents and mucosal surfaces were examined and worms picked off and collected into a container for subsequent counting and identification.

The abomasum was opened along the greater curvature and the contents released into a plastic bucket. The mucosa was thoroughly washed in warm water and the washings added to the contents of the bucket. No digestes of the mucosa were made. The contents and washings were made up to one litre. After a figure of 8 mixing, three or four samples were collected into a 300 ml container to which 5 mL of undiluted formalin was added.
The small intestines were washed three times by flushing about 150 mL of hot water through them. The contents and washing of the small intestine were made up to one litre and samples were collected as for the abomasum.

The samples of abomasum and small intestinal contents were washed on a sieve (350 μ mesh), to remove fine particles, formalin and colouring matter, and then washed back into the container. The volume was adjusted to the previous level by the addition of water.

The samples were mixed by bubbling air through the contents of the container, and sub-samples of five or 2.5 mL were put into a petri dish, and were examined under a dissecting microscope at magnifications of 8 to 50 times. For each worm species, counts were made of adult males and females, developing fourth stage larvae and early fourth stage larvae. Total worm numbers were calculated using the appropriate dilution factor.

### 2.6 Measures of Animal Production

#### 2.6.1 Bodyweights

The weaner sheep in each paddock were weighed with electronic scales (Tru-test model 703™, Auckland, New Zealand) to an accuracy of 0.5kg, at intervals of four to eight weeks during the weaner grazing period.

#### 2.6.2 Wool Production

Mid-side samples of wool were collected from all weaner sheep in October. Samples were tested by the Australian Wool Testing Authority for fibre diameter and fibre diameter variability using the laserscan technique. Yield of the samples was estimated using the IWTO 19 test method (Anon 1995).

All weaner sheep were shorn in November. The unskirted fleeces were weighed to the nearest 0.1kg using electronic scales (Ruddweigh, Guyra, NSW).
2.7 *Dag scores*

The degree of soiling around the breech of weaner sheep was assessed and scored on a scale from 0 (no dag) to 5 (heavy dag) using the method described by Larsen *et al* (1994).

2.8 *Measures of Pasture Production*

Two methods for the estimation of available dry matter of pasture were used. When pastures were green and growing, availability was estimated using a modification of the sward surface height technique (Bircham and Hodgson 1983). When pastures were senescent or dead, the pasture within six or ten quadrats (25 by 25 cm) randomly spaced in each paddock was cut at ground level, dried for at least two weeks and weighed.

2.9 *Meteorological observations*

Daily rainfall, relative humidity at 9am and 3pm, and air temperature at 9am and 3pm was obtained from an automatic weather station less than 2 km from the experimental site.

2.10 *Statistical analysis*

2.10.1 Analysis of variance

For statistical analysis, the unit of observation was the paddock. Analysis of variance of paddock means was used to determine the effect of treatment and year using a model with fixed effects for year and treatment. Interactions were removed when not significant (P > 0.05).

The production parameters that were analysed were mean November bodyweight, mean clean fleece weight, mean fibre diameter and mean dag score prior to crutching.
All worm count values were transformed by $\log_{10}(x + 10)$ before analysis and geometric mean $O.\ circuncincta$, $Trichostrongylus$ spp, and $Nematodirus$ spp worm burdens for each of the four ‘tracer’ periods during the weaner grazing period were analysed.

Mean total egg output of weaner sheep during the weaner grazing period was analysed by analysis of variance. For each replicate of both treatments, an estimate of total strongyle and $Nematodirus$ spp egg output was determined by calculating the area under the curve of the mean egg count of the weaner sheep during the weaner grazing period.

2.10.2 Other statistical analysis

(i) Summer ‘tracer’ worm and worm egg counts

Linear regression was used to assess the linear relationship between log of worm egg count and log of adult worm burden for both strongyles and $Nematodirus$ spp. Total worm count values were transformed by $\log_{10}(x + 10)$ and worm eggs counts by $\log_{10}(x + 7.5)$ before analysis.

(ii) Worm burdens of weaner sheep during the weaner grazing period

Mean $Ostertagia\ circuncincta$, $Trichostrongylus$ spp, and $Nematodirus$ spp worm burdens were analysed using Student’s t-test. All worm count values were transformed by $\log_{10}(x + 10)$ before analysis.
Chapter 3 Results

3.1 Meteorological Data

Total monthly rainfall for each year was calculated from daily readings at the site, and is compared with long term averages in Figure 3.1. Rainfall for the years 1998 and 1999 was 464 and 446 mm respectively, both of which were less than the 40 year average of 517 mm. However, there were differences in the distribution of the rainfall between years.

(i) Preparation Period
Rainfall for the period November to March inclusive in year one and year two was 104 mm (45% below average) and 241 mm (28% above average), respectively.

(ii) Weaner Grazing Period
For the period April to August, rainfall was 207 mm in year one and 170 mm in year two, which was 10 and 26% below the average rainfall for the period. Rainfall for September and October was 20 and 25% below average for years one and two, respectively.

(iii) Fortnightly periods (November to March 1998/99)
A summary of the rainfall, temperature and relative humidity for periods of 14 days from 27 October, 1998 to 1 March 1999 is set out in Table 3.1. There was little variation in the values for maximum and minimum temperatures or relative humidity between periods but there were 3 periods in which rainfall was in excess of 20 mm.
Figure 3.1. Monthly rainfall (millimetres) for the experimental site from November to October. Mean rainfall is shown on the bottom graph (blue bars), and years one (yellow bars) and two (green bars) on the top graph.

Table 3.1. Mean relative humidity, temperature, number of rainy days and total rainfall for each two week period from October 27 1998 to March 1 1999.

<table>
<thead>
<tr>
<th>Period</th>
<th>Relative humidity (%)</th>
<th>Temperature (°C)</th>
<th>Rainy days</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Oct.- 9 Nov.</td>
<td>76 54</td>
<td>13 18</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>10 Nov.-23 Nov.</td>
<td>87 72</td>
<td>12 16</td>
<td>7</td>
<td>53</td>
</tr>
<tr>
<td>24 Nov.-7 Dec.</td>
<td>78 60</td>
<td>14 18</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>8 Dec.- 21 Dec.</td>
<td>74 56</td>
<td>15 18</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>22 Dec.- 4 Jan.</td>
<td>75 54</td>
<td>16 22</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>5 Jan.-18 Jan.</td>
<td>83 64</td>
<td>17 22</td>
<td>5</td>
<td>24</td>
</tr>
<tr>
<td>19 Jan.-1 Feb.</td>
<td>82 57</td>
<td>18 23</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>2 Feb.-15 Feb.</td>
<td>77 57</td>
<td>19 25</td>
<td>6</td>
<td>68</td>
</tr>
<tr>
<td>16 Feb.-1 Mar.</td>
<td>88 59</td>
<td>15 22</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>
3.2 Worm egg counts

3.2.1 Preparation Period
(i) Strongyle egg counts

The mean strongyle egg counts of sheep in the 'standard' and 'new' strategy paddocks for 1997-98 and 1998-99 are depicted in Figures 3.2 and 3.3. In the first year, mean worm egg counts of sheep in the continuously grazed ('standard') paddock began increasing six weeks after the first anthelmintic treatment, and were about 200 eggs per gram of faeces (epg) by early January. Mean egg counts continued to increase during January to reach a maximum of about 260 epg at the time of the second anthelmintic treatment. After the second anthelmintic treatment, mean worm egg counts remained very low for nine weeks, and then increased to about 50 epg before the sheep were removed from the paddocks on 21 April, 1998.

In the second year, mean worm egg counts of wethers in the continuously grazed paddock began increasing six weeks after the first anthelmintic treatment. Mean egg counts increased steadily during December and January and reached about 400 epg at the time of the second anthelmintic treatment, almost 150 epg more than at the corresponding time in year one. Mean worm egg counts increased sharply to about 100 epg six weeks after the second anthelmintic treatment. The wethers were removed from the paddock on 30 March, 1999, eight weeks after the second anthelmintic treatment, with a mean egg count of about 100 epg.

In both years, the mean worm egg counts of the wethers that were intensively grazed for one month were only 2 epg at the end of all grazing periods. Low worm egg counts (15 epg) were detected in only one or two sheep in each replicate. Thus, very few worm eggs were deposited on to the paddocks that was prepared using the 'new' strategy for the entire preparation period in both years.
Figure 3.2. Mean counts of strongyle eggs in the faeces of sheep grazing paddocks prepared in the period November to April 1997/98 according to the 'standard' (—■—) or 'new' (—○—) strategy. ‘A’ indicates when sheep were treated with anthelmintic, * indicates when the wethers were removed from the paddocks and the weaner grazing period began.

Figure 3.3. Mean counts of strongyle eggs in the faeces of sheep grazing paddocks prepared in the period November to April 1998/99 according to the 'standard' (—■—) or 'new' (—○—) strategy. ‘A’ indicates when sheep were treated with anthelmintic, * indicates when the wethers were removed from the paddocks and the weaner grazing period began.
(ii) *Nematodirus* spp egg counts
In the ‘standard’ paddocks in both years, mean *Nematodirus* spp worm egg counts remained at zero or below 15 epg of faeces for all observation during the preparation period. In both years, no *Nematodirus* spp eggs were deposited onto the paddocks prepared using the ‘new’ strategy.

3.2.2 Weaner Grazing Period
(i) Strongyle egg count patterns
The mean faecal strongyle egg counts from sheep in each treatment is shown in figures 3.4 and 3.5. In the first year, egg counts from sheep in both treatments increased at a similar rate from April until July. In the ‘new’ strategy paddocks, egg counts reached about 250 epg, and then began to decrease in late September. However, in the ‘standard’ paddocks, egg counts continued to rise, and reached a peak of about 400 epg in August, before decreasing in late September. Therefore for July, August and September, worm egg counts in the ‘new’ strategy paddocks were about 150 epg (40%) less than those in the ‘standard’ paddocks.

In the second year, egg counts in the ‘standard’ paddocks increased sharply by late April and remained around 300 epg until mid August, when they increased to more than 400 epg. Worm egg counts began to decrease from late September onwards. In the ‘new’ strategy paddocks, worm egg counts remained below 50 epg until June, when they rose to about 150 epg, and remained at this level until mid August. In late August, counts rose to over 300 epg, but then decreased from late September onwards.
Figure 3.4. Mean faecal Strongyle worm egg counts from Merino weaners grazed at 15 dse/Ha from April to October 1998 on paddocks prepared according to ‘standard’ (——) and ‘new’ (—–) preparation strategies. Weaners in both groups were treated with anthelmintic when put on the paddocks, as indicated by ‘A’.

![Graph showing mean faecal Strongyle worm egg counts from April to October 1998](image)

Date 1998

Figure 3.5. Mean faecal Strongyle worm egg counts from Merino weaners grazed at 15 dse/Ha from April to October 1999 on paddocks prepared according to ‘standard’ (——) and ‘new’ (—–) preparation strategies. Weaners in both groups were treated with anthelmintic when put on the paddocks, as indicated by ‘A’.

![Graph showing mean faecal Strongyle worm egg counts from April to October 1999](image)

Date 1999

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As in year one, worm egg counts from sheep grazing the paddocks that had been prepared using the ‘new’ strategy were about 150 eggs per gram of faeces less than those grazing paddocks prepared using the ‘standard’ strategy.

The area under the strongyle egg count curve of the three replicates of each treatment was compared statistically. The weaners grazing the paddock prepared using the ‘new’ strategy deposited less eggs ($P = 0.001$) than those grazing the paddock prepared using the ‘standard’ strategy (Table 3.2). Assuming the faecal output of each weaner was one kilogram per day, the mean egg deposition per sheep for the weaner grazing period was about 30 million eggs per sheep for those grazing the ‘new’ strategy paddocks in both years compared with about 45 million eggs in year one and 60 million eggs in year two for sheep grazing paddocks prepared using the ‘standard’ strategy.

(ii) *Nematodirus* spp egg count patterns

The egg count patterns of *Nematodirus* spp differ greatly from those of the strongyle eggs and are shown in Figures 3.6 and 3.7. In the first year, the worm egg counts follow a similar pattern for both groups. *Nematodirus* spp egg counts increased during autumn, and reached a peak during May. The peak was about 200 epg for both treatments. Worm egg counts gradually decreased and were almost zero by November.

In the second year, *Nematodirus* spp egg counts increased quickly to peak in May at about 150 epg, before decreasing afterwards. After low egg counts in July, worm egg counts from sheep grazing the paddocks prepared using the ‘new’ strategy increased above 100 epg, before decreasing to almost zero by November. The second peak was not as great nor for as long in the paddocks prepared using the ‘standard’ strategy, and counts were almost zero by November.

There was no significant difference between treatments for total *Nematodirus* spp eggs deposited on paddocks during the weaner grazing period in both years (Table 3.3).
Table 3.2. Total area under the mean strongyle egg count curve for weaner sheep grazing during the weaner grazing period (eggs per gram of faeces per day).

<table>
<thead>
<tr>
<th></th>
<th>Total area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>1998</td>
<td>48228</td>
<td>24934</td>
</tr>
<tr>
<td></td>
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<td>29241</td>
</tr>
<tr>
<td></td>
<td>47470</td>
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<tr>
<td>Mean</td>
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<td><strong>27663</strong></td>
</tr>
<tr>
<td>1999</td>
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<td>22971</td>
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<tr>
<td></td>
<td>61707</td>
<td>24390</td>
</tr>
<tr>
<td></td>
<td>74591</td>
<td>39691</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>60865</strong></td>
<td><strong>29017</strong></td>
</tr>
<tr>
<td>Overall mean</td>
<td>53107 *</td>
<td>28340 *</td>
</tr>
</tbody>
</table>

* Difference between treatments was significant P = 0.001, SEM = 3783.

Table 3.3. Total area under the mean Nematodirus spp egg count curve for weaner sheep grazing during the weaner grazing period (eggs per gram of faeces per day).

<table>
<thead>
<tr>
<th></th>
<th>Total area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>New</td>
</tr>
<tr>
<td>1998</td>
<td>11187</td>
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<td><strong>12504</strong></td>
</tr>
<tr>
<td>1999</td>
<td>10696</td>
<td>17397</td>
</tr>
<tr>
<td></td>
<td>9600</td>
<td>11116</td>
</tr>
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<td></td>
<td>9367</td>
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<tr>
<td>Mean</td>
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<td><strong>13578</strong></td>
</tr>
<tr>
<td>Overall mean</td>
<td>11780*</td>
<td>13041*</td>
</tr>
</tbody>
</table>

* Difference between treatments was not significant P = 0.50, SEM = 1283.
Figure 3.6. Mean faecal *Nematodirus* spp worm egg counts from Merino weaners grazed at 15 dse/Ha from April to October 1998 on paddocks prepared according to 'standard' (---) and 'new' (----) preparation strategies. Weaners in both groups were treated with anthelmintic when put on the paddocks, as indicated by 'A'.

![Graph showing mean faecal Nematodirus spp worm egg counts from April to October 1998.]

Figure 3.7. Mean faecal *Nematodirus* spp worm egg counts from Merino weaners grazed at 15 dse/Ha from April to October 1999 on paddocks prepared according to 'standard' (---) and 'new' (----) preparation strategies. Weaners in both groups were treated with anthelmintic when put on the paddocks, as indicated by 'A'.

![Graph showing mean faecal Nematodirus spp worm egg counts from April to October 1999.]

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3.3 Dag Scores

Average dag scores for the 15 sheep in each replicate are shown in Table 3.4. The differences in mean dag score between treatments were not significant at any time. In July of the first year, mean dag scores were 1.2 and 1.4 respectively for the ‘new’ and ‘standard’ treatments. Dag scores increased by about one dag score by September. In the second year, dag scores were similar in both July and September, reaching a mean score of almost 3 in September.

3.4 Worm counts

3.4.1 Winter ‘tracers’ (June – September)
Mean ‘tracer’ worm counts for the 1998 and 1999 weaner grazing periods are shown in Tables 3.5, 3.6 and 3.7. The results from both years show ‘tracer’ sheep grazing paddocks prepared using the ‘new’ strategy had lower T. vitrinus counts in all four grazing periods than ‘tracers’ grazing paddocks prepared using the ‘standard’ strategy. The ‘new’ strategy reduced the numbers of O. circumcincta in most ‘tracer’ grazing periods and Nematodirus spp were significantly reduced in first ‘tracer’ grazing period.

In June and August of both years, mean O. circumcincta worm burdens of ‘tracer’ sheep that grazed paddocks prepared using the ‘new’ strategy were significantly less than those of ‘tracers’ grazing paddocks prepared using the ‘standard’ strategy. For the June ‘tracer’ period, the sheep grazing the ‘new’ strategy paddocks had about 75% fewer worms than those in the ‘standard’ strategy paddocks. ‘Tracers’ that grazed the ‘new’ strategy paddocks during August had O. circumcincta burdens between 20 and 60% of the ‘tracers’ grazing the ‘standard’ strategy paddocks.

In July of the first year, mean O. circumcincta burdens were similar in ‘tracers’ grazing both the ‘new’ and the ‘standard’ strategy paddocks. However, in the second year, mean O. circumcincta burdens in the ‘tracers’ grazing the paddocks prepared using the ‘new’ strategy were about 25% of the burdens of the ‘tracers’ grazing the ‘standard’ strategy paddocks. This difference between years resulted in a statistical interaction for this ‘tracer’ grazing period.
For the September grazing period of both years, the mean worm burdens of ‘tracers’ that grazed paddocks prepared using both the ‘new’ and ‘standard’ strategies were similar, and not statistically different.

In each ‘tracer’ grazing period of both years, ‘tracers’ grazing the paddocks prepared using the ‘new’ strategy had lower mean counts of *T. vitrinus* than ‘tracers’ grazing the paddocks prepared using the ‘standard’ strategy. For each ‘tracer’ grazing period in 1998, the reduction was between 50 and 75%. In 1999, the reduction was between 85 and 90%, with mean worm count in the ‘new’ strategy paddocks less than about 700 worms for each grazing period.

For the June, July and August ‘tracer’ grazing periods of both years, ‘tracers’ grazing the paddocks prepared using the ‘new’ strategy had significantly lower mean *T. vitrinus* burdens than the ‘tracers’ grazing the paddocks prepared using the ‘standard’ strategy. For the September ‘tracer’ period, the differences were not statistically significant.

Two hundred male *Trichostrongylus* spp from small intestinal samples were examined to determine their species and all were *T. vitrinus*. No attempt was made to speciate *Trichostrongylus* spp from abomasal samples, because numbers were extremely low. It was therefore concluded the great majority of *Trichostrongylus* spp were *T. vitrinus*.

In each of the four grazing periods in year one, mean *Nematodirus* spp worms in ‘tracers’ that grazed the paddocks prepared using the ‘new’ strategy were less than for ‘tracers’ grazing the paddocks prepared using the ‘standard’ strategy. This difference was statistically significant during the first period. This pattern was similar in the second year, except for a greater mean worm count in the ‘tracers’ grazing the ‘new’ strategy paddock for July.

One hundred male *Nematodirus* spp from small intestinal samples were examined to determine their species. Sixty percent were *Nematodirus spathiger*, 36% *Nematodirus filicollis* and 4% *Nematodirus abnormalis*. 

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Table 3.4. Mean dag score of 15 Merino weaner sheep in July and September grazing the three paddocks prepared using either the 'standard' or 'new' strategy. The presence of dag was scored from 0 (no dag) to 5 (heavy dag).

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th></th>
<th>September</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>1998</td>
<td>0.5</td>
<td>1.5</td>
<td>2.0</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>1.7</td>
<td>2.2</td>
<td>2.1</td>
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<tr>
<td></td>
<td>1.8</td>
<td>0.9</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Mean</td>
<td>1.2</td>
<td>1.4</td>
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<td>2.1</td>
<td>2.5</td>
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<td></td>
<td>2.8</td>
<td>3.0</td>
<td>3.5</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>3.1</td>
<td>2.7</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Mean</td>
<td>2.8</td>
<td>2.9</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Overall mean</td>
<td>2.0 *</td>
<td>2.2 *</td>
<td>2.6 **</td>
<td>2.4 **</td>
</tr>
</tbody>
</table>

* Difference between treatments was not significant ($P = 0.55$, SEM = 0.16).
** Difference between treatments was not significant ($P = 0.59$, SEM = 0.23).
Table 3.5. Mean counts of *Ostertagia circumcincta* worms from 'tracer' sheep that grazed paddocks prepared using either the 'standard' or 'new' strategy in June, July, August and September of 1998 and 1999. Each mean is from nine 'tracer' sheep.

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>1998</td>
<td>1798</td>
<td>307</td>
<td>1153</td>
<td>1029</td>
</tr>
<tr>
<td>1999</td>
<td>2444</td>
<td>620</td>
<td>8008</td>
<td>2024</td>
</tr>
<tr>
<td>Mean log</td>
<td>1998</td>
<td>3.16</td>
<td>2.31</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>3.30</td>
<td>2.71</td>
<td>3.80</td>
</tr>
<tr>
<td>Pooled SE</td>
<td></td>
<td>0.07</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>*</td>
<td>0.018</td>
<td>0.403</td>
</tr>
</tbody>
</table>

* a significant interaction occurred between treatment and year.

Table 3.6. Mean counts of *Trichostrongylus vitrinus* worms from 'tracer' sheep that grazed paddocks prepared using either the 'standard' or 'new' strategy in June, July, August and September of 1998 and 1999. Each mean is from nine 'tracer' sheep.

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>1998</td>
<td>1002</td>
<td>253</td>
<td>500</td>
<td>237</td>
</tr>
<tr>
<td>1999</td>
<td>896</td>
<td>91</td>
<td>4732</td>
<td>701</td>
</tr>
<tr>
<td>Mean log</td>
<td>1998</td>
<td>2.89</td>
<td>2.31</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>2.88</td>
<td>1.64</td>
<td>3.48</td>
</tr>
<tr>
<td>Pooled SE</td>
<td></td>
<td>0.14</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td>P value</td>
<td>0.002</td>
<td>0.030</td>
<td>0.005</td>
<td>0.091</td>
</tr>
</tbody>
</table>
Table 3.7. Mean counts of *Nematodirus* spp worms from ‘tracer’ sheep that grazed paddocks prepared using either the ‘standard’ or ‘new’ strategy in June, July, August and September of 1998 and 1999. Each mean is from nine ‘tracer’ sheep.

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>1998</td>
<td>9751</td>
<td>3547</td>
<td>4257</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>11512</td>
<td>7507</td>
<td>2851</td>
</tr>
<tr>
<td>Mean log</td>
<td>1998</td>
<td>3.73</td>
<td>2.83</td>
<td>2.80</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>3.82</td>
<td>3.71</td>
<td>2.44</td>
</tr>
<tr>
<td>Pooled SE</td>
<td></td>
<td>0.12</td>
<td>0.31</td>
<td>0.26</td>
</tr>
<tr>
<td>P value</td>
<td></td>
<td>0.015</td>
<td>0.676</td>
<td>0.416</td>
</tr>
</tbody>
</table>
3.4.2 Weaner worm counts (August 1999)
Mean worm burdens of weaner sheep that grazed from 30 March 1999 until 24 August 1999 are shown in Table 3.8.

Sheep grazing the paddocks prepared using the ‘new’ strategy tended to have lower worm burdens of both *O. circumcincta* and *T. vitrinus* than the sheep grazing the paddocks prepared using the ‘standard’ strategy. Numbers of adult *O. circumcincta* were reduced by about 40% to a mean of about 1000 worms but this difference was not significant (*P* = 0.54). Numbers of immature *O. circumcincta* were similar in both groups. Numbers of both adult and immature *T. vitrinus* were reduced by about 75% in the sheep grazing the paddocks prepared using the ‘new’ strategy, with this difference statistically significant for adult *T. vitrinus* (*P* = 0.05).

More adult *Nematodirus* spp were present in the sheep grazing the paddocks prepared using the ‘new’ strategy than the ‘standard’ strategy. This difference in adult *Nematodirus* spp was not significant (*P* = 0.22). The number of immature *Nematodirus* spp was similar between groups.

The caecum and colon of each sheep was examined for the presence of *Chabertia* spp, *Oesophagostomum* spp and *Trichuris* spp. Sheep in all paddocks were infected with *Chabertia* spp, except for both sheep grazing one paddock prepared using the ‘new’ strategy. Numbers of adult worms ranged from 1 to 57. *Oesophagostomum* spp was found in only one sheep. *Trichuris* spp were present in four of six sheep grazing the ‘standard’ paddocks but counts were not made. None of the sheep grazing the paddocks prepared using the ‘new’ strategy were infected with *Trichuris* spp.
3.4.3 Additional Tracers (December 1998- March 1999)
Mean counts of strongyle and *Nematodirus* spp eggs for each week after the group of nine ‘tracer’ sheep had grazed the ‘standard’ paddocks are shown in Figures 3.8 and 3.9 for each of the six successive grazing periods between December 1998 and March 1999.

For strongyle eggs (Figure 3.8) the weekly mean counts from sheep grazing in periods one (8 to 22 December) and six (16 February to 2 March) were greatly higher than those from other grazing periods. No eggs were detected in the faeces of the fourth group of ‘tracers’ for six weeks after the end of the grazing period (19 January to 2 February). In contrast, the pattern for *Nematodirus* spp eggs (Figure 3.9) there was little if any difference between mean counts of ‘tracers’ from any of the grazing periods.

The relationship between worm egg counts and worm counts was examined for the groups of sheep in grazing periods one and five, representing high and low worm egg counts respectively. The mean worm counts of each species and the mean egg counts are shown in Table 3.9. The linear relationship between log egg counts and log worm counts are shown in Figures 3.10 and 3.11. For *O. circumcincta* and *Trichostrongylus* spp together, the r value was 0.75, P < 0.001, the intercept was 1.33 (SEM = 0.26) and slope was 0.60 (SEM = 0.13). The corresponding result for *Nematodirus* spp are r = 0.54, P = 0.02, with an intercept of 2.38 (SEM = 0.47) and slope of 0.55 (SEM = 0.21).
Table 3.8. Arithmetic mean counts of adult and immature *Ostertagia circumcincta*, *Trichostrongylus vitrinus* and *Nematodirus* spp of six weaner sheep that grazed paddocks prepared using either the 'standard' or 'new' strategy from 30 March to 24 August 1999. Mean log values of the group and standard error of the mean log are shown in brackets.

<table>
<thead>
<tr>
<th></th>
<th><em>O. circumcincta</em></th>
<th><em>T. vitrinus</em></th>
<th><em>Nematodirus</em> spp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
<td>Immature</td>
<td>Adult</td>
</tr>
<tr>
<td>'standard'</td>
<td>1743</td>
<td>4137</td>
<td>12870</td>
</tr>
<tr>
<td>'new'</td>
<td>1072</td>
<td>1043</td>
<td>11542</td>
</tr>
</tbody>
</table>

Table 3.9. Arithmetic mean counts of adult worms of *Ostertagia circumcincta*, *Trichostrongylus vitrinus* and *Nematodirus* spp of nine 'tracers' killed 3 and 5 weeks after grazing paddocks from 8 to 22 December 1998 (Group 1) and 2 to 15 February 1999 (Group 5) respectively. Mean counts of strongyle and *Nematodirus* eggs per gram of faeces are included for comparison. Mean log values of the group and standard error of the mean log are shown in brackets.

<table>
<thead>
<tr>
<th></th>
<th><em>O. circumcincta</em></th>
<th><em>T. vitrinus</em></th>
<th>Strongyle FEC</th>
<th><em>Nematodirus</em> spp</th>
<th><em>Nematodirus</em> FEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>512 (2.59, 0.12)</td>
<td>496 (2.39, 0.24)</td>
<td>358 (2.33, 0.21)</td>
<td>6376 (3.65, 0.13)</td>
<td>232 (2.20, 0.17)</td>
</tr>
<tr>
<td>Group 5</td>
<td>88 (1.91, 0.10)</td>
<td>51 (1.59, 0.16)</td>
<td>35 (1.45, 0.14)</td>
<td>4171 (3.44, 0.21)</td>
<td>168 (2.06, 0.18)</td>
</tr>
</tbody>
</table>
Figure 3.10 Linear regression of log transformed strongyle egg count (epg) and log transformed adult worm burden of *Ostertagia circumcincta* and *Trichostrongylus vitrinus* for 18 ‘tracer’ sheep. $r = 0.75$, $P < 0.001$.

![Graph showing linear regression for Ostertagia and Trichostrongylus](image)

Figure 3.11 Linear regression of log transformed strongyle egg count (epg) and log transformed adult worm burden of *Nematodirus* spp for 18 ‘tracer’ sheep. $r = 0.54$, $P = 0.02$.

![Graph showing linear regression for Nematodirus](image)
3.5 Production from weaners

3.5.1 Bodyweight.
Bodyweights of weaner sheep during the weaner-grazing period are shown in Figures 3.12 and 3.13. In the first year, weaner sheep were about 22.5 kg at the beginning of the weaner grazing period. Sheep grazing paddocks prepared using the 'new' strategy were 1 kg heavier in June, 2.5 kg heavier in August and ended the weaner grazing period 1.7 kilograms heavier than sheep grazing the paddocks prepared using the 'standard' strategy.

In the second year, weaner sheep were 24 kg at the beginning of the weaner grazing period. Sheep grazing paddocks prepared using the 'new' strategy were about 4 kg heavier after six weeks of grazing than the weaners grazing the paddocks prepared using the 'standard' strategy. At the end of the weaner grazing period, sheep in the 'new' strategy paddocks were 4.6 kg heavier than those grazing the paddocks prepared using the 'standard' strategy.

Analysis of variance showed no significant differences in bodyweight of sheep in the different paddocks at the start of the weaner grazing periods in either year. Sheep grazing paddocks prepared using the 'new' strategy were significantly heavier (P = 0.01) than those grazing paddocks prepared using the 'standard' strategy at the end of the weaner grazing period of both years (see Table 3.10).
Figure 3.12. Mean bodyweights of Merino weaner sheep for the period April to November 1998 grazing paddocks prepared according to 'standard' (—■—) or 'new' (—•—) preparation strategies.

Figure 3.13. Mean bodyweights of Merino weaner sheep for the period April to November 1999 grazing paddocks prepared according to 'standard' (—■—) or 'new' (—•—) preparation strategies.
3.5.2 Wool Production
Mean fibre diameter and clean fleece weights for sheep in each replicate are shown in Table 3.11. In the first year, Merino weaner sheep in the ‘new’ strategy paddocks grew almost 200 grams more clean wool, with a fibre diameter of 16.8 µ, half of one micron greater than sheep in the paddock prepared using the ‘standard’ strategy. In the second year, the increased wool production was almost 350 grams more clean wool that was 0.8 microns greater in diameter.

The combined results for both years showed Merino weaner sheep grazing paddocks prepared using the ‘new’ strategy grew more clean wool (P < 0.001) with an increased fibre diameter (P = 0.01) than sheep grazing paddocks prepared in using the ‘standard’ strategy.

3.6 Pastures
The amount of herbage on the paddocks was estimated at the beginning and end of each intensive grazing period and at the beginning and end of the weaner grazing period. There was no significant difference between the pasture height in the paddocks prepared using the ‘standard’ strategy or ‘new’ strategy at the beginning of the first intensive grazing period. However, at the end of the first intensive grazing period, the pasture height was significantly higher in the ‘standard’ paddocks than the ‘new’ strategy paddocks (10.2cm vs 6.2cm, respectively; P = 0.04). At no other time in either the preparation or weaner grazing periods was there a significant difference in pasture height or pasture dry matter.

At the beginning of the weaner grazing period of year 2, more green pasture was present in the ‘new’ strategy paddocks. Although the difference in available pasture was not statistically significant, the difference may have been important and may have lead to greater growth rates for weaners in the ‘new’ strategy paddocks.
Table 3.10. Mean bodyweights for weaner sheep at the end of the weaner grazing period. The paddock mean was based on observations from 15 sheep in year 1 and 13 sheep in year 2.

<table>
<thead>
<tr>
<th></th>
<th>Body weight (kg)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>43.2</td>
<td>46.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42.2</td>
<td>42.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42.7</td>
<td>44.4</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>42.7</td>
<td>44.5</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>41.7</td>
<td>49.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>43.5</td>
<td>47.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>46.2</td>
<td>48.5</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>43.8</td>
<td>48.4</td>
<td></td>
</tr>
</tbody>
</table>

Overall mean

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>42.3 *</td>
</tr>
<tr>
<td>1999</td>
<td>46.5 *</td>
</tr>
</tbody>
</table>

* Difference between treatments was significant $P = 0.01$, SEM = 0.69.

Table 3.11. Fibre diameter (μm) and clean fleece weights (kg) for Merino weaner sheep shorn in November. The paddock mean was based on observations from 15 sheep in year 1 and 13 sheep in year 2.

<table>
<thead>
<tr>
<th></th>
<th>Fibre diameter (μ)</th>
<th>Clean fleece weight (kg)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>standard</td>
<td>new</td>
<td>standard</td>
<td>new</td>
</tr>
<tr>
<td>1998</td>
<td>16.2</td>
<td>17.3</td>
<td>1.79</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>16.3</td>
<td>16.4</td>
<td>1.68</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>16.4</td>
<td>16.6</td>
<td>1.80</td>
<td>1.99</td>
</tr>
<tr>
<td>Mean</td>
<td>16.3</td>
<td>16.8</td>
<td>1.76</td>
<td>1.93</td>
</tr>
<tr>
<td>1999</td>
<td>17.1</td>
<td>17.6</td>
<td>2.39</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td>16.5</td>
<td>17.1</td>
<td>2.18</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>16.3</td>
<td>17.6</td>
<td>2.33</td>
<td>2.70</td>
</tr>
<tr>
<td>Mean</td>
<td>16.6</td>
<td>17.4</td>
<td>2.30</td>
<td>2.64</td>
</tr>
</tbody>
</table>

Overall mean

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre diameter (μ)</td>
<td></td>
</tr>
<tr>
<td>16.5 *</td>
<td>17.1 *</td>
</tr>
<tr>
<td>Clean fleece weight (kg)</td>
<td></td>
</tr>
<tr>
<td>2.03 **</td>
<td>2.29 **</td>
</tr>
</tbody>
</table>

* Difference between treatments was significant $P = 0.01$, SEM = 0.14.

** Difference between treatments was significant $P < 0.001$, SEM = 0.04.
Chapter 4 Discussion

This experiment shows that the 'new' strategy was highly successful in reducing worm egg contamination during the summer period. Subsequently, weaner sheep that grazed the prepared pastures during the late autumn, winter and spring were exposed to fewer parasites than weaners grazing paddocks prepared in the 'standard' way. Increased bodyweight gains and wool growth were also recorded in the weaners grazing the 'new' strategy paddocks when compared with similar sheep grazing paddocks prepared using the 'standard' strategy.

The objective of both the 'standard' and 'new' strategies was to limit worm egg contamination on the pasture during the summer and early autumn so that the numbers of infective larvae available to sheep grazing during the late autumn, winter and spring would be reduced. To achieve zero deposition of eggs is difficult when sheep are set-stocked because small numbers of infective larvae are available on pasture during the summer (Anderson 1972). Any larvae ingested after treatments in summer that develop to adult worms will subsequently produce eggs that are deposited onto the pasture during summer. It is known that in summers with above average rainfall, there is a higher availability of infective larvae to grazing sheep (Southcott and Barger 1976, Donald et al 1978). Therefore, as a consequence of this, large numbers of worm eggs may be deposited onto the pasture in years with above average summer rainfall.

In both years of this study, worm egg counts of mature wethers that were continuously grazed during the preparation period began to increase six weeks after the first anthelmintic treatment given at the start of November. This increase corresponds with infection that occurred about three weeks after the anthelmintic treatment. By the end of January, mean worm egg counts of sheep in the 'standard' paddocks had increased to about 270 and 400 epg for years one and two respectively.

After the second treatment in February of the first year, mean worm egg counts from the wethers remained less than 50 epg for 11 weeks until the sheep were removed from the
paddock. In the second year, mean counts increased to almost 100 epg six weeks after the treatment in February. This indicates that in the second year infection had occurred soon after the second treatment was given. Rainfall in the summer of the second year was 28% above the long-term average.

The numbers of infective larvae available to the wethers were estimated from the worm egg counts and worm burdens of groups of ‘tracer’ sheep that grazed successive periods of two weeks during the summer of the second year. These counts were related to weather data to determine the periods of parasite transmission.

The mean worm egg count from the first group of ‘tracer’ sheep (8 to 21 December) was about 400 epg two weeks after the end of the grazing period. This count corresponded with an arithmetic mean of about 500 adult *O. circumcincta* and 500 adult *Trichostrongylus* spp (Table 3.6). Worm egg counts from the next group of ‘tracers’ did not exceed a mean of 45 epg thus indicating that fewer infective larvae were available during the period between 22 December to 5 January compared to the period 8 to 21 December. The weather during the later period was hotter, with a mean 3pm temperature of 22 degrees centigrade, 4 degrees greater than for the previous period.

From early January until March of the second year, mean 9am and 3pm temperatures were similar for each two week grazing period (Table 3.1) but total rainfall for each period varied considerably. The differences in rainfall for the grazing periods corresponded to differences in the worm egg counts of the groups of ‘tracer’ sheep.

Mean counts from the ‘tracer’ sheep that grazed from 5 to 18 January were below 25 epg and for the 19 January to 1 February period, no eggs were detected. These results indicate very low numbers of infective larvae on the pasture during these periods. This was despite 17 mm of rain falling over three consecutive days during the 5 to 18 January period, suggesting that this rainfall event did not lead to an increase in the number of infective larvae on the pasture.
Towards the end of the period to 15 February, 60 mm of rain fell over two consecutive
days, but only 7 mm of rain had fallen during the first 10 days of the period. The mean
worm egg count of the nine ‘tracer’ sheep five weeks after removal from the paddock
was only 35 eggs per gram of faeces. The low egg counts of the previous groups of
‘tracer’ sheep combined with the rainfall events during this period would indicate that
infective larvae became available as a result of the 60 mm of rainfall.

During the final ‘tracer’ grazing period from 16 February to 1 March, a total of 13 mm of
rain fell in two separate two-day periods. The mean worm egg counts of this group were
about 150 epg two weeks after the grazing period finished. The infective larvae that this
group of animals ingested are likely to have become available as a consequence of the 60
mm of rain in the preceding two week period, because the rainfall events during their
grazing period were less than 20 mm and unlikely to have resulted in enough available
larvae to produce worm egg counts of 150 epg.

The idea that the 60 mm of rain resulted in an increase in the number of available larvae
is consistent with the worm egg counts from the wethers grazing the same paddock that
increased from virtually zero to about 100 epg one month after the 60 mm of rain fell.
Earlier, Young (1983) had also found that 60 mm of rain during February was associated
with increase numbers of *O. circumcincta* larvae moving from faecal deposits to herbage
and soil.

Although the amount of re-infection was low (Table 3.7 and Figure 3.8), the resulting
worm egg counts in both ‘tracers’ and mature wethers were relatively high. Re-infection
occurred soon after rainfall, and therefore the higher worm eggs counts observed in the
set-stocked wethers in the second year can be attributed to the greater amount of rainfall
that occurred during the second summer.

The relationship between worm egg counts and total adult worm burdens appears to be
different in different seasons for both immature and adult sheep. In December, spring-
born weaners with a mean strongyle egg count of about 350 epg had a mean burden of
about 1000 adult *O. circumcincta* and *T. vitrinus* (Table 3.9). Comparatively, in August, spring-born weaners that had grazed the paddocks prepared using the 'standard' strategy from April also had a mean strongyle egg count of about 350 epg (Figure 3.5), but had a mean worm burden of about 5000 adult *O. circumcincta* and *T. vitrinus* (Table 3.8). The mean strongyle egg count of the mature wethers that grazed the 'standard' strategy paddocks during March of the second year was almost 100 epg, although only small numbers of infective larvae were available on the pasture (Figure 3.8, Table 3.9) and therefore their worm burdens would have been low. In a similar environment, Larsen *et al.* (1994) found that maiden ewes with worm burdens ranging from 420 to 13300 (mean about 5800) in September had low worm egg counts, 60 to 270 epg. These findings are consistent with Pullman *et al.* (1991) who reported high egg counts during the summer months and low egg counts throughout the winter in spring-born weaners during their first year.

A main effect of the intensive grazing and destocking periods used in the 'new' strategy was to prevent contamination of pastures with worm eggs from the time of the first summer treatment (November) until the weaners were put into the prepared paddock in April. Even if the wethers were re-infected shortly after the anthelmintic treatment, then for at least three weeks (the pre-patent period of the main parasites) little or no contamination of the pastures would occur although these sheep would add to the contamination on other parts of the property when moved from the paddocks.

In addition to limiting worm egg deposition, the 'new' strategy may reduce the number of larvae present on the pasture during the preparation period in two other ways. The increased number of sheep that graze during each of the intensive grazing periods could have a 'vacuum cleaning effect' on available larvae, reducing their numbers substantially. Secondly, larvae that move from faecal deposits to herbage after the end of the second intensive grazing period will have greater exposure to the desiccating effects of sunlight and heat because of the reduction in herbage. These two factors may be particularly important in years when large numbers of larvae are present on pasture during the preparation period, such as in a 'wet' summer.
Support for these views can be seen in the results of the *Nematodirus* spp worm counts. Despite almost no *Nematodirus* spp eggs being deposited on paddocks of either treatment during the preparation period, there were significantly fewer larvae available on the 'new' strategy paddocks during June of both years. Brunsdon (1963) found numbers of *Nematodirus* spp larvae on pasture increase rapidly in January and February. Therefore, if the number of larvae were reduced by either a 'vacuum cleaning effect' or by desiccation in February and March, then fewer larvae would be available in June.

The effects of the two preparation strategies on parasite numbers were compared by estimating larval availability during the weaner-grazing period, by estimating worm egg output and total worm burdens of the weaners during the weaner grazing period. All these estimates showed fewer infective larvae were available on the paddocks prepared using the 'new' strategy (Tables 3.5 and 3.6, Figures 3.4 and 3.5). This finding was consistent in both years for all 'tracer' grazing periods except September.

The reduction in the numbers of available larvae associated with the 'new' strategy was greater for *T. vitrinus* than for *O. circumcincta*. The number of *T. vitrinus* in 'tracer' sheep grazing paddocks prepared using the 'new' strategy remained low during June, July, August and September in both years, and were between 50 and 90% lower than for the 'tracers' grazing the paddocks prepared using the 'standard' strategy. Comparatively, the difference between the numbers of infective larvae of *O. circumcincta* on the paddocks prepared using the 'new' and 'standard' preparation strategies reduced progressively from June until August, and in September there were no differences in numbers between the two treatments (Table 3.5). From these observations, it can be concluded that numbers of *T. vitrinus* infective larvae were greatly reduced for the entire winter as a result of the 'new' strategy. However, numbers of infective *O. circumcincta* were not reduced for the entire winter and this may have been due to the biotic potential of *O. circumcincta*.
Because virtually no worm eggs were deposited on the paddocks prepared using the ‘new’ strategy during the summer preparation period, the majority of available larvae present during May, June and July must have come from eggs deposited before the previous November. The worm burdens of the ‘tracer’ sheep that grazed during these periods were low, with a mean burden of about 300 T. vitrinus and 1000 O. circumcincta for each period. Although these are low worm counts, this finding indicates that some eggs and larvae can survive from late October until May and give rise to infective larvae during the winter, and supports the findings of Anderson (1983).

In this experiment, the paddocks were allocated to the same preparation strategy for both years of the experiment, which may have lead to parasite carry-over effects. However, any effect was likely to be minimal because of the poor survival of infective larvae over the preparation period.

The advantage of the ‘new’ strategy was also shown by the reduction in worm egg counts of the weaner sheep grazing during the weaner grazing period. In all replicates, in both years, mean worm egg counts were less in the weaners grazing the paddocks prepared using the ‘new’ strategy than those in the ‘standard’ strategy. In both years, mean worm egg counts of weaners grazing the ‘new’ strategy paddocks remained below 250 epg from April until mid August. In this environment a mean egg count of over 250 epg is commonly used to indicate that an anthelmintic treatment needs to be given to weaners. Using this ‘rule of thumb’ the weaners grazing the paddock prepared using the ‘new’ strategy did not need to be treated. However, the mean worm egg count of the weaners grazing the paddocks prepared using the ‘standard’ strategy exceeded 300 epg in June of both years (Figures 3.2 and 3.3). Producers in this environment would have treated these sheep although in this experiment there was no reason for this decision because there were no signs of disease, body condition of the sheep was good and available green pasture exceeded 500 kg/ha of dry matter.

The findings from this experiment suggest that a decision to treat set-stocked weaners with anthelmintics during the winter should not be based on a faecal worm egg count.
alone. The reason for this treatment is to prevent deaths due to Trichostrongylid infection. Mortalities and production losses are likely to be greater in sheep that are malnourished than those that have access to adequate pasture and are gaining weight.

In August of the second year, two set-stocked weaners were selected from each replicate to relate worm egg count to worm burden. Weaners were selected that had a worm egg count close to the mean worm egg count of all the sheep in the respective paddock. Mean worm egg counts of the sheep grazing the paddocks prepared using the 'standard' strategy were about 400 epg, and were associated with a mean worm burden of about 6000 adult and 3000 immature *O. circumcincta* and *T. vitrinus*. These weaners were gaining weight and were grazing adequate pasture. These sheep were not treated with an anthelmintic and no sheep died. Further research is required to develop guidelines for evaluating worm egg counts, bodyweights and pasture availability to assist farmers with decisions about treatments in winter.

The worm burdens of the weaners that grazed from April until late August of the second year, showed that weaners grazing the paddocks prepared using the 'new' strategy had significantly lower mean worm counts of *T. vitrinus*, about 25% of the counts from weaners grazing in paddocks prepared using the 'standard' strategy. These weaners also had about 40% fewer adult *O. circumcincta*. However, sheep from both treatments had similar numbers of immature *O. circumcincta*. These findings support the 'tracer' worm counts, suggesting that the 'new' strategy is more successful at reducing numbers of available *T. vitrinus* than *O. circumcincta* in the late winter period.

After mid August of the second year, mean worm egg counts of weaners in both the 'new' and 'standard' strategy paddocks increased to over 300 and 400 eggs per gram of faeces respectively. This increase was unexpected, especially in the 'new' paddocks, because weaners grazing the 'new' strategy paddocks had been exposed to low numbers of infective larvae during the preceding two months, as shown by the mean 'tracer' worm counts for June and July. Inspection of egg count data showed that about 10% of animals had egg counts over 1000 epg, whereas the majority had egg counts of between 100 and
500 epg. This finding can be explained by the presence of *Chabertia ovina* in the set-stocked weaners killed in August. Three of the 12 sheep were infected with about 30 adult females. Gordon (1981) classifies *Chabertia ovina* as a 'medium egg producer', with a single female capable of laying 3000 to 5000 eggs per day. Therefore, counts of more than 1000 epg in a few sheep may have been associated with burdens of about 100 *Chabertia ovina*.

The results from this experiment also give some insight into the seasonal patterns of *Nematodirus* spp in this environment. During the preparation periods of both years, almost no *Nematodirus* spp eggs were deposited on the pastures in either the 'standard' or 'new' preparation treatments. However, the 'tracers' that grazed during the summer of the second year were infected with large numbers of *Nematodirus* spp larvae (Figure 3.9). This finding suggests that despite large numbers of infective larvae being available on the pasture during the summer, re-infection of the wethers was very low and consequently they deposited very few eggs onto the pasture.

In both years, the egg counts of *Nematodirus* spp during the weaner grazing period followed a similar pattern, reaching a maximum in May, and slowly decreasing to zero by October. Because almost no *Nematodirus* spp eggs were deposited on the paddocks of either strategy during the preparation period, the infective larvae must have been derived from eggs deposited before the previous November. This finding is consistent with studies conducted in New Zealand (Brunsdon 1963) that showed large numbers of infective larvae were available on the pasture in autumn following contamination in the preceding spring or summer.

Ecological studies are now required to determine quantitatively the environmental conditions that affect the free-living stages of *O. circumcincta*, *T. vitrinus* and *Nematodirus* spp in the Victorian environment. In particular, a better understanding of the effect of rainfall on the migration of larvae from dung pellets during the summer will provide much needed information for recommendations on the timing of anthelmintic treatments in late spring and summer.
There were gains in productivity in the weaner sheep that grazed the paddocks prepared using the ‘new’ strategy when compared with those in the ‘standard’ strategy. In the ‘new’ strategy, the weaners grew about 10 and 15% more clean wool with an increased fibre diameter of 0.5 and 0.8μ in years one and two than those grazing the ‘standard’ paddocks. However, the financial benefit of increasing clean fleece weight may be offset by the increase in fibre diameter.

In the first year, weaners grazing the ‘new’ strategy paddock were slightly heavier at the end of June, and their bodyweights continued to gradually increase so that they were about 4% heavier at the end of the weaner grazing period. In the second year, the weaners grazing the ‘new’ strategy paddocks were almost 4 kg (15%) heavier four weeks after the start of the weaner grazing period. These weaners continued to grow at a greater rate than the weaners grazing the paddocks prepared using the ‘standard’ strategy, and were almost 5 kg (11%) heavier at the end of the weaner grazing period.

This large and rapid increase in bodyweight of the weaners grazing the paddocks prepared using the ‘new’ strategy in the second year was associated with more herbage in these paddocks. Rainfall during March caused the re-growth of dormant grasses and the germination of clover and annual species. On paddocks prepared using the ‘new’ strategy there was about one month of pasture growth at the beginning of weaner grazing period. Comparatively, on the ‘standard’ strategy paddocks there was less herbage because they had been grazed up to the start of the weaner grazing period. The difference in pasture height between the two treatments was visibly obvious but the measurements were variable and not statistically significant. However, the increases in bodyweight of the weaners show that the visible difference was biologically important.

Measurements of pasture availability throughout the preparation and weaner grazing periods showed a consistent trend in both years, and, except at the end of the first intensive grazing period, there were no significant differences in pasture availability between paddocks used for the two treatments. From the estimates however, it was
concluded that the 'new' strategy did not have any detrimental effect on the amount of available pasture during either the preparation period or the weaner grazing period. As shown in the second year, the 'new' strategy can actually improve the amount and quality of available pasture at the start of the weaner grazing period if rainfall is sufficient for the germination and growth of pasture species to occur after the end of the second intensive grazing period.

The relative contribution of increased pasture availability and reduced worm burdens to increase productivity in weaners grazing the paddocks prepared using the 'new' strategy cannot be determined. However, the combined result, namely heavier sheep and increased wool production, can be attributed to the 'new' preparation strategy.

There are several financial benefits of the 'new' preparation strategy. This experiment showed mean worm egg counts of the weaners were below the threshold for anthelmintic treatment during winter (250 epg) and therefore saving could be made as a result of reduced anthelmintic treatments. The weaners grew to heavier bodyweights and grew more clean wool of an increased fibre diameter than similar sheep grazing pastures prepared the usual 'standard' way. Therefore, paddocks prepared using the 'new' strategy could be stocked at a higher rate than those prepared in the 'standard' way. Increased stocking rates will reduce mean bodyweight, individual wool production and mean fibre diameter but will increase wool production per hectare thereby increasing farm income.

In this experiment, no additional direct costs were associated with the implementation of the 'new' strategy. However, there may be some indirect costs associated with this strategy that were not taken into account. The 'new' strategy minimises worm egg deposition on one area of the property, namely the paddocks to be grazed by weaner sheep during the winter. Contamination of the pasture with worm eggs may be increased on other areas of the property if re-infection occurs during summer and there may be some costs associated with the increase. For example, Barger and Southcott (1975 b)
showed that wool production of resistant sheep exposed to moderate challenges of *T. colubriformis* larvae was 11% less than for similar unchallenged sheep.

In years when re-infection occurs after the anthelmintic treatments given in the summer, the potential production losses in mature sheep are likely to be less than those in weaner sheep if both groups were exposed to moderate numbers of infective larvae. Therefore, the ‘new’ strategy is likely to have a beneficial effect on overall production from a farm even if worm egg deposition increases on some areas of the property.

The bodyweights of wethers that grazed during the preparation period were not monitored in this experiment. It was assumed that the ‘new’ preparation strategy would have a similar effect on bodyweights as the ‘standard’ strategy because the average stocking rate during the preparation period was similar for both treatments. If supplementary feeding was needed it could be given to sheep on the paddocks being prepared, provided their period in the paddock did not exceed four weeks. Alternatively, the sheep could be fed on another part of the farm.

The ‘new’ strategy is a simple concept that was designed to integrate grazing management with the two summer anthelmintic treatments. Grazing the paddock for a period of no more than four weeks after each of these treatments will almost eliminate worm egg contamination on the pasture for the summer and early autumn, and make the paddock parasite ‘safe’ for the winter grazing period. The exact stocking rate used during the intensive grazing periods is flexible, with the number and class of stock used for this purpose having no impact on the parasitological success of the strategy. The stocking rate that should be used is one that efficiently utilises the available herbage during each of the two grazing periods. Since the strategy is not dependent on any particular stocking rate or class of stock used, it can potentially be used on any sheep producing property, irrespective of flock structure.

In this experiment, the ‘new’ strategy was used to prepare parasite ‘safe’ pastures for spring born Merino weaners. However, this preparation strategy can be used to prepare
parasite 'safe' pastures for any class of stock on properties where the two-summer treatment program is used.

The improved parasite control achieved with the 'new' strategy is unlikely to be associated with an increase in selection for anthelmintic resistance in the parasite population. Two anthelmintic treatments are used in both the 'standard' and 'new' strategies, with the 'new' strategy only changing the distribution of worm eggs over the property. Therefore, there should be no difference in the rate that the 'new' and 'standard' strategies select for anthelmintic resistance.

If the same area was subjected to the 'new' grazing strategy for many years, it is possible that there would be selection for parasites that are able to survive long periods of unfavourable conditions (summer). For this reason, it is recommended that different paddocks be prepared for weaners every few years.

The integration of intensive grazing with anthelmintic treatment in summer is a simple, practical and effective way of producing parasite 'safe' pastures in autumn, winter and spring for Merino weaner sheep. It can be used on all properties in areas where the two summer treatment program forms the basis of control of O. circumcincta and Trichostrongylus spp infections in sheep.
Addendum

After this experiment finished in November 1999, the Woolmark Company funded a program to promote the 'new' strategy to producers in southeast Australia. The program was designed to demonstrate to producers the advantages of the 'new' strategy. I was appointed program leader. Working with interstate collaborators, demonstration sites were established on commercial wool growing properties throughout southeast Australia. Two field days were planned for each site to allow producers to see the 'new' strategy implemented on a farm and to explain the ideas behind the strategy. One field day was conducted during the preparation period and the other is to be held during the winter grazing period.

Demonstration sites were established in Victoria (Woodside and Coleraine), South Australia (Millicent), New South Wales (Wagga Wagga) and Tasmania (Perth). Two similar paddocks were selected on each site. The size of the paddocks ranged from 12 hectares to 40 hectares. During the summer of 1999/2000, one paddock on each site was prepared using the 'standard' strategy and the other paddock prepared using the 'new' strategy.

Weaner sheep commenced grazing the paddocks in autumn 2000. On each property, between 500 and 1000 weaners were used in the demonstration. Stocking rates that were appropriate for the property were used, and were between 10 and 18 dse/hectare. Bodyweights and worm egg counts of a sample of these sheep will be monitored during the winter and spring. Results from all the sites will be presented at the second field day.

An assessment of this technology transfer program and the adoption of the 'new' strategy by producers will be made at the end of the program.

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