Alternative management strategies to prevent and control endo-parasite diseases in sheep and goat farming systems - a review of the recent scientific knowledge

Gerold Rahmann[1] and Hannah Seip[1]

Abstract

Infestation with gastro-intestinal nematodes (GIN) in small ruminants can cause server economic losses and endanger animal welfare. The development of organic farming systems, the increased public awareness for drug residues in agricultural products and the development of resistant strains of parasites have enforced the search for sustainable alternatives.

The aim of this review is to summarise the current scientific knowledge of alternative strategies to prevent and control endo-parasitic diseases in sheep and goat farming systems. Many scientific studies and projects have shown big discrepancies between results obtained under in vitro and in vivo conditions. Often research has been carried out under clinical conditions for extended periods before being moved to on farm trials and it was observed that extensive clinical research on a topic does not necessarily result in the discovery of a practical control option.

Effective pasture management on the other hand proved promising and offers solutions that can be successfully transferred to most farming situations with applied knowledge about host-parasite interactions and interrelations building the base for low pasture infection rates for grazing animals. There are also a number of possible management strategies (e.g. stocking rate reduction and regular intensive monitoring of animal condition) that can also help optimise animal health status. The area of selective breeding has also shown promise as a viable control option. The influence of nutritional status was also investigated in the context of non-chemotherapeutical options for control. It was found that optimised nutrition improves the ability of animals to cope with the adverse effects of worm infestation. Protein nutrition proved to be playing a key role as it is needed for growing processes as well as for immune responses. The investigation of alternative anthelmintic treatments like bioactive forage, phytotherapy, homeopathy and copper-oxide are not discussed in this paper.

Keywords: endo-parasite, small ruminants, organic farming, alternative treatments

1 Federal Agricultural Research Centre (FAL), Institute of Organic Farming, Trenthorst 32, 23847 Westerau/Germany; Email: oel@fal.de

Zusammenfassung

Alternative Managementstrategien zur Vermeidung und Kontrolle von Endoparasiteninfektionen in der Schaf- und Ziegenhaltung - Ein Überblick über den gegenwärtigen Stand des Wissens

Infektionen mit Endoparasiten – insbesondere den Magen-Darm-Strongyliden (MDS) - sind eine der bedeutendsten Probleme in der Schaf- und Ziegenhaltung. Die Ausweitung des Ökologischen Landbaus, die größere öffentliche Aufmerksamkeit für den Tierarzneimitteleinsatz und Resistenzen bei den Parasiten haben dazu geführt, dass weltweit verstärkt nach nicht-medikamentösen Methoden der Vermeidung und Kontrolle von Endoparasiteninfektionen gesucht wurde. Das Ziel dieser Literaturanalyse war es, den gegenwärtigen Stand des Wissens für die Schaf- und Ziegenhaltung darzustellen und zu bewerten. Bei dieser Studie wurden alternative Entwurmungsmittel (Anthelmintika) wie bioaktive Futtermittel, Phytotherapie, Homöopathie und Kupferoxide nicht betrachtet.

Es konnte festgestellt werden, dass es ein beträchtliches Potenzial der medikamentenfreien Vermeidung und Kontrolle von Endoparasiteninfektionen in der Schaf- und Ziegenhaltung gibt. Biologische Methoden, optimiertes Weidemanagement, Zuchtprogramme und eine verbesserte Ernährung - insbesondere die Proteinversorgung - spielen dabei eine zentrale Rolle.

In der Literatur wurden viele widersprüchliche Ergebnisse festgestellt, zum Beispiel zwischen /in vitro/ und /in vivo/ Studien. Erfolgreiche Studien unter klinischen bzw. experimentellen Bedingungen wurden bei – selten durchgeführten – Studien unter Praxisbedingungen meistens nicht bestätigt.

Optimierte Weidemanagementsysteme mit besonderer Beachtung der Parasit-Umwelt-Wirtstier-Wechselwirkungen (Ätiologie) scheinen ein großes Potenzial in der Vermeidung von klinischen Endoparasitosen zu haben. Eine reduzierte Besatzdichte der Weidetiere und eine angepasste Tierbeobachtung und -bewertung (standardisiertes qualifiziertes Monitoring) sind dabei wichtige Instrumente. Eine gezielte Zucht auf Wurmtoleranz (resilience) erscheint ebenfalls möglich, wenn auch die Heretabilität relativ niedrig zu sein scheint. Eine verbesserte Ernährung – besonders in der Proteinversorgung – erlauben dem Tier eine verbesserte Abwehrkraft gegenüber Infektionen.

Schlüsselworte: Kleine Wiederkäuer, Ökologischer Landbau, Alternative Behandlungsmethoden

1 Introduction

Since the development from extensive to intensive agriculture, animal health problems have developed with alarming speed. In areas with intensive sheep and goat farming systems endo-parasites have been become a major threat, which is reflected in the sales figures of many countries (Coles, 2005).

Infections with gastro-intestinal nematodes can have a detrimental effect on animal health (Lüscher et al., 2005), leading to clinical and sub-clinical diseases, that may result in financial loss and overall decreased productivity (Rahmann et al., 2002).

Current large scale sheep and goat production relies heavily on the application of chemical anthelmintics. The compulsory and often excessive use of chemo-therapeutics (Hein and Harrison, 2005), often in combination with poor management practises (Wolstenholme et al., 2004), has resulted in endo-parasite nematodes starting to develop resistance to treatment drugs. At present, resistant strains of endo-parasites can be found all over the world, with some strains being resistant to most active agents.

With the increasing problem of resistance and the development of the organic movement aiming for more sustainable ways of farming, the search for alternatives has become necessary (Thamsborg and Roepstorff, 2003).

This paper is a literature review of current scientific knowledge on alternative management strategies to prevent and control endo-parasitic diseases in sheep and goat farming systems. It will investigate the current level of research, summarise and discuss the experiences and results obtained in the last decade, and recommend suitable alternative control strategies.

Using both primary and secondary literature sources; available books, research reports, workshop proceedings, reviews and internet articles were collected to provide an overview and base for both historical and recent findings.

The principle of this strategy bases on the rule that all species of animal are regulated by other living organisms to prevent the uncontrolled increase of one population. In the context of parasite control it usually means the use of a naturally occurring antagonist to lower a pest population which would otherwise cause losses to animal production. Grønvold et al. (1996) conclude that of all possible antagonistic organisms only nematophagous fungi, earthworms and dung beetles have realistic potential as biological control agents, although there are several species that little or nothing is known about and therefore their potential use for biological control cannot be assessed/estimated.

2 Controlling helminths through effective pasture management

Understanding the influence of pasture management on the internal parasite control possibly starts with detailed epidemiological knowledge of the development of the parasites in and outside their hosts (Table 1). What varies with different climates is the larval development outside the host and therefore no reliable statement can be made for larval availability and survival that applies to all climates. That is why the following points should be considered when attempting to control internal parasites on the pasture.

Larval availability and survival on pasture (Barger, 1999):

- the intake of infective larvae will be proportional to the concentration of infective larvae on herbage
- if larval availability is observed over a longer period of time, peak and troughs will be discovered and once peaks are known, the optimal timing of control measures can be determined
- searching the origin of a peak is necessary for further prevention
- Larval survival is different for each climate and it is essential to know reasonably exact survival times for the estimation of a substantial decline in pasture infectivity

As an example Uriarte et al. (2003) studied the seasonal changes of parasitic nematode burdens in sheep and identified three generations of parasites during the experiment (approx. one year). The first generation derived from larvae inhibited within the animals that continued their development in spring. The next generation resulted from the over-wintering absorbed larvae on the pasture and was the most important source of newly acquired infections in lambs, often leading to clinical symptoms. The last generation that was observed in autumn had little impact on the animals but was identified as the main source of pasture contamination for the following season. This experiment shows the applicability of the above-mentioned points and the importance of epidemiological knowledge for successful grazing management.

In context with grazing management and epidemiological knowledge the two terms ‘safe’ and ‘clean’ pasture are often referred to and it seems advisable to explain them to avoid misunderstandings.

‘Clean’ pasture is the expression for a pasture with a nil or very low infection risk when animals are firstly grazed on it (Younie et al., 2004), this is achieved by a three year rotation between a susceptible species, an unsusceptible species and the use of the land for forage or crops (Thamsborg et al., 2004).

Table 1:

Summary of all helminths parasitizing the gastro-intestinal tract (Behrens, 1987; Kassai, 1999; Rommel et al., 2000; Vlassow et al., 2001; Bostedt und Dedié, 1996; Winkelmann, 2005)

Disease	Genus and species	Common name	Site	Prepatent period	Longevity*	Optimal temp.
Cooperiosis	Cooperia curticei, C. oncophora	Small intestinal worm	Small intestine	15 - 18 days	Several months	20 - 25 °C
Haemonchosis	Haemonchus contorus H. placei , H. similis	Barber's pole/ Twisted stomach/ Wireworm	Abomasum	2 - 4 weeks	Eggs need warm/ moist conditions then they live for some weeks	20 - 25 °C
Ematodirosis	Nematodirus battus N. fillicolis, N. furcatus, N. helvetianus, N. spathinger	Thread-necked worm	Small intestine	N. battus 15 days N. helvet. 20 - 26 days	Eggs survive for one year and longer, they can overwinter, once hatched they live for approx. 3 weeks	20 - 25 °C
Ostertagiosis	Ostertagia ostertagi O./ Teledorsagia circumcincta, O. crimensis, O. leptospicularis, O. pinnata, O. trifucata	Medium brown stomach worm	Abomasum	17 - 28 days	Several months, survives mild winters	20 - 25 °C
Tricho-strongylosis	Trichstrongylus aexi, T. capricola, T. colubriformis, T. rugatus, T. vitrinus	Bankrupted worm	Small intestine	2 - 4 weeks	Several months	20 - 25 °C
Monieziosis/ Tapeworm disease/ Cestodoses	Moniezia benedeni, M. expansa	Tapeworm	Duode-num	30 - 52 days	Survival of the infected interm. host 1,5 - 2 years	Develop. at 28 °C in interm. Host in 4 weeks
Cystic echinococcosis/ Hydatidosis/ Hydatid disease	Echinicoccus cysticus (hydatidosus)	Tapeworm hydatid	Various inner organs	1.5 - 2 years, sometimes less	No data available	
Strongyloidosis	Strongoloides papillosus	Dwarf thread worm	Small intestine, lungs, skin	9 - 14 days	Larvae max. 4 months	> 10 °C 20 °C opt.
Oeso-phagostomosis/ Nodular worm disease	Oesophagostomum columbianum O. venulosum	Nodular worm	Small intestine, colon	45 days approx.	6 months or more	Ca. 25 °C
Chabertiosis	Chabertia ovis	/	Small intestine, colon, rectum	5 - 7 weeks	Larvae 6 - 8 weeks in summer	Ca. 25 °C
Bunostomosis/ Hookworm disease	Bunostomum trigonocephalum	Hook worm	Skin, lungs, small intestine	7 weeks	Eggs 1 - 2 years Larvae 7 weeks in summer	20 - 30 °C
Paramphistomatidosis/ Rumen fluke disease	Paramphistomum cervi, Caulicophoron daubneyi…	Rumen fluke	Duode-num, rumen	14 weeks approx.	Up to 6 months in temperatures < 10 °C	Develop. at 16 - 17 °C in interm. host in 110 days

* Longevity can vary greatly depending on climatic conditions, particularly temperature and humidity

'Safe' pastures are referred to those that are minimally contaminated. It takes approximately 3 to 9 months for pasture infectivity to decrease significantly for most species, depending on the climate and time of the year (Barger et al., 1999), an exception are certainly Nematodirus ssp. whose eggs are able to survive on pasture for more than a year (Younie et al., 2004).

In Northern European conditions a pasture can be considered safe if it meets the following criteria (Thamsborg et al., 2004):

<u>Spring:</u>

1. Pastures that have not been grazed by small ruminants in the last grazing season
2. Pastures that have not been grazed by small ruminants since midsummer of the previous year are safe all nematode species except for Nematodirus ssp.

<u>Summer and Autumn:</u>

1. Pastures last grazed in autumn of the previous year that have not been grazed in spring the following year
2. Pastures that have not been grazed for 3 months during summer are safe except for Nematodirus ssp.

In this context it is not only necessary to know about the time frames for safe pastures to keep pasture contamination at a low level, it is as important to know for which period of time animals can remain on the pasture until the next generation of infective larvae has developed, which is shown in Table 2.

Table 2:
Guideline for contamination of safe pasture in temperate climates (Thamsborg et al., 2004; Eysker et al., 2005)

	Spring	**Summer/Autumn**
Infected animals	Up to 6 weeks	2 – 3 weeks
Uninfected animals	Approx. 8 – 12 weeks (Mid June)	At least 6 weeks

3 Earthworms

Earthworms are soil inhabitants that live on organic matter deposited on the soil surface. Organic matter gets pulled down below the surface either for food or to plug the earthworms burrows. Therefore the major contribution of earthworms towards the biological control of nematodes is seen in the destruction of eggs and larvae by digesting them or transferring them to deeper levels of the soil where chances that they can reach the surface as infective larvae are very low (Persson, 1974). A New Zealand study examined the ability of mixed earthworm populations, alone or in combination with other biological control organisms to reduce pasture infectivity in two experiments (spring and autumn) (Waghorn et al., 2002). "Earthworms reduced the total number of larvae recovered in both trials and the number recovered from herbage in trial 1."

4 Dung Beetles

The term 'dung beetle' refers to those beetles that live partly or exclusively on the dung of herbivores. Most species belong to the family *Scarabaeidae*. Adult beetles use the liquid contents of manure for their nourishment and some species form dung balls which they bury and lay their eggs in, others just live in the manure pats (Thomas, 2001). The activity of dung beetles is being discussed controversially: by breaking up the pats and partially burying the manure, they enhance the drying up of the dung which deteriorates growing conditions for larvae (Grønvold et al., 1996) but by the same activities in bad weather conditions they might help the larvae to survive by airing out the pats and thereby providing oxygen to the larvae.

Bryan (1973 and 1976) was able to show in his experiments that dung beetles can reduce larvae on herbage in between 40 to 93%, the percentage of reduction correlated positively with the number of beetles. Bryan also found out that the burial of dung containing larvae contributed to their longevity and he concluded that the burial can create a favourable environment for larval development because they are protected from extreme climatic conditions. Waghorn et al. (2002) also confirmed the influence of dung burial in respect to larval development with the result of significantly more larval recoveries than when dung was not buried, although dung was manually buried in order to mimic the natural activities of the dung beetle. Vlassoff et al. (2001) also mention that results of studies with dung beetles have been variable, some species reduce and others increase larval numbers (Fincher, 1973).

5 Nematophagous fungi

In this special case, it means the use of the naturally occurring nematophagous or nematode-destroying fungi to control parasitic nematodes in ruminants. Nematophagous fungi are soil inhabitants and can be found in most soil types throughout the world. Research has shown they are found more frequently in organic production systems than any other (Jansson and Lopez-Llorca, 2004).

The fungi can be divided into groups depending on their mode of affecting nematodes: there are nematode trapping, parasitic fungi and toxin producing fungi (Jansson et al., 1997). The fungi of the nematode trapping group all have in common that they form a vegetative hyphal system that produces trapping organs such as sticky nets, knobs or rings (Hertzberg et al., 2002). When for example a nematode gets trapped, the fungi penetrate the nematode cuticle with their hyphae that then grow out and fill the body of the nematode to finally digest it.

The idea of using nematophagous fungi to control parasitic nematodes is based on the reduction of the larval level in the faeces before larvae reach the vegetation, which requires a high density of spores in the faeces. There are two possible ways to reach that high spore density, the first is to artificially inoculate the faeces and the second way is to administer the spores orally. Since the first way seems not viable the only possibility was to discover those fungi that are able to survive the gastro-intestinal tract of ruminants. This complex problem may have been one reason for the rather slow progress of science concerning this topic.

Research had started as early as in the 1940's but with little success at the time. In the 1960's there was evidence found for predaceous fungi working against parasitic nematodes (Parnell and Gordon, 1963), but these experiments were not continued. The major breakthrough was achieved at the beginning of the 1990's when Larsen et al. (1991) selected fungi that were able to survive in vitro conditions simulating the passage through the gastro-intestinal tract of cattle. The two genera tested, *Arthrobotrys* and *Duddingtonia*, both showed the ability for survival with the genus *Duddingtonia* performing significantly better, 87.5% versus 46% (Larsen et al., 1991). These results were the final trigger for detailed research in this area and since then many trials have been undertaken in several countries in which faecal samples of sheep have been screened for predacious fungi (Larsen et al, 1994; Hay et al., 1997; Ghahfarokhi et al., 2004). Even after the promising results of the feeding trials with *Duddingtonia flagrans* (Wolstrup et al., 1994; Githigia et al., 1997; Faedo et al., 1998) science continued to research a wider range of fungi until the end of the 1990's when trials with fungi other than *Duddingtonia flagrans* started to decrease.

From the year 2000 onwards most scientists started to focus on the potential of *D. flagrans*. One of the first questions that occurred in that context was whether or not *D. flagrans* had the ability to grow beyond faeces into the surrounding soil and by doing so it could control emerging third stage larvae from eggs deposited prior or post deposition of fungal spores (Faedo et al., 2000). The results confirmed that *D. flagrans* significantly reduces the number of infective larvae that migrate onto the pasture and it also showed that there was no effect on larval migration of prior and post deposited faeces. In the first years, most of in vivo trials focused on the potential of larval reduction by the fungus and either there was only little knowledge about the amount of chlamydospors necessary for a successful reduction nor was it clear if the larvae of different species would be affected in the same way.

5.1 Sheep

Githigia et al. (1997) were the first to assess the preventative effects of *D. flagrans* under field conditions in lambs and their results were the first to show varying possibilities and potential limitations with the use of *D. flagrans* under field conditions. The results showed that sub-clinically infected lambs grazed on contaminated pasture, fungus feeding does not eliminate the risk of severe infection and can consequently only be applied on uninfected animals and clean pastures.

Within the framework of the EU-project called 'Worm control in organic production systems for small ruminants (WORMCOPS) a series of field trials have been conducted in Northern Europe to assess the performance of *D. flagrans* in two different management systems (animals either set-stocked or moved regularly) (Thamsborg et al., 2004). The experiments in Denmark and in the UK observed the applicability of *D. falgrans* in set-stocked farming systems in the time from 2002 to 2004 and both trials had rather disillusioning results:

- At times there was a lack of any beneficial effects
- Unreliability in the control of Nematodirus ssp.
- Animals needed either de-worming or moving to clean pastures to survive the trials
- Administered supplement was only slowly accepted
- No or insignificantly reduced pasture infectivity

The evaluation of *D. flagrans* on the two farms in Sweden from 2001 to 2003 was the only set of trials that had an overall positive result: All ewes were de-wormed before turnout in these experiments and went to naturally infected paddocks receiving supplement with or without fungus. Faecal egg counts and worm burdens were comparatively low throughout the evaluated time, indicating that the farms had had reasonably good helminths control strategies anyway (Waller et al., 2004).

Contrary to these results were the results from studies conducted in the Netherlands in 2002 and 2003: Although the sheep were moved at 3 week intervals no useful effects could be observed (Thamsborg et al., 2005). At the same time there was another field trial undertaken in Northern Germany that was independent from WORMCOPS. The trial investigated the influence of *D. flagrans* on the infection risk for sheep and goats under set-stocked conditions (Holst, 2005). In this trial infected and uninfected sheep were moved to contaminated pastures. Throughout the whole time there were no significant differences in faecal egg counts or pasture infectivity between control and fungus receiving sheep. Another field trial that was undertaken in Malaysia showed very good results for *D. flagrans* in combination with rapid rotationally grazing (Chandrawathani et al., 2004).

5.2 Goats

Several studies have dealt with the possibilities of the administration of *D. flagrans* spores to goats; however these have consisted of a limited number of field trials. As with studies concerning sheep there seems to be the same discrepancy between conclusions based on short-term trials under in vitro and in vivo experimental conditions (Paraud and Chartier, 2003; Paraud et al., 2003; Waghorn et al., 2003; Terill et al., 2004; Paraud et al., 2006) and the applicability under field conditions (Holst, 2005; Chartier and Paraud, 2005).

All the studies that were conducted under experimental conditions show positive results, where the reduction of larval development ranged from 40.4% to 89% (Wagehorn et al., 2003), 60.8% to 93.6% (Terill et al., 2004), 62.8% to 99.5% (Paraud et al., 2006). In contrast to these results Holst (2005) observed no significant larval reduction due to *D. flagrans* under field conditions.

6 Climatic conditions

The particular climate of an area always influences the grazing management because egg hatching and larval development both depend on prevailing climatic conditions. Larval survival times can range from some weeks in the wet tropics (Banks et al., 1990) to more than a year in temperate climates (Barger, 1987). For this reason there is no universally applicable grazing system that regulates pasture infectivity in every climate.

For example a grazing system that has proved to be reliable for parasite control in the tropics is referred to as “rotational grazing” (Barger, 1999). This system is based on rapid pasture movement (every 3-4 days) to provide safe pasture, followed by longer periods of spelling (30+ days) based on the duration of the parasite cycle (infective larvae develop and die within 4-6 weeks in the tropics) (Chandrawhathani et al., 2004).

Rotational grazing has already proved its efficiency in the tropics (Chandrawathani et al., 2004) but it cannot be applied to temperate climates for several reasons, one of which is the long amount of time for pasture to become safe again (Barger, 1999). In Table 2 the guidelines for contamination of safe pasture in temperate climates are shown and can be used to develop moving strategies.

The Mediterranean climate comprises various sub climates that lead to a great diversity in this area and to two basic differences in management strategies (Thamsborg et al., 2004). The main difference is whether there is a break in the middle of the grazing season (dry lands/ transhumance) or not (irrigated land).

7 Grazing system and herd management in respect to control strategies

There are basically two different types of grazing systems and three different types of management. Grazing systems differ in the stock movement frequency; this can vary from no movement at all to frequent changes between pastures. In the case of no movement animals remain on the same pasture for the whole grazing season (set-stocked). Both grazing systems have advantages and disadvantages but in terms of parasite control it is easy to imagine that sub-clinically infected animals that stay within the same area for a complete season keep contaminating the pasture continuously and by doing that they constantly increase the infection risk for uninfected animals.

In terms of different management strategies there are organic, integrated and conventional ways of managing a farm, which principles are assumed to be known and therefore won’t be discussed in detail.

An interesting fact in this context that appears to be worth mentioning is the influence of the management strategy on parasite diversity. A French study that conducted investigations into the impact of management strategy on the parasite diversity found that organic farms have a significant higher diversity of parasites on pastures and in infected animals (Cabaret et al., 2002a). A further study that researched the relationship between diversity and intensity of infection in dairy goats detected that intensity of infection was negatively correlated with helminths diversity (Silvestre et al., 2000).

The main function of any grazing system is to provide safe/clean pastures on which animals can safely graze as well as sufficient forage availability for grazing animals (Barger, 1999). In order to control gastro-intestinal nematodes through grazing management three strategies can be categorized as measures to minimize new and re-infection. The three categories are ‘preventive strategies’, ‘evasive strategies’ and ‘diluting strategies’ and they are summarized in Table 3.

Studies in France and in Denmark (Bouilhol and Mage, 2001; Githigia et al., 2001) highlighted in their results how important a well thought-out grazing system is. The French survey analysed different management concepts for organic meat sheep farms and found that concepts were varying in (1) time of lambing and (2) management for weaners (moved to either infected or uninfected pastures). The first important outcome of this survey was that early lambing appears to be the key for sufficient weight gain because it

Table 3:
Overview of different grazing management strategies (Barger, 1997; Cabaret et al., 2002b, Thamsborg et al., 1999; Younie et al., 2004)

Preventive Strategies	**Evasive Strategies**	**Diluting Strategies**
Turning out parasite free animals on clean pastures	*Worm challenge is evaded by moving animals from contaminated to clean pasture*	*Worm challenge is relieved by diluting pasture infectivity*
⇨ *Delayed turnout*		
⇨ Changing pastures between seasons	⇨ *Moving to safe pastures within the same season*	⇨ *Avoid stocking rates close to carrying capacity of plant production*
⇨ Moving at weaning		
⇨ Late lambing	⇨ Alternate grazing of different species	⇨ *Reduction of the general stocking rate*
⇨ Grass reseeds	⇨ Hay/silage aftermaths	⇨ Mixed grazing with other host species
⇨ Cultivation of annual forge crops	⇨ New grass reseeds	⇨ Alternate grazing with other host species
⇨ Silage/ hay aftermaths	⇨ Cultivation of annual forage crops	⇨ Mixed grazing with other age groups
⇨ Alternation of different host species		

uses the seasonal plant growth to full capacity (Bouilhol and Mage, 2001). Their other finding confirms that moving weaners to safe pastures is a successful measure for parasite control.

In the Danish experiment the ‘dose and move’ strategy was compared to a ‘move only’ strategy (from an infected to a clean pasture) for lambs at weaning time. As a result acute parasitic gastroenteritis could be prevented and weight gains were comparable for all groups, although pasture contamination was higher on the pastures that had been grazed by the ‘move only’ group (Githigia et al., 2001).

8 Stocking rate and animal behaviour

The base for successful parasite control in small ruminants is to keep the pasture infection level low so that the animals are not exposed to an excessive larval population on the pasture. A further fact that may be considered in this context is the possible correlation between actual migration height of infective larvae and stocking rate. Research results appear dissonant and controversial in this particular question. While one source states that the majority of larvae usually “crawl only one inch from the ground onto herbage, so not allowing animals to graze below that point will cut down a lot of infestation” (Wells, 1999). Another source writes that about 80% of the infective larvae can be found on the first two inches of vegetation, so avoiding grazing to below this level will reduce problems (Schoenian, 2005). On the other hand Thamsborg et al. (1996) argue that a reduced plant cover can as well create condition less favourable for larval development and that faecal deposits on short grass result in significantly reduced infective larvae on the surrounding pasture (Secher et al., 1992)

Although the correlation between stocking rate and parasite infestation is mentioned, only two studies could be found in the run-up of the literature inquiry.

Thamsborg et al. (1996) investigated the influence of an increasing stocking rate on nematode infection rate in sheep in an experiment. Their results demonstrated that the stocking rate has a rather long term effect than short term consequences because only little differences were observed in the first year whereas higher levels of infection, related to an increased stocking rate, were confirmed for the second year of the experiment.

A more recent study investigated the relationship between nematode infections and general farming aspects and characteristics on 20 French dairy goat farms (Vallade et al., 2000). In this survey those farms that needed the fewest annual anthelmintic treatments either fed supplements or had a reduced stocking rate. While Vallade et al. see a clear connection, Thamsborg et al. (1996) assume that the relationship between stocking rate and infection level is neither strong nor consistent but is very complex.

This complex relationship could originate from the fact that larval intake is not simply determined by pasture contamination but by a living organism which has a foraging strategy that might protect itself from the excessive intake of parasites “Ruminants are known to avoid grazing herbage which is contaminated with faeces” (Hutchings et al., 1998). Cooper et al. (2000) concluded in their experiments that sheep generally prefer grazing uncontaminated patches of pasture and that the presence of faeces enables sheep to detect and avoid contaminated patches. Further on in the experiment sheep generally appeared to consume fewer larvae than were present on herbage and infected sheep consumed more larvae than uninfected ones. The authors conclude that “parasite infection status and faecal distribution influence grazing behaviour and rate of infective larvae consumption”.

A study that was conducted in context with nutrition found that grazing behaviour changes with parasite infection, suggesting that sheep are able to detect metabolic signals caused by parasitism, and according to these signals start selecting plants with higher nutritional values (Cosgrove and Niezen, 2000).

Engel (2002) approached this subject by exploring behaviours of wild animals and how they manage internal parasites. It was shown that most animals have a very good understanding of what is wrong with them and often know and use the appropriate medical plants. To some extent this instinctive knowledge is still present in domesticated animals; research with goats and tanniferous plants has shown that if goats are given a choice they will select diets with moderate tannin levels.

The above discussed studies once more document how complex the relation between grazing animals and internal parasites is. It appears logical that keeping animals at the upper limit of pasture productivity interferes with the inherent necessity of ruminants to graze further away from faeces and therefore a decreased stocking rate may help to control nematodes in sheep and goats.

9 Monitoring and intervention

The principle of Monitoring and Intervention builds part of the base for organic farming, particularly because, as shown in chapter two, the preventive use of any conventional treatment is prohibited. Therefore regular intensive monitoring is inevitable to guarantee animal welfare (Thamsborg et al., 2004) and protect animals against unnecessary suffering.

Because any preventive use of anthelmintics is outside the organic standards, the treatment method applied at the moment is the strategic usage of anthelmintics, where only individuals are treated (Waller, 2005). However, before any therapy can be administered it has to be established which animals are physically affected by parasitic nematodes.

There are three commonly applied methods to determine worm infestation with different explanatory powers:

(1) scoring general body condition
(2) determine faecal egg count (FEC)
(3) scoring for deviate physical conditions

The body condition should be monitored not only for signs of nematode infestation but also other negative influences. Early practice in Australia showed good results for worm control treating only a small percentage of the flock (10-20%), those animals with the highest FEC and those with the lowest weight gain. Nevertheless, treating animals with low weight gain seems risky as weight loss or limited weight gain can be due to several other conditions not necessarily due to parasitic nematodes (Waller, 2005).

The determination of faecal egg counts appears very useful in obtaining a clear picture of worm infestation within single animals as well as within a mob (mob counts) (Thamsborg et al., 2004). When the FEC reaches a specified limit (e.g. over 400 eggs/gram (EPG) in lambs) it indicates the need for treatment (Younie et al., 2004). However, recommendation in New Zealand (http://www.ceresfarm.co.nz/internalparasites.htm) estimates trigger levels to be the following: below 500 EPG is low, in between 600 and 2000 EPG stands for moderate infestation and above 2000 EPG is critical. Consequently body condition scoring as well as faecal egg count determination allows treatment to be carried out on selected animals and therefore minimize the risk of the buildup of anthelmintic resistance within the flock.

An approach that is quite similar to the above-mentioned faecal screening, is the use of the FAMACHA© chart to determine the degree of haemonchosis in sheep and goats (Koopmann and Epe, 2006). This chart gives farmers the possibility to assess the clinical condition by the colour of the eye mucosa (score 1 - 5) and drench only those animals that have a score above 3 (Bath et a., 2001). If animals become heavily infected and there is a requirement for chemical intervention, there are some points that need to be considered before the administration of any conventional de-wormer (Humann-Ziehank and Ganter, 2005):

- never treat the whole flock, only treat infected animals
- always confirm infestation by laboratory examination of a faecal sample
- check for resistance before deciding on a particular remedy
- administer treatment on empty stomach to increase efficiency
- avoid inappropriate dosing
- do not move immediately animals after drenching, wait for 1 - 2 days
- check success 7 - 10 days after drenching by laboratory FEC

10 Improvement of animal resistance through selective breeding

A further possibility of controlling parasitic nematodes in sheep and goats lies within the breeding management. The idea is to use only those animals for breeding that shows either an inherently occurring resistance or resilience to nematode challenges (Bishop et al., 1996). This idea has, as other alternative strategies, come into the fore since the extent of the spreading anthelmintic resistance of parasites has become more and more obvious.

Research that has been done in the last decades could successfully show “that it is possible to exploit genetic variation in resistance to nematode parasites of sheep by selection” (Gray, 1997). The selection for resistant animals is possible within different animals as well as within different breeds of sheep and goats (SAC, 2000). Various studies have been done on this issue, some focused on the varying degrees of resistance amongst differing breeds (Baker and Gray, 2004; Amarante et al., 2004), and others focused on the occurrence of resistance and its heritability within one breed (Bisset et al., 1996; Bouix et al., 1998; Gauly and Erhardt, 2001).

The outcome of these studies confirmed that within and amongst populations of animals that are challenged by internal parasites there are always animals that perform better than others, they are either resistant, resilient or tolerant (explanation see glossary) (Bishop and Stear, 2003). Breeding in recent years has concentrated on resistance last but not least because resilience is far less heritable then resistance (Eady et al., 2006). Tolerance on the other hand is not a desirable trait at all because tolerant perform well indeed but contribute to pasture contamination (Meat New Zealand, 1999).

10.1 Possibilities for estimating breeding value

The starting point of science was to explore the ways of nematode transmission and how transmission could be restricted by modifying animals (Bishop and Stear, 2003). This led to the question of how resistance in animals could be measured to determine the criteria for which animals were being selected.

All studies that have been reviewed for this paper estimated breeding value on the base of faecal egg counts, however there are other methods which can also be used like the use of genetic markers and blood immunity response tests (Gray, 1997). In this context dag scores (DS) and faecal consistency scores have been looked into as possible indirect indicator traits for resistance but correlation between FEC and these traits has not been explored in full detail and results remain contradicting (Pollott et al., 2004)

In recent years most selection has been done on the basis of faecal egg counts (Bishop and Stear, 2003) but there is an additional blood screening test that has been developed to assist selection that is called the ‘Host Resistance Test’ (HRT) (AGresearch, 2004). This test measures the host antibody level and makes it thereby possible to select for animals with relatively high levels (AgVax, 2006).

In New Zealand, one of the leading countries in selective breeding, a selection index has been developed to give farmers the chance to select for resistance as well as production traits (Meat New Zealand, 1999). Those farmers that have been using this index for over ten years show a significant reduction in FEC, improved wool production and higher growth rates in ewes and lambs on their farms (SAC, Stapledon Report, 2000).

10.2 Relation of resistance to other traits

Sheep and goats have been bred for many centuries in differing and sometimes contrasting environments for various reasons, parasite resistance normally not being in the foreground. Today there is a variety of breeds - from milk to meat to dual purpose breeds either high-performing or extensive, a wide range of sheep and goats has been bred. Since the beginning of breeding towards enhanced animal resistance its relation to other performance traits (like e.g. fleece weight, body weight, fibre diameter, milk production) has been discussed and studied (Bishop and Stear, 2003). The results of the existing sources are contradicting and range from no marked genetic relationship between FEC and production traits (Eady et al., 2006), to small unfavorable genetic relationship between fleece weight and FEC (Meat New Zealand, 1999), to a significant negative correlation between FEC and daily weight gain (Gauly and Erhardt, 2001). The complex correlation of these different traits can possibly be cleared by taking a look at the underlying physiological processes (Bishop and Stear, 2003).

Animals that get challenged by nematode parasites need a surplus of energy either for an immune response or to maintain performance (e.g. growth, pregnancy, and lactation), therefore resistance and performance competes for resources, particularly for protein. These findings are confirmed by a study of Kahn et al. (2003) in which is shown that supplementation of ewes during the peri-parturient period enhances their ability to resist infection and consequently reduces faecal egg output overall in those animals previously selected for nematode resistance. The study also confirmed lower fleece weights and wool growth rates for resistant ewes and lower birth-weights for their lambs. This once more shows the physiological problem of pregnant and lactating ewes and does. Under normal conditions nematode infection would have little impact on the animal, however during pregnancy or lactation, body resources have to be divided and in more resistant animals the division turns out to be in favour of immunity (Bishop and Stear, 2003). A similar process applies for wool growth, in which case the two traits are competing for scarce sulphur containing amino acids.

So all in all these studies show that the relation in between resistance and performance traits “are a balance of the costs of being resistant versus the beneficial consequences of being resistant” (Bishop and Stears, 2003).

11 Enhancing host resilience and resistance through nutrition

The following section will concentrate on the interrelation between the nutritional status and parasite infestation in sheep and goats. This issue has been, more or less, intensively researched for about a decade now and still holds a few open questions.

The fact that the gastro-intestinal tract builds the base for a lot of physiological processes, and that it is at the same time, the central location for all those parasites this paper focuses on, makes this section particularly interesting.

The whole subject can be considered from two different points of view, the first how parasites affect the physiological processes of their hosts, and the second, how the nutritional status of the hosts can be influenced in order to enhance their resilience and resistance (Coop and Holmes, 1996).

In general it can be claimed that well nourished animals cope better and overcome infection with parasitic nematodes quicker then malnourished ones (Wells, 1999). The groups that are most susceptible to parasitism are young lambs and kids (when immunity has not been established yet) and their mothers (because of the peri-parturient drop of their immune system) (Waller and Thamsborg, 2004). Protein availability in particular (Van Houtert et al., 1995a and 1995b, Valderrábano et al., 2002) and balanced mineral supply (Sykes and Coop, 2001) seem to play key-roles in the protection from nematode infections.

As already discussed in the last section do Coop and Holmes (1996) as well as Bishop and Stears (2003) support the thesis that an animal has only a certain amount of nutritional resources (particularly protein) that have to be allocated amongst the different body functions. If the protein supply for example does not cover the necessary requirements, certain functions will be prioritized (usually to the disadvantage of immunity).

In this context the role of dietary protein has been researched intensively. Van Houtert et al. (1995a, 1995b) showed in their studies that the administration of protein supplement reduced production losses, enhanced expulsion, reduced the need for drenching significantly, increased wool production and fibre diameter and reduced faecal egg counts.

More recent studies have carried out investigations into the impact of different forage types on the performance of parasitized sheep. These studies showed a correlation between administered forages and ability to cope with worm infestation. The reviewed feeding trials both showed the positive effects on lambs feed with white clover. Niezen et al. (2002c) discovered that an increased proportion of white clover in the diet of lambs resulted in improved weight gain and overall better performance. These findings are confirmed by Marley et al. (2005) who researched the effects of forage legumes in comparison to ryegrass in lambs, moreover they showed that the consumption of white clover leads to lower FEC and a reduced adult worm burden.

Coop and Holmes (1996) reviewed studies on the influence of nutrition on (1) parasite establishment, (2) established infections and (3) immune responses. In their conclusion protein supplementation appears to have no influence on the initial parasite establishment but on established infection and the immune response which is indicated by a reduced FEC and worm burdens and by enhanced resistance to re-infection.

Valderábano et al. (2002) could not confirm a reduction in faecal egg counts in their study but it was observed that female worm size and fecundity decreased significantly with the level of nutrition. A further review comments on what other studies have demonstrated “that protein supplementation of ewes around lambing may limit the peri-parturient rise in faecal egg counts depending on protein level during pregnancy” (Thamsborg, 2001a).

Kahn et al. (2003) showed in their study that supplementation did not affect faecal egg output in the phase prior to birth but it reduced FEC by more than 50% postpartum.

The latest study that was reviewed for this paper assessed the rate of immunity improvement in lactating ewes when the demand for protein was either decreased or fulfilled (Houdijk et al., 2006). This study points out that optimized host protein nutrition could be able to reduce the establishment of parasites around the peri-parturient loss of immunity. Further more the experiment showed that the decrease in protein demand is able to induce the regain of immunity in ewes within short periods of time. The authors conclude that if the decrease in demand is able to lead to such a dramatic improvement of immunity, the optimization of nutrition might result in an equally quick improvement.

12 Conclusions

Parasitic nematodes remain a major threat to the health and welfare of small ruminants all over the world and the demand for alternative control measures has constantly increased during the last years. Infestation with endo-parasites can have severe consequences for the animal as well as for the livestock farmers leading to economic loss and restricted productivity (Holst, 2005).

In the last decades parasites have been controlled with the preventive use of anthelmintics which has resulted in parasitic drug resistance. Although resistance in parasites is spreading, commercial farming continues to rely on the preventive use of anthelmintics.

The aim of this paper was to investigate the level of research in alternative strategies for control and prevention of endo-parasitic diseases in sheep and goat farming systems, and discuss the obtained results with regard to overall viability in organic agriculture. The emphasis was put on alternative strategies for prevention because this measure aligns more with the overall principles of organic agriculture, which is to maintain health rather than curing disease.

Reviewed were the following options: biological control, pasture management, selective breeding and optimised nutrition. Although a lot of research has been done on biological control options the outcome of this area of investigation proved rather disillusioning. The use of fungus spores to control infective larvae on the pasture cannot be recommended because of the high variance between results obtained under experimental conditions and those obtained in field trials.

Effective pasture management on the other hand proved promising and offers solutions that can be successfully transferred to most farming situations with applied knowledge about host-parasite interactions and interrelations building the base for low pasture infection rates for grazing animals. There are also a number of possible management strategies (e.g. stocking rate reduction and regular intensive monitoring of animal condition) that can also help optimise animal health status.

The area of selective breeding has also shown promise as a viable control option. It is currently being practised in New Zealand and Australia with good results. Animals with strong resistance to infection are being selected for future breeding lines and as a result flocks of animals with higher resistance are being produced. As yet limited research or results have been obtained under European production conditions but this is an area which warrants future investigation.

The influence of nutritional status was also investigated in the context of non-chemotherapeutical options for control. It was found that optimised nutrition improves the ability of animals to cope with the adverse effects of worm infestation. Protein nutrition proved to be playing a key role as it is needed for growing processes as well as for immune responses. Two measures can be recommended from the findings of this report. First of all farmers should ensure sufficient food supply for their stocks at all times to avoid nutritional stress. Secondly animals that are particularly susceptible can be helped by placing them on protein-rich diets.

Many scientific studies and projects have been reviewed for this paper and these have often shown big discrepancies between results obtained under in vitro and in vivo conditions. Often research is carried out under clinical conditions for extended periods before being moved to on farm trials and it was observed that extensive clinical research on a topic does not necessarily result in the discovery of a practical control option. While the difficultly of field trials is acknowledged (difficulty controlling parameters, etc.), it is important for them to be undertaken as early as possible to prove the viability of further research.

In conclusion the most viable control strategies proved to be development of sustainable farming systems and adoption of effective management strategies.

References

Aerts RJ, Barry TN, McNabb WC (1999) Polyphenols and agriculture : beneficial effects of proanthocyanidins in forages. Agric Ecosyst Environ 75(1)1-12

AgResearch (2004) Selection of sheep for resilience to nematodes [online].Zu finden in <www.maf.govt.nz/sff>

AgVax (2006) Host resistence rest [online]. Zu finden in <http://www.agvax.com/animal_health/sheep/host_resistance_test.html>

Amarante AFT, Bricarello PA, Rocha RA, Gennari SM (2004). Resistance of Santa Ines, Suffolk and Ile de France sheep to naturally acquired gastrointestinal nematode infections. Vet Parasitol 120:91–106

Baker RL, Gray GD (2004) Appropriate breeds and breeding schemes for sheep and goats in the tropics [online]. Zu finden in www.aciar.gov.au/web.nsf/att/JFRN-6BN9EA/$file/worm_control_b.pdf [Zitiert am 04.04.2007]

Banks DJD, Singh R, Barger IA, Pratap B, Le Jambre LF (1990) Development and survival of infective larvae of Haemonchus contortus and Trichstrongylus colubriformis in a tropical environment. Int J Parasitol 20: 155-160

Barger IA (1997) Control by management. Vet Parasitol 72:493-506

Barger IA (1999) The role of epidemiological knowledge and grazing management for helminth control in small ruminants. Int J Parasitol 29:41-47

Bath GF, Hansen JW, Krecek RC, van Wyk JA, Vatta AF (2001) Sustainable approaches for managing haemonchosis in sheep and goats : final report of Food and Agriculture Organization (FAO)Technical Co-operation Project No. TCP/SAF/8821(A)

Behrens H (1987) Lehrbuch der Schafkrankheiten. Berlin : Parey, 297 p

Bishop SC, Bairden K, McKellar QA, Stear MJ (1996) Genetic parameters for faecal egg count following mixed, natural predominantly Ostertagia circumcincta infection and relationships with live weight in young lambs. Anim Sci 63:423-428

Bishop SC, Stear MJ (2003) Modelling of host genetics and resistance to infectious diseases : understanding and controlling nematode infections. Vet Parasitol 115:147–166

Bisset SA, Vlassoff A, Douch PG, Jonas WE, West CJ, Green RS (1996) Nematode burdens and immunological responses following natural challenge in Romney lambs selectively bred for high and low faecal worm egg count. Vet Parasitol 61:249-263

Bostedt H, Dedié K (1996) Schaf- und Ziegenkrankheiten. Stuttgart : Ulmer, 617 p

Bouilhol M, Mage C (2001) Parasitism in organic sheep farming. In: Hovi M, Vaarst M (ed) Positive health - preventive measures and alternative strategies : proceedings of the 5th NAHWOA Workshop in Roddinge, Denmark, November 11-13, 2001, pp 79-91

Bouix J, Krupinski J, Rzepecki R, Nowosad B, Skrzyzala I, Roborzynski M, Fudalewicz-Niemczyk W, Skalska M, Malczewski A, Gruner L (1998) Genetic resistance to gastrointestinal nematode parasites in Polish long-wool sheep. Int J Parasitol 28:1797-1804

Bryan RP (1973) The effects of dung beetle activity on the numbers of parasitic gastrointestinal helminth larvae recovered from pasture samples. Aust J Agric Res 24:161-168

Bryan RP (1976) The effect of the dung beetle, Onthophagus gazella, on the ecology of the infective larvae of gastrointestinal nematodes of cattle. Aust J Agric Res 27:567-574

Cabaret J, Mage C, Bouilhol M (2002a) Helminth intensity and diversity in organic meat sheep farms in centre of France. Vet Parasitol 105:33–47

Chandrawathani P, Jamnah O, Waller PJ, Larsen M, Gillespie A, Zahari WM (2003) Biological control of nematode parasites of small ruminants in Malaysia using the nematophagous fungus Duddingtonia flagrans. Vet Parasitol 117:173-183

Chandrawathani P, Jamnah O, Waller PJ, Larsen M, Gillespie AT (2004) Field studies on the biological control of nematode parasites of sheep in the tropics, using the microfungus Duddingtonia flagrans. Vet Parasitol 120:177-187

Chartier C, Paraud C (2005) Biological control of nematodes in goats with Duddingtonia flagrans, from laboratory to field trials: promising results yet to be confirmed. In: Thamsborg SM, Larsen M, Busch M (2004) Sustainable, non-chemical control of small ruminant nematode parasites in Europe : proceedings from an International Workshop held at Danish Centre of Experimental Parasitology Royal Veterinary and Agricultural University, Frederiksberg, Denmark, 20-21 October 2004

Coles GC (2005) Anthelmintic resistance - looking to the future : a UK perspective. Res Vet Sci 78: 99-108

Coop RL, Holmes PH (1996) Nutrition and parasite interaction. Int J Parasitol 26:951–962

Coop RL, Kyriazakis I (2001) Influence of host nutrition on the development and consequences of nematode parasitism in ruminants. Trends Parasitol 17:325-330

Cooper J, Gordon IJ, Pike AW (2000) Strategies for the avoidance of faeces by grazing sheep. App Anim Behav Sci 69:15–33

Cosgrove GP, Niezen JH (2000) Intake and selection for white clover by grazing lambs in response to gastrointestinal parasitism. App Anim Behav Sci 66:71–85

Dawson JM, Buttery PJ, Jenkins D, Wood CD, Gill M (1999) Effects of dietary quebracho tannin on nutrient utilisation and tissue metabolism in sheep and rats. J Sci Food Agric 79:1423-1430

Eady SJ, Doyle E, Bell A (last updated 2006) Breeding for worm resistance - a component of sustainable worm control [online]. Zu finden in www.csiro.au/files/files/p66p.pdf [Zitiert am 04.04.2007]

Engel C (2003) Wild health : how animals keep themselves well and what we can learn from them. London : Phoenix, 305 p

Eysker M, Bakker N, Kooyman FNJ, Ploege, HW (2005) The possibilities and limitations of evasive grazing as a control measure for parasitic gastroenteritis in small ruminants in temperate climates. Vet Parasitol 129:95-104

Faedo M, Barnes EH, Dobson RJ, Waller PJ (1998) The potential of nematophagous fungi to control the free-living stages of nematode parasites of sheep : pasture plot study with Duddingtonia flagrans. Vet Parasitol 76:129-135

Faedo M, Larsen Mm, Thamsborg SM (2000) Effect of different times of administration of the nematophagous fungus Duddingtonia flagrans on the transmission of ovine parasitic nematodes on pasture - a plot study. Vet Parasitol 94:55-65

Fincher GT (1973) Dung beetles as biological control agents for gastrointestinal parasites of livestock. J Parasitol 59:396-399

Gauly M, Erhardt G (2001) Genetic resistance to gastrointestinal nematode parasites in Rhön sheep following natural infection. Vet Parasitol 102:253-259

Ghahfarokhi MS, Abyaneh MR, Bahadori SR, Eslami A, Zare R, Ebrahimi M (2004) Screening of soil and sheep faecal samples for predacious fungi : isolation and characterization of the nematode-trapping fungus Arthrobotrys oligospora. Iranian Biomed J 8:135-142

Githigia SM, Thamsborg SM, Larsen M, Kyvsgaard N, Nansen P (1997) The preventive effect of the fungus Duddingtonia flagrans on trichostrongyle infections of lambs on pasture. Int J Parasitol 27:931-939

Githigia SM, Thamsborg SM, Larsen M (2001) Effectiveness of grazing management in controlling gastrointestinal nematodes in weaner lambs on pasture in Denmark. Vet Parasitol 99:15-27

Gray GD (1997) The use of genetically resistant sheep to control nematode parasitism. Vet Parasitol 72:345-366

Gronvold J, Henriksen SA, Larsen M, Nansen P, Wolstrup J (1996) Biological control : aspects of biological control – with special reference to arthropodes, protozoans and helminths of domesticated animals. Vet Parasitol 64:47-64

Hay FS, Niezen JH, Miller C, Bateson L, Robertson H (1997) Infestation of sheep dung by nematophagous fungi and implications for the control of free-living stages of gastro-intestinal nematodes. Vet Parasitol 70:247-254

Hein WR, Harrison GBL (2005) Vaccines against veterinary helminths. Vet Parasitol 132:217-222

Hertzberg H, Larsen M, Maurer V (2002) Biologische Helminthenkontrolle bei Weidetieren mit nematophagen Pilzen. Berl Münch Tierärztl Wschr 115:278-285

Holst CR (2005) Untersuchungen zum Einfluss nematophager Pilze auf das Nematoden-Infektionsrisiko bei Schafen und Ziegen. Hannover : Tierärztliche Hochschule, 218 p

Houdijk JGM, Jackson F, Coop RL, Kyriazakis I (2006) Rapid improvement of immunity to Teladorsagia circumcincta is achieved through a reduction in the demand for protein in lactating ewes. Int J Parasitol 36:219-227

Humann-Ziehank E, Ganter M (2005) Neue Strategien für eine effektive Wurmbekämpfung. Dtsche Schafzucht 12:4-6

Hutchings MR, Kyriazakis I, Anderson DH, Gordon IJ, Coop RL (1998) Behavioural strategies used by parasitized and non-parasitized sheep to avoid ingestion of gastro-intestinal nematodes associated with faeces. Anim Sci 67:97-106

Jansson HB, Lopez-Llorca LV (2004) Control of nematodes by fungi. In: Arora DK (ed) Fungal biotechnology in agricultural, food and environmental applications. New York : Dekker, pp 205-215

Jansson HB, Tunlid A, Nordbring-Hertz B (1997) Nematodes. In: Anke T (ed) Fungal biotechnology. London ; Weinheim : Chapman & Hall, pp 39-50

Kahn LP, Knox MR, Walkden-Brown SW, Lea JM (2003) Regulation of the resistance to nematode parasites of single- and twin-bearing Merino ewes through nutrition and genetic selection. Vet Parasitol 114:15-31

Kassai T (1999) Veterinary helminthology. Oxford : Butterwoth-Heinemann, 260 p

Koopmann R, Holst C, Epe C (2006) Erfahrungen mit der FAMACHA-Eye-Colour-Karte zur Identifizierung von Schafen und Ziegen für die gezielte anthelminthische Behandlung. Berl Münch Tierärztl Wschr 119(9-10):426-442

Larsen M, Faedo M, Waller PJ (1994) The potential of nematophagous fungi to control the free-living stages of nematode parasites of sheep : survey for the presence of fungi in fresh faeces of grazing livestock in Australia. Vet Parasitol 53:275-281

Larsen M, Faedo M, Waller PJ, Hennessy DR (1998) The potential of nematophagous fungi to control the free-living stages of nematode parasites of sheep : studies with Duddingtonia flagrans. Vet Parasitol 76:121-128

Larsen M, Wolstrup J, Henriksen SA, Dackman C, Gronvold J, Nansen P (1991) In vitro stress selection of nematophagous fungi for bio control of parasitic nematodes in ruminants. J Helminthol 65:193-200

Lüscher A, Häring DA, Heckendorn F, Scharenberg A, Dohme F, Maurer V, Hertzberg H (2005) Use of tanniferous plants against gastro-intestinal nematodes in ruminants. In: Köpke U, Niggli U, Neuhoff D, Cornish P, Lockeretz W, Willer H (eds) Researching sustainable systems : proceedings of the First Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), 21-23 September 2005, Adelaide, South Australia. Frick : Forschungsinstitut für biologischen Landbau FIBL, 660 p

Marley CL, Fraser MD, Fychan R, Theobald VJ, Jones R (2005) Effect of forage legumes and anthelmintic treatment on the performance, nutritional status and nematode parasites of grazing lambs. Vet Parasitol 131:267-282

Meat NZ (1999) Breeding sheep with resistance to nematode infection [online]. Zu finden in www.meatnz.co.nz/main.cfm [Zitiert am 25.04.2007] R&D Brief 34

Niezen JH, Charleston WAG, Robertson HA, Shelton D, Waghorn GC, Green R (2002a) The effect of feeding sulla (Hedysarum coronarium) or lucerne (Medicago sativa) on lamb parasite burdens and development of immunity to gastrointestinal nematodes. Vet Parasitol 105:229-245

Niezen JH, Robertson HA, Sidey A, Wilson SR (2002c) The effect of pasture species on parasitism and performance of lambs grazing one of three grass-white clover pasture swards. Vet Parasitol 105:303-315

Niezen JH, Robertson HA, Waghorn GC, Charleston WAG (1998) Production, faecal egg counts and worm burdens of ewe lambs which grazed six contrasting forages. Vet Parasitol 80:15-27

Niezen JH, Waghorn GC, Graham T, Carter JL, Leathwick DM (2002b) The effect of diet fed to lambs on subsequent development of Trichostrongylus colubriformis larvae in vitro and on pasture. Vet Parasitol 105:269–283

Paraud C, Chartier C (2003) Efficacy of Duddingtonia flagrans against infective larvae of gastrointestinal nematodes (Teladorsagia circumcincta) and small lungworm (Muellerius capillaris) in goat faeces. Parasitol Res 89:102-106

Paraud C, Hoste H, Lefrileux Y, Pommaret A, Paolini V, Pors I, Chartier C (2003) Administration of Duddingtonia flagrans chlamydospores to goats to control gastro-intestinal nematodes : dose trials. Vet Res 36:157-166

Paraud C, Pors I, Chicard C, Chartier C (2006) Comparative efficacy of the nematode-trapping fungus Duddingtonia flagrans against Haemonchus contortus, Teladorsagia circumcincta and Trichostrongylus colubriformis in goat faeces: influence of the duration and of the temperature of coproculture. Parasitol Res 98:207-213

Parnell IW, Gordon HM (1963) Predaceous fungi : a possible method of biological control of parasitic nematodes. J Helminthol 37:339-342

Persson L (1974) Studies on the bionomics of eggs and infective larvae of Ostertagia ostertagi and Cooperia oncophora in soil. Zentralbl Veterinaermed [B] 21:318-328

Pollott GE, Karlsson LJE, Eady S, Greeff JC (2004) Genetic parameters for indicators of host resistance to parasites from weaning to hogget age in Merino sheep. J Anim Sci 82:2852-2864

Rahmann G, Koopmann R, Hertzberg H (2002) Gesundheit erhalten statt Krankheit kurieren : Tiergesundheit im ökologischen Landbau. Forschungsrep Verbrauchersch Ern Landwirtsch (1):4-7

Rommel M, Eckert J, Kutzer E, Körting W, Schneider T (2000) Veterinärmedizinische Parasitologie. Berlin : Parey, 915 p

SAC (Scottish Agricultural College) (2000). Stapledon Report - the control of worms in sheep. (5) The control of worms by breeding resistant sheep [online]. Zu finden in <www1.sac.ac.uk/animal/external/publications/stapledon%20rep/staple25.htm>

Schoenian S (2005) Internal parasite control [online]. Zu finden in www.sheep101.info/201/parasite.html [Zitiert am 25.04.2007]

Secher B,Gronvold J,Thamsborg S (1992) Unpublished data. In: Thamsborg SM, Jörgensen SM, Waller PJ, Nansen P (1996) The influence of stocking rate on gastrointestinal nematode infections of sheep over a 2-year grazing period. Vet Parasitol 67:207-224

Silvestre A, Chartier C, Sauvé C, Cabaret J (2000) Relationship between helminth species diversity, intensity of infection and breeding management in dairy goats. Vet Parasitol 94:91–105

Sykes AR, Coop RL (2001) Interactions between nutrition and gastrointestinal parasitism in sheep. NZ Vet J 49:222-226

Terrill TH, Larsen M, Samples O, Husted S, Miller JE, Kaplan RM, Gelay S (2004) Capability of the nematode-trapping fungus Duddingtonia flagrans to reduce infective larvae of gastrointestinal nematodes in goat feces in the south-eastern United States : dose titration and dose time interval studies. Vet Parasitol 120:285-296

Thamsborg SM (2001b) Options for parasite control using tanniferous forages in livestock in Northern temperate areas. Lecture given on: The 18th International Conference of the World Association for the Advancement of Veterinary Parasitology : Promoting Advancement, Preserving Tradition, Stresa, Italy, 26.-30. August 2001[online]. Zu finden in http://orgprints.org/4519 [Zitiert am 25.04.2007]

Thamsborg SM (2001a) Parasite control on organic sheep farms - options and limitations. In: Hovi M, Vaarst M (eds) Positive health - preventive measures and alternative strategies : proceedings of the fifth NAHWOA Workshop. Rodding, Denmark, November 11-13, 2001, pp 92-101

Thamsborg SM, Jörgensen SM, Waller PJ, Nansen P (1996) The influence of stocking rate on gastrointestinal nematode infections of sheep over a two-year grazing period. Vet Parasitol 67:207-224

Thamsborg SM, Larsen M, Busch M (2004) Sustainable, non-chemical control of small ruminant nematode parasites in Europe : proceedings from an International Workshop held at Danish Centre of Experimental Parasitology Royal Veterinary and Agricultural University, Frederiksberg, Denmark, 20-21 October 2004

Thamsborg SM, Mejer H, Bandier M, Larsen M (2003) Influence of different forages on gastrointestinal namatode infections in grazing lambs. Lecture given on: The 19th International Conference for the Advancement of Veterinary Parasitology : Old Dreams – New Visions, Veterinary Parasitology in the 21st Century, New Orleans, Louisiana, USA, 10.-14. August 2003 [online]. Zu finden in http://orgprints.org/4520 [Zitiert am 25.4.2007]

Thamsborg SM, Mejer H, Roepstorff A (2001) Sainfoin reduces the establishment of nematode infections in grazing lambs. Lecture given on: The 18th International Conference of the World Association for the Advancement of Veterinary Parasitology : Promoting Advancement, Preserving Tradition, Stresa, Italy, 26.-30. August 2001 [online]. Zu finden in http://orgprints.org/4517 [Zitiert am 25.04.2007]

Thamsborg SM, Roepstorff A (2003) Parasite problems in organic livestock and options for control. J Parasitol 89:277-284

Thamsborg SM, Roepstorff A, Larsen M (1999) Integrated and biological control of parasites in organic and conventional production systems. Vet Parasitol 84:169-186

Thomas ML (2001) Dung beetle benefits in the pasture ecosystem [online]. Zu finden in http://attra.ncat.org/attra-pub/PDF/dungbeetle.pdf [Zitiert am 25.04.2007]

Uriarte J, Llorent MM, Valderrábano J (2003) Seasonal changes of gastro-intestinal nematode burden in sheep under an intensive grazing system. Vet Parasitol 118:79–92

Valderrábano J, Delfa R, Uriarte J (2002) Effect of level of feed intake on the development of gastrointestinal parasitism in growing lambs. Vet Parasitol 104:327-338

Vallade S, Hoste H, Goudeau C, Broqua C, Lazard K, LeFrileux Y, Chartier C, Etter E (2000) Relationship between nematode parasitism of the digestive tract and the characteristics of dairy goat farms in two French regions. Rev Med Vet 151:1131-1138

Van Houtert MFJ, Barger IA, Steel J, (1995a) Dietary protein for young grazing sheep: interactions with gastrointestinal parasitism. Vet Parasitol 60:283-295

Van Houtert MFJ, Barger IA, Steel JW, Windon RG, Emery DL (1995b) Effects of dietary protein intake on responses of young sheep to infection with Trichostrongylus colubriformis. Vet Parasitol 56:163-180

Vlassoff A, Leathwick DM, Heath ACG (2001) The epidemiology of nematode infections of sheep. NZ Vet J 49:213-221

Waghorn TS, Leathwick DM, Chen L-Y, Gray RAJ, Skipp RA (2002) Influence of nematophagous fungi, earthworms and dung burial on development of the free-living stages of Ostertagia (Teladorsagia) circumcincta in New Zealand. Vet Parasitol 104:119-129

Waghorn TS, Leathwick DM, Chen L-Y, Skipp RA (2003) Efficacy of the nematode-trapping fungus Duddingtonia flagrans against three species of gastro-intestinal nematodes in laboratory faecal cultures form sheep and goats. Vet Parasitol 118:227-234

Waghorn TS, Molan AL, Deighton M, Alexander RA, Leathwick DM, McNabb WC, Meagher LP (2006) In vivo anthelmintic activity of Dorycnium rectum and grape seed extract against Ostertagia (Teladorsagia) circumcincta and Trichostrongylus colubriformis in sheep. NZ Vet J 54:21-27

Waller PJ (2005) Targeted use of anthelmintics. In: Thamsborg SM, Larsen M, Busch M (2004) Sustainable, non-chemical control of small ruminant nematode parasites in Europe : proceedings from an International Workshop held at Danish Centre of Experimental Parasitology Royal Veterinary and Agricultural University, Frederiksberg, Denmark, 20-21 October 2004

Waller PJ, Faedo M, Ellis K (2001b) The potential of nematophagous fungi to control the free-living stages of nematode parasites of sheep: towards the development of a fungal controlled release device. Vet Parasitol 102:299-308

Waller PJ, Knox MR, Faedo M (2001a) The potential of nematophagous fungi to control the free-living stages of nematode parasites of sheep: feeding and block studies with Duddingtonia flagrans. Vet Parasitol 102:321-330

Waller PJ, Schwan O, Ljungström B-L, Rydzik A, Yeates GW (2004) Evaluation of biological control of sheep parasites using Duddingtonia flagrans under commercial arming conditions on the island of Gotland, Sweden. Vet Parasitol 126:299-315

Waller PJ, Thamsborg SM (2004) Nematode control in 'green' ruminant production systems. Trends Parasitol 20(10)

Wells A (1999) Integrated parasite management for livestock [online]. Zu finden in www.attra.org/attra-pub/PDF/livestock-ipm.pdf [Zitiert am 25.04.2007]

Winkelmann J (2005) Schaf- und Ziegenkrankheiten. Stuttgart : Ulmer, 128 p

Wolstenholme AJ, Fairweather I, Prichard R, von Samson-Himmelstjerna G, Sangster NC (2004) Drug resistance in veterinary helminths. Trends Parasitol 20(10)

Wolstrup J, Gronvold J, Henriksen SA, Nansen P, Larsen M, Bogh HO, Ilsoe B (1994) An attempt to implement the nematode-trapping fungus Duddingtonia flagrans in biological control of trichostrongyle infections of first year grazing calves. J Helminthol 68:175-80

Younie D, Thamsborg SM, Ambrosini F, Roderick S (2004) Grassland management and parasite control. In: Vaarst M (ed) (2004) Animal health and welfare in organic agriculture. Wallingford : CABI, pp 309-324