Impact of grazing management on cattle and sheep parasites

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Submitted to:

Liz Genever – EBLEX

Lynfa Davies- HCC

Prepared by:

ADAS UK Ltd

Acknowledgements

Project Team

I declare that this report represents a true and accurate record of the results obtained/work carried out.

Karen Wheeler	28 April 2011
(Authors' signature)	(Date)
Kate Phillips	28 April 2011
(Verifier's signature)	(Date)

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Key messages

- This review was commissioned to assess whether current advice on grassland management is in line with good parasite management
- There is little evidence to support changing the current sward height recommendations based on the findings of this report
- Although higher numbers of infective larvae are found towards the base of the sward they are found throughout the grazing horizon of ryegrass based swards
- The infective L3 larvae of helminth parasites are well adapted to the temperate UK environment and can survive for a considerable period of time on pasture
- Rotational grazing systems do not generally offer greater parasite control over set stocking. Larval development can range between a few days to several weeks depending on temperature and moisture and makes planning the length of rotational grazing cycles virtually impossible
- Mixed grazing systems can improve pasture utilisation and improve the growth rates of lambs through dilution of parasites and differences in grazing behaviour and grazing height between cattle and sheep.
- Chicory has been shown to be beneficial for grazing lambs resulting in lower faecal egg counts and improved weight gains.

1 Introduction

Well managed grassland is essential to optimise cattle and sheep performance. The proven benefits of using sward heights to manage grass for sheep and cattle have led to the advice that sward heights in set-stocked systems of 4-6 cm for ewes and lambs and 6-8 cm for cattle are ideal. For sheep in particular maintaining a sward height of around 4cm will ensure grass quality is at its highest. Maintaining sward heights at these levels may however have consequences for parasite control.

The objective of this report is to review and comment on the available information on:

distribution of parasites within the sward profile, and how this changes with sward height and plant type.

how the risk changes with different grazing strategies and rest periods, e.g. set stocking vs various rotational grazing systems, and how this changes with time of year, parasites and climate.

the difference in risk between lowland, upland and hill grazing, and the impact of environmental grazing.

the benefits of tight grazing, taking into consideration feed quality versus risk of parasite ingestion.

the potential of bioactive forages, and the likelihood of them being successfully grown in the UK.

2 Lifecycle of nematode parasites

Cattle and sheep can each be parasitised by up to 20 different species of nematode although pathogenicity varies with nematode species, number present and susceptibility of the host (Abbott et al, 2009, Taylor, 2010). Additionally all grazing animals can be affected by the trematode *Fasciola Hepatica* (liver fluke) although it is less pathogenic in cattle than sheep.

2.1 A typical nematode lifecycle

The following life-cycle is typical for many of the gastrointestinal nematodes of grazing livestock (e.g. *Teladorsagia, Trichostrongylus, Haemonchus* and *Ostertagia*). Worm eggs laid within the host by adult worms are passed out in the faeces of the animal and hatch to produce first-stage larvae (L1) which then develop further and moult to become second-stage larvae (L2). These stages take place within the dung where the larvae feed on bacteria. At the second moult to produce the infective, third stage larvae (L3) the cuticle of the L2 larvae remains as a protective sheath preventing the larva from feeding. The L3 larvae are the infective stage and they migrate onto the surrounding herbage where they are ingested by the grazing animal. Following ingestion the life-cycle is completed within the animal in about 14 days. The time period between ingestion of L3 larvae and the appearance of worm eggs in the faeces is typically between 16 – 21 days. The free-living stages (between eggs and the L3 stage) can take up to 12 weeks for eggs deposited in the early spring but can be as short as 7 days in the summer.

Historically, seasonal and geographical differences have been found between nematode species although changes have been seen in recent years. Haemonchus infection of sheep was typically confined to the South East of England but has now become widespread whilst Trichostrongylus, which was traditionally a problem for lambs in the autumn is now seen earlier in the summer and persisting for longer during mild winters.

2.2 Variations to the typical lifecycle

Some notable differences in life-cycle do exist for some nematode species e.g.:

Nematodirus - where development to the L3 stage takes place within the egg. For *N battus* (in sheep) the release of the L3 larva is initiated by a chill period followed by mean daily temperatures above 10°C. *N battus* has a relatively slow lifecycle with infection in one year being passed to the following lamb crop. As a result of the specific requirements for egg hatching, large numbers of infective larvae can be produced at once, resulting in a high parasite challenge to lambs. *N battus* has been seen historically as a problem in the spring but more recently has been seen at other times in the year. *N helvetianus* (in cattle) does not appear to have the same requirements for a chill period resulting in larvae often being produced within 2-3 weeks.

Dictyocaulus viviparous (Parasitic bronchitis of cattle). Adult worms in the lungs produce eggs containing fully developed larvae that hatch almost immediately. L1 larvae migrate up the trachea, are swallowed and passed out in the faeces. Under optimal conditions the L3 stage can be reached in 5 days but will typically be longer. The L3 larvae leave the faecal pat either by their own movement or by windborne spread by a fungus that grows on faecal pats. L3 larvae are ingested and complete the lifecycle in the animal.

Fasciola hepatica (trematode known as liver fluke). The life-cycle is complex compared to other helminths as it involves an intermediate host (the mud snail *Galba* (*Lymnaea truncatula)* and several free-living stages. The adult fluke lay eggs that are passed out in the faeces and under suitable conditions a miracidium develops within the egg, hatches and migrates, seeking out the snail host. Following further development within the snail cercaria migrate to the herbage where they become the infective stage of the parasite (metacercaria). Following ingestion by grazing livestock, the young fluke migrate to the liver. It typically takes 10–12 weeks for fluke eggs to be produced following ingestion with the whole cycle taking around 18-20 weeks, although development within the snail can vary between five weeks to a few months depending on temperature and moisture. The snail prefers the conditions associated with poor drainage and therefore the incidence of liver fluke is higher in the wetter areas of the country and in years with high summer rainfall. Sheep grazing wet fields in the autumn and winter are particularly at risk of infection so excluding animals from these areas can offer some measure of control.

3 Factors affecting the development, survival and migration of parasites

The development of infective (L3) larvae within the faeces, the migration of L3 larvae from faeces to herbage and their location within the herbage is a key factor in parasite transmission to grazing livestock. This is highly influenced by environmental conditions including temperature, relative humidity, light intensity and rainfall. Understanding these factors can help explain differences in infectivity of pasture for grazing livestock.

3.1 Development of the eggs to the infective stage

Hatching of the eggs and the development of the larvae to the L3 stage is primarily dependent on temperature and moisture. These factors determine both the success rate and the speed of development. In a review of the ecology of the free-living stages of trichostrongylid parasites of sheep, O'Connor et al (2006) discussed the variation between species and between free-living stages within species. This review noted that the influence of temperature and other environmental effects has been studied across a range of climates with the effect of temperature on egg development being a particular focus.

Many of the early studies looking at the effect of temperature were carried out under controlled laboratory conditions providing optimum temperatures for larval development. More recent studies have looked at the effect of cold temperatures on development success. O'Connor et al (2006) reviewed the findings of many studies looking at the resistance to low temperatures across three important nematode species of sheep (*Haemonchus contortus, Teladorsagia circumcincta and Trichostrongylus colubriformis*) and have estimated the temperature range within which development is likely (Table 1.) In a study carried out by van Dijk and Morgan

(2008), *Nematodirus battus* eggs were able to develop between 11.5 and 27°C with development more successful at the lower end of the range.

Table 1.Temperature range for development of egg to infective larval stage for some important sheep nematode species

	Optimum temperature range °C	Overall temperature range °C
T. circumcincta	16 - 30	1 - 35
T. colubriformis	22 - 33	6 - 39
H contortus	25 - 37	11 - 41

Source: O'Connor et al (2006)

The time taken for eggs to reach the infective larval stage together with the proportion of eggs that actually develop can be used to predict the timing and extent of pasture infectivity. A range of studies have shown the minimum time from egg to L3 larvae to be in the order of 3 – 4 days where moisture is not limiting and temperatures are in the optimal range (O'Connor et al 2006). Lower temperatures slow the development to L3 larvae and can extend the interval to weeks rather than days. Stromberg (1997) reported from a number of studies that under optimal conditions in the laboratory at 25°C *Ostertagia ostertagi* eggs can hatch in 12 to 24 hours and develop into L3 larvae in 5-6 days but could take up to 42 days at 5°C. This sensitivity to temperature means that development of L3 larvae from eggs deposited in early spring may take weeks whilst taking only days for those deposited later. This tends to result in the majority of eggs reaching the infective stage at the same time resulting in high levels of pasture infectivity from mid-summer.

Fewer studies have examined the effect of different moisture levels on the development of the free-living stages. At low temperatures, development is generally limited irrespective of moisture levels but the interaction between the two factors becomes important at higher temperatures. Predictive models developed for *H. contortus* and *T. colubriformis* typically use cumulative precipitation and evaporation figures to model the development of larvae to the L3 stage and highlight the importance of rainfall events. However other studies have seen L3 development in the absence of rainfall where green, leafy swards have slowed the drying of faecal pellets of sheep due to the micro climate of the sward. O'Connor et al (2006) suggested that faecal moisture content (which is influenced by temperature, rainfall, evaporation and pasture condition) is likely to be the key factor in development rate and success from egg to L3 larvae. In the same review it was noted that differences in resistance to desiccation for the pre-infective stages between nematode species have been observed. *H. contortus* appears to be the most susceptible to dehydration, followed by *T. colubriformis* with *T. circumcincta* being the most resilient.

3.2 Survival and migration of infective larvae

The infective L3 larvae are much less susceptible to unfavourable climatic conditions than the developing stages although temperature and moisture still play a significant role. It has been suggested (O'Connor et al 2006) that this may be due to the ability of the larvae to move towards more favourable environments. The protective larval sheath may also play a part by improving resistance to desiccation. However the ensheathed L3 larvae are unable to feed and are susceptible to high temperatures that cause them to deplete their energy reserves more rapidly.

3.2.1 Factors affecting the migration of infective larvae to herbage

Larvae must move away from the faecal mass and onto the surrounding foliage to be ingested by grazing livestock. This movement is facilitated by a continuous film of moisture on herbage. Where moisture is not limiting, temperature will have a greater influence over migration (Stromberg, 1997). Silangwa and Todd (1964) found that migration was favoured by higher humidity, with significantly more larvae moving at 95% compared with 56% relative humidity. Larvae were also more likely to climb wetted leaf blades. Low temperatures adversely affected the ability of the larvae to climb herbage with significantly more larvae climbing at 27°C than 4°C.

Several studies (as reviewed by O'Connor et al, 2006) have reported differences between nematode species on the rate of migration from the faecal mass. In British studies *H. contortus* and *T. colubriformis* have both been observed to migrate rapidly onto herbage once development was complete with negligible numbers remaining in faeces within a few weeks. In the same study *T. circumcincta* larvae deposited in May were reported to remain in the faecal pellets and on pasture for up to 10 months providing a long-term reservoir of infection. Differences in migratory behaviour can help explain contrasting periods of larval decline between these important sheep nematode species.

The ability of faecal pats to act as a reservoir of infective larvae during dry periods was demonstrated in an Australian study (Barger et al 1984) where large numbers of infective larvae remained viable during 18 months of drought and resulted in high concentrations of larvae on pasture once the drought ended.

3.2.2 Factors affecting the survival of infective larvae

The success of management practices that aim to reduce grazing on heavily infected pastures are affected by the survival of L3 larvae. As mentioned above the infective larvae are more resistant to temperature and moisture fluctuations than the pre-infective stages leading to potentially long periods of L3 infectivity on pasture. Generally cool, dry weather prolongs larval survival and hot, wet weather shortens it (Barger, 1999). O'Connor et al (2006) highlighted work carried out to look at the predicted survival of *H. contortus* on pasture at varying temperatures (12 to 28°C) and humidity (35 to 85% RH). The model suggested that survival is enhanced at lower temperatures and increased relative humidity. A number of laboratory studies have demonstrated differences between the L3 larvae of nematode species to survive sub-zero temperatures (-10°C). Only 1% of *H. contortus* were able to survive beyond 24hrs and few *T. colubriformis* larvae lasted more than 8 days. The larvae of *T. circumcincta* however remained viable for up to 3 months. Survival of these three species was noted to be considerably longer at 3°C. The ability of the infective larvae to cope with cold temperatures facilitates the over-wintering of the free-living population and means that they are capable of infecting grazing livestock the following spring.

O'Connor et al (2006) reported that seasonal and inter-species differences in L3 longevity are closely correlated with the rate of larval migration to herbage from the faeces. In particular T. circumcincta is able to take advantage of the protection of the faecal pellets during adverse conditions whereas H. contortus and T. colubriformis moved rapidly to the relatively exposed herbage.

Van Dijk et al (2009) reported that the longevity of L3 larvae is related to temperature and humidity but that these two parameters alone cannot fully account for the observed abundance on pasture, with a number of studies noting that the decline in L3 populations at pasture is more rapid than predicted. Additional factors could include predation, loss to the soil, temperature fluctuations and sunlight. Van Dijk et al (2009) established in controlled experiments that natural levels of ultraviolet light increased mortality rates in infective larvae of *H. contortus*, *T. circumcincta* and *N. battus* although significant differences were found between nematode species. *H. contortus* proved to be more resistant to UV than either of the other two species. These results could help to explain patterns of abundance of L3 larvae on pasture especially the rapid decline in spring when solar radiation rises but temperature remains low. Actual mortality of larvae at pasture is likely to vary with UV dose at ground level. On pasture L3 larvae will be shaded from sunlight to some degree by the herbage.

O'Connor et al (2006) summarised the key environmental influences on some major nematode species of sheep and these are shown below in Table 2. Identifying these factors can explain the seasonal and geographic distribution of specific parasites e.g. *H. contortus* being historically more prevalent in South East England although now more widespread as a result of a series of milder winters and wetter summers.

Table 2.Key environmental influences on the free-living stages of the major sheep nematode species

	Stage of lifecycle			
Nematode species	Unembryonated egg	Embryonated egg	Pre-infective larvae	Infective larvae
H. contortus	Highly susceptible to cold and desiccation. High mortality below 10°C	Susceptible to cold and desiccation. Negligible hatching below 10°C. Low hatching rates in absence of moisture	Highly susceptible to cold and desiccation	Optimum survival in warm, moist weather. Poor survival in cool or warm dry weather and sub-freezing winters
T. colubriformis	Intermediate susceptibility to cold and desiccation. High mortality below 5°C	Intermediate susceptibility to cold. Low susceptibility to desiccation.	Susceptible to cold. High mortality below 5°C. Susceptible to desiccation	Optimum survival in cool or warm, moist weather. Poor survival over sub-freezing winters
T. circumcincta	Low susceptibility	Low	Intermediate	Optimum

	to cold, High egg viability at 0-10°C. Intermediate susceptibility to desiccation	susceptibility to cold and desiccation. Hatching below 5°C	susceptibility to cold. Susceptible to desiccation	survival in cool moist weather and sub-freezing winters. Poor survival in warm, dry weather.

Source: O'Connor et al (2006)

4 Distribution of parasite larvae on pasture

Sward factors such as density and height will determine the levels of light, moisture and temperature at different height strata within the sward and influence the distribution of larvae. Typically taller swards will be moister and cooler than short swards of the same density and dense swards will be cooler and moister than sparse swards (Soil Association, 2000). Moss and Bray (2006) confirmed that larval recovery was greater from denser swards. Crofton (1948) studied the climatic conditions in herbage and showed that the temperature within the sward can differ considerably from the air temperature with a general gradient of temperature between the upper and lower parts of the herbage. He also established that high humidity occurred in the base of the sward even when atmospheric humidity was low. Van Dijk et al (2009) reported that a similar vertical gradient would be expected to exist for UV irradiation. In this study it was suggested that exposure to UV may explain why larvae may constantly move on and off herbage, secondly why around 90% of larvae are generally recovered from the base of the sward and thirdly why the height to which larvae migrate appears to be related to leaf shape.

In the same study the authors suggested that there is an energy related trade off determining the optimum distance for horizontal migration of larvae and there is likely to be a further trade off determining vertical migratory behaviour: that of the probability of being ingested by climbing higher versus being exposed to higher UV intensity, higher temperatures and lower humidity at higher positions.

4.1 Horizontal distribution of L3 larvae on pasture

Boom and Sheath (2008) investigated the effect of successive harvests of grazable herbage around cattle faecal pats on the population dynamics of L3 larvae. They reported that a number of studies (including Gruner and Sauve, 1982) had looked at the development and migration of L3 larvae from cattle faecal pats. Most of the studies concluded that few larvae migrate further than 30 cm from the faecal pat even after significant time and rainfall. In their study Boom and Sheath reported that herbage was harvested four times (22–248 days) from around the faecal pats in three zones (0–20 cm, 20–35 cm and 35–45 cm from the centre of the faecal pat). In this study, L3 remained aggregated close to the faecal pats they emerged from even after two successive harvests and significant rainfall. The successive harvests simulated the effect of repeated grazing events by non-infective stock. After two grazing events L3 presence on herbage fell to <3% of the original population.

Gronvold et al (1989) described the factors affecting rain splash dispersal of infective larvae from cow pats. Simulated rainfall on dry pats resulted in dispersal of very few L3 larvae in contrast to pre-watered pats. In pre-watered pats (equivalent to 1.6 mm of rain) L3 larvae were stimulated to move to the surface of the pat where they could be hit by rain drops. In the controlled laboratory conditions more than 90% of the larvae were transported passively by splash droplets rather than by active migration. On pasture, faecal pats are often surrounded by tufts of rejected grass and will restrict horizontal movement of splash droplets resulting in larvae falling a few cm from the pat. Where splash droplets could move freely L3 larvae were found up to 90 cm away from the pats.

In another study Gruner and Sauve (1982) assessed the distribution of L3 larvae (primarily *Cooperia* and *Ostertagia* spp.) around faecal pats in relation to the grazing behaviour of calves. Their study also examined the distribution of L3 larvae in relation to the age of the faecal pat. Results suggested a progressive move from the faecal pat to the surrounding grass over 6-8 weeks.

4.2 Vertical distribution of L3 larvae on pasture

Crofton (1948) described the number of L3 larvae (*Trichostrongylus retortaeformis)* on different portions of herbage across three different plant species: *Festuca* (fescue*)*, clover and *Carex nigris* (common sedge)*.* The distribution of larvae on sedge (25cm in height) showed larvae to be limited to the lower 5cm, whilst larvae were evenly distributed vertically over the stems and leaves of clover. The distribution of L3 larvae on *Festuca* varied with plant height: on grass 13 cm high 90% of the larvae were found in the lower 7.5 cm (and 50% below 3.8 cm) whilst on grass 7.5 cm high 90% of larvae were found below 2.5 cm.

In the same study the distribution of larvae in the soil, 'mat' and herbage was measured throughout the year and showed highly seasonal differences. In the summer months (June-August) the majority of larvae were found on the foliage and more were found in the soil than the 'mat'. In the spring and autumn more larvae were found in the 'mat' and fewer in the soil or on the foliage whilst in winter larvae were concentrated in the 'mat'.

Silangwa and Todd (1964) carried out laboratory experiments to investigate the ability of L3 larvae (Trichostrongylid) to migrate vertically on grasses under controlled environmental conditions. Even under favourable conditions only a small proportion (2-3%) of larvae applied to the soil actually climbed the foliage. Of these 59% were found in the bottom 2.5 cm, 27% up to 5cm, 10% to 7.5 cm, 3% to 10 cm and 1% above this, supporting the findings of Crofton.

Callinan and Westrcott (1986) also studied the vertical distribution of L3 larvae on grass or clover and in soil at controlled temperatures and humidities over 4 days. They recovered the vast majority of L3 larvae from the soil with only 2% being recovered from herbage. Of those L3 larvae that migrated onto the herbage 68% were recovered at 0-2 cm and only 4% over 6cm. In this study the number of larvae recovered from grass and clover did not differ significantly.

Although the above studies provide good evidence that more larvae tend to be present towards the base of the sward this may not translate to more per kg of dry matter. Moss and Vlassof (1993) reported that larval densities (larvae per kg dry matter) for ryegrass/white clover swards were lowest in the 0-25 mm zone and increased to similar levels in the 26-75 mm, 76-125 mm and >125mm zones above this height. They noted some difference between forage species with chicory having lower larval densities above 75 mm from the base than below this height. Larval density on herbage is important as it determines the infectivity of the sward for the grazing animal. Herbage with a lower larval density will result in animals taking in fewer larvae overall than herbage with higher densities assuming that daily dry matter intakes are similar on both swards. Moss and Vlassof commented that their data indicated little opportunity to control larval intake by manipulating grazing intensity as the larvae were distributed evenly throughout the sward horizon. Niezen et al (1998) commented that high larval densities were measured in the top stratum of white clover, ryegrass and common bent (brown top) in particular and may predispose animals to higher levels of parasitism than from herbages that had lower larval densities.

4.3 Animal grazing behaviour

Sward height and density affect the bite depth and herbage intake rate of grazing livestock. Studies on herbage intake for cattle have shown bite depth to be a relatively constant proportion of sward height, ranging from 34% -48% of the ungrazed herbage (Ungar and Ravid (1999), Laca et al (1992) and Brerton and McGilloway (1996). Based on this information cattle grazing swards at 6-8 cm could be taking the top 2-3 cm off the top of the sward as they graze. Grazing behaviour in sheep is broadly similar with Bartham (1981) reporting the grazing depth of sheep on ryegrass swards to vary between 1cm on very short (3 cm) swards up to around 2.5cm on swards of 6cm or over.

Cattle and sheep will generally avoid grazing near faeces and Hutchings et al (1998) demonstrated that sheep were sensitive to both the amount and age of faecal deposition. They commented that rejection was most apparent around very fresh faeces that actually pose less of a parasite risk because the L3 larvae had not developed. Sheep were shown to alter their behaviour when grazing swards with high levels of faecal contamination, increasing contamination was associated with a reduction in animal bite depth, bite mass and bite rate. Gruner and Sauve (1982) commented on the grazing behaviour of calves in their study. They observed grazing close to the faecal pats where larval density was highest a month after pat deposition in August Sward heights fell during the grazing period from around 8cm in June to only 3cm in October and are likely to have encouraged animals to graze closer to the pats supporting the findings from other studies that showed reduced rejection at high stocking rates. They also quoted results from other studies that showed that ewes came back close to recently deposited faeces after 5-8 days delay.

5 Effect of different forage plants

Different pasture species can influence the sward microclimate or possess a sward structure that is unsuitable for the parasites and therefore affect the larval population and number of L3 larvae ingested by grazing livestock (Moss and Bray, 2006). A number of studies have investigated the effect of different plant species on the migration and survival of L3 larvae and the effect on grazing livestock. Scales et al (1994) and Moss and Vlassof (1993) observed fewer larvae on chicory and lucerne than on various grasses and Niezen et al (1993) reported lower faecal egg counts from lambs grazing Yorkshire fog or ryegrass than common bent or tall fescue.

Knapp (1964) reported on a USA study to determine the influence of different types of forage on the overwinter survival and subsequent infectivity of *H. contortus* for lambs. The numbers of adult worms recovered from tracer lambs were compared from six grass or clover crops and showed higher recovery of worms from lambs grazing white or subterranean clover than those on the two grasses (perennial ryegrass or Yorkshire fog). The author suggested that greater numbers of larvae can overwinter on forage species with heavy, dense growth characteristics than those with a more open type of growth. It was also noted that larvae were more successful on Tall Fescue compared to Smooth Brome grasses due to the morphology of the grasses (Silangwa and Todd, 1964). The results of these studies suggest that differences exist between herbage species and this has been shown to alter larval density in various height strata.

Moss and Vlassof (1993) researched the effect of different forage species on the development and distribution of nematode larval populations. Plots of perennial ryegrass, prairie grass or chicory (all sown with white clover) and lucerne were compared. The grass based swards had higher larval populations than lucerne or chicory, and lucerne more than chicory. Larval density tended to be higher in the 26-75 and 76-125 mm zones than the 0-25 mm zone. Chicory swards offered the best opportunity to reduce larval intake in grazing animals as they had the lowest larval populations.

In a comparison of white clover, red clover, lucerne and perennial ryegrass, Marley et al, (2006) showed red clover affected the development of *H. contortus* larvae and all legumes affected larval migration with reduced numbers of larvae above 50 mm above soil level compared to ryegrass.

Work in New Zealand carried out by Niezen et al (1998) compared the development, survival, migration and density of *T. circumcincta* and *T. colubriformis* larvae on a range of grasses and other herbage species. Herbage species had a significant effect on the total number of larvae recovered with the greatest number recovered from Yorkshire fog, ryegrass and cocksfoot and lowest from lucerne and white clover. Differences were due to development success and the ability to migrate onto the foliage rather than survival of L3 larvae. A greater proportion of the total larvae were recovered from the lowest strata of Yorkshire fog and prairie grass than white clover indicating larvae had greater difficulty migrating up these grass species. However in most herbage species, despite more larvae being recovered from the lowest stratum, larval density (L3/kg herbage DM) was highest in the top stratum.

The effect of various diets on the development and survival of parasites in sheep faeces was studied by Marley et al (2003). Lambs grazed birdsfoot trefoil, chicory, ryegrass/red clover or ryegrass/white clover. Forage diet had no effect on egg hatchability but did affect the development/survival of L3 larvae. Birdsfoot trefoil was found to increase the percentage of parasites that reach the L3 stage. Further laboratory and field studies on the effect of chicory and birdsfoot trefoil indicated that the number of infective larvae on the trefoil and chicory was reduced by the effect of their sward structure on the development/survival/migration of nematodes.

5.1 Effect of various forage plants on animal performance

Niezen et al (1998b) reported on the performance, faecal egg counts and worm burdens of lambs grazing various forage plants. Three contained condensed tannins (*L. corniculatus, L. pedunculatus* and sulla) and were compared with lucerne, plantain and ryegrass/white clover. The experiment demonstrated that *L pedunculatus* and sulla were able to maintain good rates of liveweight gain in lambs with a parasite burden. Plantain was not palatable resulting in poor growth rates.

In a further study Niezen et al (2002) compared the performance of lambs grazing three grass/white clover swards over two years. Sward height was maintained at 5 cm as would be tyoical in continuous grazing systems. Performance in year 1 was similar on ryegrass and browntop (common bent) swards but poorer on Yorkshire fog swards. In year 2 performance was best on the ryegrass swards and was related to an increase in white clover. Faecal egg counts in year 2 were lowest for ryegrass/clover and highest for browntop/clover swards. This study demonstrated the beneficial effect of white clover in alleviating/reducing the production losses due to parasitism.

6 Bioactive forages

Recent work on bioactive forages has highlighted the potential of these to contribute to parasite control. Legume forages such as sulla (*Hedysarium coronarium*), white clover (*Trifolium repens*), red clover (*Trifolium pratense*), lotus or big trefoil (*Lotus pedunculatus*) birdsfoot trefoil (*Lotus corniculatus*), sainfoin (*Onobrychis viciifolia*) and chicory (*Cichorium intybus*) have been studied. With the exception of chicory all these forages contain condensed tannins which are secondary plant metabolites that may have evolved as a defence mechanism against insect predation and grazing by herbivores. Chicory contains only traces of tannins but is rich in other compounds such as coumarins and phenolic compounds.

In a review by Hoste et al (2006) it was noted that the majority of studies investigating the effects of bioactive plants against nematode infections have focussed on grazing sheep with none being reported for cattle. The review highlights large variability in the anthelmintic activity of tannins in various studies but does report general beneficial effects on animal physiology and performance compared with control herbage plants, and that the most commonly observed effect on nematode populations is a decrease in faecal egg count (FEC). Some reasons for variability in results are discussed such as the concentration and structure of the condensed tannins in different plant species. An overview of the results suggests that there is a threshold of 30-40g of tannins per kg dry matter for anti-parasitic activity although excessive levels can be detrimental to the animal. Results also suggest that the effects of the active compounds could vary with parasite species and stage of development.

Research has shown that grazing these alternative crops may reduce the level of parasites in livestock (Niezen et al., 1993; Scales et al., 1994). Studies have shown that any reduction may involve a combination of improved protein utilisation, improved trace element or mineral status and/or improved immunity to nematode parasites. These mechanisms may act separately, or in combination, with the effects of secondary plant compounds (e.g. condensed tannins) on parasites in the gut, leading to reduced nematode survival, growth and/or fecundity. Herbage species has also been shown to alter the percentage of nematode parasite larvae that reached the infective stage in the faeces of parasitized sheep (Marley et al., 2003b).

Marley et al (2006b) reported that the number of infective stage larvae on birdsfoot trefoil and chicory pasture was reduced by the effect of their sward structure on the development/survival/migration of ovine parasitic nematodes. When forages were compared on a dry matter basis, by day 16 there were 31% and 19% fewer larvae on birdsfoot trefoil and chicory than on ryegrass, respectively. In the second experiment results showed there was a minimum of 58% and 63% fewer infective stage parasitic larvae on birdsfoot trefoil and chicory respectively, compared with ryegrass on day 14 and 35 when forages were compared on a dry matter basis.

Recent research has investigated the effects of alternative forages on parasite control. Athanasiadou et al (2007) found the faecal egg counts of lambs from undrenched ewes grazing on chicory were significantly lower than those of lambs from undrenched ewes on grass. They also found that lambs grazing chicory had improved weight gain compared to those on grass. Athanasiadou et al (2007) concluded that although chicory grazing did not affect ewe nematode egg excretion, it resulted in lower egg counts in lambs and improved live-weight gain.

The effect of birdsfoot trefoil and chicory on parasite intensities and performance were compared to those on ryegrass/white clover swards by Marley et al, (2003a). The lambs grazing chicory and birdsfoot trefoil were found to have fewer parasites than those on ryegrass/white clover swards. Lambs grazing birdsfoot trefoil had the lowest FECs on day 7 and fewer adult worms on day 35. Lambs on chicory did not have lower FECs but did have a lower abomasal worm burden than ryegrass/clover lambs. Liveweight gain was however highest for lambs grazing chicory as has been found in other studies.

6.1 Bioactive forages for UK conditions

Although alternative forages have been found to be beneficial under experimental conditions the practicality of using these in commercial situations needs to be considered. Chicory, birdsfoot trefoil and sulla were considered to have the most advantages in terms of improving performance, controlling parasites and for reducing methane production relative to ryegrass swards (Ramirez-Restrepo, 2005). Birdsfoot trefoil is most suited to hot dry summer climates and warm winters and has been found to last 3-4 years in these conditions (in wet summers the crop may only persist for 2 years due to poor competitiveness). Sulla is a biennial crop and requires inoculation with rhizobium bacteria, factors reducing the likely uptake amongst NZ or UK farmers.

Chicory has shown the most promise to date with commercial varieties of perennial chicory now available in the UK (Puna II, sold by British Seed Houses). Careful establishment and management is the key to maintaining the crop with the emphasis on regular grazing, but without damage to the crown of the plant. Chicory has been grown successfully as a pure stand or incorporated within mixed swards with grass and/or clover and can persist for 4-6 years. By contrast although birdsfoot trefoil shows promise as a bioactive forage there are currently questions over its persistence under UK conditions (IOTA).

Forage chicory is a broad-leaved perennial crop with good tolerance to drought, acid soils and major pests. In summer it has an erect growth habit whilst over winter it has broad prostrate leaves. It produces a large quantity of high quality forage with yields of up to 7-9 t/ha for pure chicory stands in the first two to three years under grazing conditions. Production then starts to decline (to around 50% by year 4) although additional N can improve yields. Forage chicory also makes a significant contribution to swards when mixed with grasses and legumes, especially in the spring and summer. Grazing management objectives should be to maximise leaf production (a 70-30% leaf to stem ratio has been suggested as ideal by Li and Kemp (2005). Grazing below 10 cm in spring at 3 week intervals and below 15 cm at 5 week intervals in summer can help achieve this. Where crops become tall and stemmy mowing is the best way to control the crop in the summer. The high feed quality and yield of forage chicory complements conventional pastures that can have poorer feed quality and low production over summer. A decline in plant density in forage chicory appears to be inevitable under grazing. Frequent hard grazing, especially in late autumn, is particularly detrimental to persistence. Avoidance of winter grazing and not grazing too frequently will prolong the lifespan of the crop, rotational rather than set-stocked grazing is preferred. Given good management, forage chicory can be productive for four to six years under grazing conditions.

Birdsfoot trefoil (*Lotus corniculatus*) is grown extensively in many countries and has several positive attributes; Lotus species are tolerant of acid soils with low fertility, have good drought tolerance and have been shown to have a beneficial impact on lamb growth rates and parasite burdens compared with ryegrass/white clover swards (Marley et al 2006b). Use of Lotus in the UK is negligible however. Work carried out in the UK in the 1970's highlighted that birdsfoot trefoil was slow to establish, had poor over-wintering capability and low subsequent productivity and survival. Since then new varieties have been developed that may be more suitable for UK conditions. Marley et al (2006b) reported on the suitability of new varieties for silage production in the UK. Although differences between varieties for yield and persistency were reported with two European varieties performing relatively well the overall conclusion was that Lotus would still be a poor choice compared with other crops such as red clover.

7 Grazing management systems

A major factor that influences the worm burden of grazing animals is the infection rate, expressed as the number of infective larvae picked up from the pasture each day (Barger, 1999). If daily forage intake by grazing livestock is assumed to be relatively constant then infection rate can be estimated by calculating the number of larvae relative to the herbage dry matter. This may be affected by plant species and the choice of grazing system.

7.1 Set Stocking

In set stocking systems a group of animals is allocated to an area of pasture for a significant part of the growing season at a fixed stocking rate. Some hill grazing systems may approach true continuous set stocking but may not match grass supply to animal needs. In these situations under-grazing can lead to poor grass utilisation allowing coarse grasses to dominate, reducing nutritive value, whilst over-grazing can lead to poaching and under-nourished stock. In intensive situations animals will typically be set stocked for the early part of the season with the overall stocking rate reducing in late season to match lower grass production.

These systems encourage the formation of a dense well tillered sward (20-30,000 tillers per square metre) that resists poaching and weed ingress. Guidelines for sward heights in set-stocked systems are often quoted as 4-6 cm for ewes and lambs and 6-8 cm for cattle early in the season. Sward heights are typically allowed to increase in late season to maintain animal performance with guidelines of 6-8 cm for finishing lambs and 8-10 cm for cattle. Grennan (1999) reported a sward height of around 6cm to be optimum for set-stocking of ewes and lambs until late May with lamb growth reduced at lower sward heights (3-4 cm) and little improvement seen at higher sward heights (8-9 cm). Post-weaning, Grennan (1999) demonstrated the benefits of an increased sward height of 8-9 cm on lamb performance with growth rates low on swards maintained at 5-6 cm reflecting the increased stemminess and lower quality of the sward later in the season. In the same study it was demonstrated that tight grazing in May and June improved pasture quality resulting in higher lamb growth rates post-weaning on the same pasture. The energy value of grass in these situations is high (around 75 D value for ryegrass). Allowing grasses to mature and go to head can reduce grass quality to around 60 D value.

In set stocked systems cattle are likely to be taking the top third to half of the sward and sheep the top 1-2.5cm. As mentioned above, although the majority of parasites are typically found in the lowest parts of the sward, larval density in terms of herbage dry matter may be higher further up the plant. There appears to be little evidence to suggest that a moderate increase in sward height above the optimum for animal performance will reduce larval concentration in the grazed horizon, although if this is accompanied by a lower stocking rate, overall worm egg deposition will be reduced. The overall infectivity of set-stocked swards typically varies over the season with overwintered larvae providing an initial source of infection in late winter/early spring but then falling rapidly over the spring months. From early summer onwards however infectivity climbs rapidly as a result of egg deposition in spring and early summer peaking in mid to late summer. In set stocking systems animals are exposed to infection from L3 larvae that develop during the current grazing period.

7.2 Rotational grazing

In rotational grazing systems the area is divided into a series of fields or paddocks which are grazed in sequence, each use being followed by a rest period. The total length of the grazing and rest period is the grazing or rotation cycle. Experience has shown that in British conditions the grazing cycle should typically be in the order of 20-30 days to ensure high quality grazing. As mentioned above the energy value of grass falls rapidly once ear emergence is reached and the aim should be to start grazing before ear emergence. In rotational systems typical sward heights see sheep grazing from around 10 cm down to 4-6 cm and cattle from 15-20 cm down to 6-8 cm. Grennan (1999) showed beneficial effects on grass quality of grazing to a residual height of 4 cm in rotational grazing for sheep but reduced lamb weaning weights. The same study suggested increasing the residual heights progressively form 4 cm in April to 6 cm in June to achieve high lamb growth rates.

Rotational grazing can take the form of rigid time based systems where animals spend a similar time in each paddock irrespective of defoliation of the sward or be flexible to take account of grass supply. A rigid system is easy to operate and can achieve high performance but care needs to be taken to complete the grazing cycle before ear emergence to avoid excessive growth and pasture deterioration.

Flexible systems allow variation in pasture growth to be taken into consideration. The time spent in individual paddocks can be varied and in some cases areas can be set aside for conservation. It remains important, particularly early in the season, that when grass growth is rapid the grazing cycle remains within the 30 days to ensure grass does not mature and energy levels fall.

Daily paddock grazing provides a number of paddocks (usually 21-30) which stock will occupy for only one day. In strip grazing systems animals are allocated fresh pasture on a daily basis by moving a temporary electric fence, the system can work well in a cycle of rotationally grazed paddocks or to manage early or late grazing. If the area is to be occupied for more than 4-7 days a back fence is recommended to prevent regrowth from being regrazed too soon. A possible advantage of providing a back fence for parasite control is the exclusion of animals from areas where larvae are emerging from faecal pats. Where conditions are favourable development to the L3 stage may take less than a week. The rest period before regrazing is however unlikely to be sufficient to allow L3 larval populations to fall significantly.

A further variation on rotational paddock grazing is forward creep grazing (or leader and follower rotational grazing). In this system young stock are allowed to 'creep' ahead of their dams to get first choice of the grass on offer. They are most commonly used with ewes and lambs to allow the lambs access to leafy herbage. Holmes (1989) suggests that an eight paddock 24 day cycle is preferred. In forward creep systems the ewes are allowed into the creep areas to clean up grass residues but this is not the case in sideways creep grazing. Leader/follower systems may be useful particularly for cattle grazing. Young cattle are grouped by age with the younger group preceding the older group around a group of rotationally grazed paddocks. It is recommended that the total time spent in each paddock is only 4-5 days to prevent sward regrowth being grazed, weakening sward recovery.

7.3 The role of rotational grazing management in worm control programmes

From a parasite control point of view it is important to keep pasture larval population as low as possible. Within a rotational grazing programme the longer the rest period the lower the pasture larval population when animals return but the length of the total rotation may expose animals to infective larvae when they return to regraze. Barger (1999) considered that achieving parasite control through rotational grazing would probably not be achievable in temperate climates because decline in pasture infectivity could take 3 to 9 months.

Rotational grazing can optimise pasture growth and productivity and lead to an increased carrying capacity. The system typically results in cattle consuming almost all the available forage which forces animals to graze close to the ground and close to faecal pats which should increase the chance of ingesting infective larvae (Stromberg and Averbeck, 1999). The results from a number of trials were discussed and it was observed that there did not appear to be any decrease in parasite populations with any of the rotational grazing practices.

Early studies on rotational grazing in cool temperate environments involved grazing periods of 7 days and rest periods of 3-7 weeks (Colvin et all, 2008). These rotations were ideal for the proliferation of parasitic nematodes allowing infection during the first grazing period and timing the next grazing at the peak of L3 availability. Time of development from egg to L3 is therefore important to determine the grazing period.

As discussed above this can be as short as 4-6 days or several weeks depending on temperature. Predicting the appearance of L3 larvae on pasture and their survival are key to establishing an effective rest period for a rotational grazing system.

Colvin et al (2008) investigated the effectiveness of intensive rotational grazing in Australia for a cool temperate environment with summer rainfall. A grazing period of 5 days followed by a rest period of 103 days was found to reduce worm egg counts and was particularly effective in controlling *H. contortus* populations. The short grazing period prevented infection with larvae from the current grazing cycle. It can also be predicted that rotational grazing systems would work particularly effectively in wet tropical climates where although development of the L3 larvae is faster and more successful, their longevity is much shorter (Waller 1997). O'Connor et al (2006) reported on a number of studies that showed survival times of 3-7 weeks on forage for a range of nematode species. The relatively short survival times of the L3 larvae under tropical conditions highlights the potential for rotational grazing strategies to manage nematode populations. Success in lowering worm egg counts in goats and sheep has been reported in systems based on a 3-5 day grazing period followed by a 31 day rest period.

7.4 Alternate and mixed grazing systems

Two grazing management strategies to control internal parasites include alternate or mixed grazing of cattle and sheep. Marley et al (2006) reported that a number of studies had found that sequential grazing with sheep following cattle had significantly reduced parasite infection in the sheep when compared to sheep only systems. Alternate grazing between cattle and sheep can be a very effective form of parasite control for both species (Waller, 1997) with effective control in temperate regions achieved from very infrequent pasture change. Most parasitic worm species are host specific and grazing cattle and sheep in alternate years will help reduce worm challenge although Nematodirus can affect both cattle and sheep. However not all studies have seen a benefit. Moss et al (1998) reported on a three year study in NZ to compare the effect of alternating sheep and cattle grazing and of different pasture species on parasitism of lambs. They found that although cattle reduced pasture larval numbers this failed to reduce parasite burdens in lambs. These results were contrary to findings in another study that saw lower FECs and worm populations in wethers grazed alternately with cattle at 6 monthly intervals. Moss et al (1998) speculated that lambs in the absence of cattle developed increased immunity in response to the greater larval availability. Bairden et al (1995) also reported on a 4 year alternate grazing study carried out in Scotland. The study demonstrated good control of parasites in calves up to the second grazing season but by the end of the study parasite burdens were similar to those on the set-stocked cattle only system.

Where clean grazing is not available infection levels can be reduced by adjusting the stocking densities to reduce larval intake by young susceptible stock. On an all sheep farm this could be achieved by lowering the overall stocking density but on mixed farms the benefits of mixed cattle and sheep grazing can be used to dilute infection (Soil Association, 2000). Mixed grazing of cattle and sheep has been shown to improve livestock productivity of one or both species involved but it has been suggested that this is due to the complementary grazing leading to improved pasture utilisation (e.g. Jordan et al 1988). Barger (1997) reported that grazing cattle and sheep together can improve performance particularly of sheep as a result of better parasite control.

Marley et al (2006c) investigated the effects of grazing upland ryegrass/white clover swards by cattle or sheep, either sequentially or mixed, on the faecal egg count (FEC) and growth rate of weaned lambs. Overall sequential grazing of pastures with cattle and sheep reduced the FEC in lambs regularly treated with anthelmintics when compared with lambs in mixed grazing or sheep only systems. However the highest growth rates were observed in lambs in the mixed cattle/sheep system.

7.5 Comparison of lowland, upland and hill

It has been suggested that lambs grazing extensively on hill land carry a very low worm burden up to weaning as a result of low overall stocking rates. However, although sparsely grazed areas may have very low levels of infective larvae, there will be areas of better grazing where sheep congregate that may be heavily contaminated (Soil Association, 2000). Additionally in upland and hill situations there may be improved pasture or lambing paddocks which have a high stock carrying capacity. Lambing paddocks in particular may pose a high risk due to the peri-parturient egg rise in ewes around lambing. Niezen et al (1996) reporting on work carried out in NZ commented on animal grazing behaviour that results in definite areas where sheep congregate and where faecal deposition and grass growth is greater. The authors suggested that grazing management recommendations for hill land should take this into account by increasing the grazing intervals by susceptible stock.

Niezen et al (1996) commented that there are varying microclimates on hill land depending on slope and aspect and studies have looked at the effect of these on pasture growth. Additionally temperature falls with increasing altitude and can affect the speed of development of worm larvae. Aspect has been found to affect soil moisture, herbage species and herbage growth. In NZ fewer larvae have been found on the south facing aspects of hill pastures than north facing. If this effect is repeated in the UK fewer larvae would be expected on north facing aspects. Additionally pasture grass species tend to differ from lowland pastures with less clover and higher proportions of second quality grasses. In NZ a diet of Yorkshire fog was found to result in lower FECs in lambs than common bent and could be a useful alternative in a hill situation.

Environmental grazing - as mentioned above reducing stocking rate can reduce the worm burden on livestock farms and may also be an important component of agri-environment schemes. In particular low-input grassland managed with low fertiliser and spray inputs will sustain a greater variety of plants and wildlife. Maintaining a heterogeneous sward with a range of heights is particularly beneficial for insects as it allows some plants to flower and provides a more varied habitat. In lower input systems forage quality will tend to decline with an increase in grasses such as Yorkshire fog at the expense of perennial ryegrass. Economic output from these swards can be severely reduced in some situations as a result of both lower yields and grass quality. Liver fluke control may become an important consideration under some environmental regimes with the protection of wetland areas that provide a suitable habitat for the snail host. In these situations it may be possible to keep stock away from the high risk areas but sheep that overwinter on wet land will be extremely susceptible even if overall stocking rates would indicate a low risk for other parasites.

8 Conclusions and recommendations

The larvae of the important nematode species of cattle and sheep have been shown to be very well adapted and can exploit changes in environmental conditions to extend their geographic and seasonal range. Hatching of nematode eggs, development of larvae to the L3 stage and the migration of the L3 larvae to herbage are primarily dependent on temperature and moisture. Differences in larval migration are seen between nematode species, *H. contortus* and *T. colubriformis* have both been observed to migrate rapidly onto herbage once development was complete with negligible numbers remaining in faeces within a few weeks. However *T. circumcincta* larvae have been reported to remain in the faecal pellets and on pasture for up to 10 months providing a long-term reservoir of infection. Similarly *O. ostertagi* larvae remain viable within faecal pats in dry summers and can be released in large numbers once rainfall occurs in the autumn leading to an increased chance of Type II ostertagiasis In young cattle.

Many studies have reported that larval numbers tend to be higher towards the base of the sward. However larval density expressed as number per kg dry matter has been shown to be higher further up the sward structure for many plant species. Larval density in the sward horizons that are grazed by cattle and sheep are important as they determine the overall infectivity of the sward and are affected by plant species. Current sward height targets of 4-6 cm for ewes and lambs and 6-8 cm for cattle in set-stocked systems as recommended for optimum productivity expose stock to infectious larvae but there is little evidence to suggest that increasing sward heights would reduce the risk.

The survival of the L3 larvae is related to temperature, humidity and levels of ultraviolet light. Differences in susceptibility to these factors are found between nematode species and help explain geographic and seasonal differences in distribution. Survival of L3 larvae is enhanced in moister, cooler conditions typically provided by tall and dense swards which can be a characteristic of intensive rotational grazing systems. Rotational grazing is characterised by grazing and rest periods, with longer rest periods resulting in lower larval populations when animals return. However although rotational grazing systems have the potential to work well in the tropics the high survival rates of L3 larvae in temperate climates do not generally offer benefits over set-stocking. Overall grazing cycles of 20-30 days may expose animals to high levels of infective larvae when they return to regraze. Rotational systems do however lead to very high utilisation of high quality forage provided the grazing cycles are managed to prevent grass going to head before being regrazed.

The majority of studies have shown that few L3 larvae migrate further than 30 cm from the faecal pat. Cattle and sheep will generally avoid grazing near faeces but where stocking rates are high and the surrounding sward height is low animals are more likely to graze the heavily infected areas around faecal pats. The potential of non-infective stock to 'clean-up' parasite infected pastures through repeated grazing events was demonstrated in a simulated grazing experiment with L3 falling to less than 3% of the original population after two grazing events.

Alternating cattle and sheep and employing mixed grazing can reduce parasite infection levels and also result in improved pasture utilisation and animal performance.

It should be acknowledged that although sparsely grazed hill pastures may have very low levels of infective larvae overall, there will be areas of better grazing where sheep congregate that may be heavily contaminated. Similarly wetter land may be high risk for liver fluke whilst having low levels of infective nematode larvae.

Work on alternative forages has highlighted the potential of these to contribute to parasite control. Legume forages such as white clover improve animal performance through increased protein intake and improved immunity and can offset the effect of parasite burdens. Larval numbers on red and white clover have also been found to be lower than on ryegrass. Chicory currently shows the most promise of the alternative crops for growing in the UK. It can be grown as a pure stand or incorporated in mixed swards and if managed carefully can persist for 4-6 years. Chicory is reported to have a lower larval population and work on animal performance has found lower faecal egg counts in lambs grazing the crop and improved weight gains.

Gaps in the literature

There appears to be little literature relating directly to the infectivity of the shorter swards associated with set-stocking in sheep, particularly in relation to the distribution of larvae in the grazing horizon.

There is little evidence of practical studies looking at comparison of larval densities on UK pastures across hill, upland and lowland pastures or comparing effects of high vs low stocking rates at differing herbage heights.

The majority of current/recent work is focussed on control of sheep parasites and anthelmintic resistance. Little work has been completed to date on the use of bioactive forages for cattle.

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