Veterinary Parasitology 196 (2013) 358–365

Contents lists available at ScienceDirect

Veterinary Parasitology

journal homepage: www.elsevier.com/locate/vetpar

Weight gain-based targeted selective treatments (TST) of gastrointestinal nematodes in first-season grazing cattle

Johan Höglund[a,*], Frida Dahlström[b], Sofia Sollenberg[a], Anna Hessle[b]

[a] Department of Biomedical Sciences and Veterinary Public Health, Section for Parasitology, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden
[b] Department of Animal Environment and Health, SLU, Skara, Sweden

ARTICLE INFO

Article history:
Received 10 July 2012
Received in revised form 16 March 2013
Accepted 24 March 2013

Keywords:
Ostertagia ostertagi
Cooperia oncophora
Gastrointestinal nematodes
Cattle
Pasture
Management
Anthelmintics
Doramectin
TST

ABSTRACT

A three-year trial was performed in south-western Sweden to compare animal performance and levels of parasite control in three grazing groups, each with 18–24 first-season grazing (FSG) calves in similar set-stocked pasture enclosures. These groups were subjected to: (1) no parasite control (NT), (2) monthly repeated doramectin (Dectomax®) injections (SP), or (3) targeted selective weight gain-based anthelmintic treatments (TST) but only when individual calf performance was inferior to the average of the poorer 50% of those calves in group SP. In each year, weight and parasitological variables were measured at turn-out and then at predetermined intervals for 22–24 weeks during the grazing season. The dewormed calves in group SP had a higher average weight gain at housing (range 0.39–0.61 kg/day) than those in TST (0.36–0.50 kg/day), which in turn always exceeded the NT group (0.23–0.42 kg/day). This indicates that the parasite challenge in the NT group was sufficiently high to result in production loss. However, the average cumulative faecal egg counts (FEC) at housing in NT were in the range 1271–1953 eggs per gram faeces (epg) and in TST 1221–1968 epg. In contrast, parasite eggs were rarely recorded in group SP and then only during the first two years (on average 12 and 38 epg). There were also no significant differences in FEC or serum pepsinogen levels between FSG in groups NT and TST. The animals in SP received 7 doses of doramectin each year, whereas those in TST received an average of 0.5 doses. Thus, the TST approach represented a 92% reduction in anthelmintic use. The average weight gain in animals subjected to TST was always significantly lower than in animals dewormed regularly. In addition, there were no signs of short-term selection for anthelmintic resistance in the group SP animals, despite the fairly intensive use of injectable doramectin.

1. Introduction

The most widespread and harmful parasites of grazing cattle in northern Europe are the gastrointestinal nematodes (GIN) *Ostertagia ostertagi* and *Cooperia oncophora* (Höglund, 2010). Both parasites are present wherever cattle are grazing, and have direct life-cycles with infective stages transmitted by the orofaecal route through ingestion of herbage on contaminated pasture (Andersson, 1992). Chronic GIN infections dramatically reduce the production of animal protein in the form of meat and milk, which are important food sources for an ever-increasing human population. Improved approaches to combat endemic parasitic diseases in ruminants are therefore important, especially as a result of the emerging issue of anthelmintic resistance (AR), which has recently been detected in nematode parasites in first grazing season cattle (FSG) in Western European herds (Demeler et al., 2009). Furthermore, future climate change is predicted to increase the level of parasite challenge (Kenyon et al., 2009b; Van Dijk et al., 2010).

* Corresponding author. Tel.: +46 18674156; fax: +46 18309162.
E-mail address: johan.hoglund@slu.se (J. Höglund).

0304-4017
http://dx.doi.org/10.1016/j.vetpar.2013.03.028

The effective management of diseases caused by GIN in ruminants on grass through targeted selective anthelmintic treatments (TST) has been proposed as a novel and sustainable control strategy to prevent the development of AR, as it will maintain populations of nematodes in refugia (*i.e.* preparasitic stages in the environment unexposed to anthelmintics). This would reduce the selection pressure for the development of AR (Van Wyk, 2001). TST also minimises the number of whole-herd anthelmintic treatments of ruminants, directing individual treatments only to those individuals within a herd that are most susceptible to disease and can derive most benefit from treatment, and/or those responsible for most pasture contamination (Kenyon et al., 2009a). Thus, TST is aimed at minimising the use of anthelmintics, which reduces any associated environmental and health risks. TST based on expected weight gain has been studied with promising results in sheep (Greer et al., 2009), but worldwide scientific knowledge of TST in cattle is limited (Greer et al., 2010).

If applied optimally, TST should not result in any significant production losses to farmers, and may produce economic benefits due to reduced drug costs (Höglund et al., 2009). Another advantage of the TST approach is that it is acceptable according to the worldwide guidelines for organic farming. We previously provided proof of concept for the suitability of the TST approach in FSG cattle, demonstrating that it can reduce anthelmintic treatments whilst maintaining animal welfare and productivity (Höglund et al., 2009). However, to date this approach has rarely been evaluated or experimentally verified in grazing cattle. Therefore in the present study we investigated a weight gain-based TST against major GIN in FSG cattle predominantly exposed to *O. ostertagi* and *C. oncophora*.

2. Materials and methods

2.1. Experimental design

The trial was conducted at Götala Research Station, Skara, in south-western Sweden (58°42′ N, 13°21′ E; elevation 150 m above sea level) in the grazing season of 2008 (22 weeks, 29 April–29 September), 2009 (23 weeks, 28 April–7 October) and 2010 (23 weeks, 5 May–11 October). The study site consisted of 28 ha of permanent semi-natural pasture, divided into three enclosures (1, 2 and 3), and with the same pasture used for the last two years of each treatment.

Three experimental groups of FSG were kept under set-stocked grazing conditions and subjected to either:

- NT: no parasite control
- SP: suppressive prophylactic treatment by doramectin (Dectomax®) subcutaneous injections (200 μg kg^{-1} body weight) at turn-out and every four weeks thereafter
- TST: targeted selective weight gain-based treatment of individual calves with doramectin, starting eight weeks after turn-out, but only when their accumulated weight gain from turn-out was inferior to the average of the poorer 50% of those calves in the SP group.

In 2008, calves in all three experimental groups were mixed in all three enclosures, with eight calves from each experimental group in enclosures 1 and 2 and six calves from each experimental group in enclosure 3. During 2009 and 2010, the experimental groups were kept separated, with NT in enclosure 1 in both years (24 calves), SP in enclosure 2 in both years (18 calves) and TST in enclosure 3 in both years (24 calves).

2.2. Animals

In each year, 66 FSG bull calves born in the previous summer were used in the study. All animals were of the dairy breeds Swedish Red (24, 17 and 28 in 2008, 2009 and 2010, respectively) and Swedish Holstein (42, 49 and 38 in 2008, 2009 and 2010, respectively), and were purchased from commercial herds during the housing period as weanlings at 2–3 months of age. During the pre-experimental indoor period, all animals were fed a total mixed ration consisting of grass/clover silage, rolled barley and protein concentrate *ad libitum*. Both before and during the experiment, water and a salt and mineral supplement were supplied to the animals.

Because of the expected worm-free status of the experimental animals, and the negligible initial levels of pasture contamination by free-living stages of the parasite in the first year of the trial, all animals received two "priming" doses of infective larvae prior to turn-out in late April 2008. The doses contained an equal mixture of *O. ostertagi* and *C. oncophora*, each with approximately 20,000 infective larvae. The parasites were obtained from the Tierärtzliche Hochschule (TiHo), Hannover, after having been passaged in four donor calves (two per species) just prior to the start of the experiment. Both isolates had no history of being refractory to treatment with any anthelmintics *in vitro* (Demeler et al., 2010).

At turn-out, the calves were allocated to the three experimental set-stocked groups, with the number of animals per group set to result in similar grazing pressure in the three enclosures, according to previous experience. The animals were first sorted according to their starting weight and then by randomly selected blocks of three, with one animal for each treatment. Two calves were excluded from the study, one in 2009 because of coccidiosis one week after turn-out, and one in 2010 because of solar dermatitis. The Ethical Committee on Animal Experiments in Gothenburg approved the protocol and execution of this study.

2.3. Weighing, sampling and parasitological examinations

In all three years, all calves were weighed on two consecutive days at turn-out and at housing, and once every second week throughout the grazing period. At the time of weighing, their body condition score (BCS) was also established on a scale from 1 (thin) to 5 (fat) (Edmonson et al., 1989). The health status of the calves was monitored daily, and signs of diarrhoea and/or coughing were noted.

Rectal faecal samples were collected from the animals at turn-out and then every four weeks until housing. The consistency of the faeces was visually determined from

residues on the rear of the calves, with diarrhoea scoring in integers (DISCO) on a scale from 1 (clean) to 6 (very dirty). The samples collected every four weeks were used for quantitative analysis of GIN faecal egg counts (FEC) per gram of faeces (epg) according to a modified McMaster technique based on 3 g faeces and with a diagnostic sensitivity of 50 epg. Pooled larvae cultures were prepared in order to investigate the relative proportions of the nematodes *O. ostertagi* and *C. oncophora*. On all sampling occasions, ~10 g faeces from all animals in each group were mixed with vermiculite (fraction size 2–4 mm) and incubated for one week at 25 °C and >90% RH. Resulting infective third stage larvae (L3) were subsequently harvested and identified according to Borgsteede and Hendriks (1974).

Every four weeks, a 5-mL blood sample was taken from the coccygeal vein or artery using a vacutainer tube equipped with a cannula (BD Vacutainer®, Becton Dickinson). Serum was separated in order to determine the pepsinogen concentration (SPC) according to a micromethod (Dorny and Vercruysse, 1998), and the values were expressed as units of tyrosine (Utyr). The level of serum antibodies to the lungworm *Dictyocaulus viviparus* were measured at housing each year according to Goździk et al. (2012).

2.4. Tracer calves

Six extra FSG dairy calves, 12 months of age, were used as "tracer animals" in the last two years of the study (*i.e.* 2009 and 2010). Two of these calves were turned out into each of the three enclosures three weeks before planned housing of the experimental calves. The tracer calves first grazed together with the experimental animals, and were then held indoors for a further three-week period before being delivered to the abattoir for slaughter and viscera collection. The abomasum and ~10 m of the proximal small intestine were processed separately. The bowel contents and rinse water from washing of the mucosal surfaces were collected in individual buckets and adjusted to a total volume of 4 L. The abomasal mucosa was scraped off and digested in a pepsin–HCl solution (10 g pepsin + 17 mL concentrated HCl dissolved in 1 L water). The final volume after digestion was adjusted to 2 L and two 20 mL sub-samples were taken from each bucket for determination of worm counts.

2.5. Pasture

All three enclosures consisted of approximately 20% dry, 60% mesic and 20% wet areas. The pasture was mainly open, but included small areas of mixed deciduous trees. In general, the dominant plant species was *Deschampsia cespitosa* (tufted hairgrass), but *Festuca rubra* (red fescue) was also prominently present. In dry areas, *F. ovina* (sheep's fescue), *D. flexuosa* (wavy hairgrass), *Nardus stricta* (matgrass) and several herb species were abundant. Besides *D. cespitosa* and *F. rubra*, herbs were prevalent in mesic areas, while *D. cespitosa* and Cyperaceae (sedges/rushes) were dominant in wet areas.

Sward height and chemical composition of the pasture herbage were measured every four weeks from turn-out to housing every year, to ensure similar conditions in the three enclosures. In each enclosure, sward height measurement followed a W-shaped route according to Frame (1993), with 50–60 recordings performed with a rising plate metre (0.3 m × 0.3 m, weight 430 g). To estimate chemical composition, 12–15 herbage samples were hand-picked in 3-m diameter circles along the route. The samples were analysed for concentrations of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) and *in vitro* organic matter digestibility (Lindgren, 1979). The DM concentration was determined at 105 °C for 24 h, CP was determined in a Tecator Kjeltec Auto Sampler 1035 Analyzer (Tecator Inc., Höganäs, Sweden), and NDF was determined according to Goering and van Soest (1970). Metabolisable energy (ME) concentration was calculated from *in vitro* organic matter digestibility (Lindgren, 1979).

2.6. Statistical analyses

Data were summarised in Excel® (Microsoft® Mac version 14.2.2), and then exported to JMP™ version 10.0.0 (SAS Institute Inc. Cary, NC, USA) and GraphPad Prism® version 4.0c (San Diego, CA, USA), where statistical analyses and graphical illustrations were carried out. Animal performance (as weight gain from turn-out to housing and daily weight gain), condition and health variables (as BCS and DISCO scores), and infection levels (as log10 transformed values of FEC + 1 and SPC) were compared between experimental groups in relation to time within the grazing period. Each year was tested separately in the fit-model platform of JMP™ using a repeated measures analysis of variance (ANOVA) design with EMS. The fixed factor in the model was treatment (*i.e.* experimental group NT, SP or TST), while animal identity within treatment and sampling point (1–7) were random factors. As the FEC was predominantly zero, NT was dropped from the FEC analysis. Pairwise differences in daily weight gain (DWG) were also compared with one-way ANOVA and then pairwise comparsions were made with Tukey-Kramer *post hoc* test. Spearman's Rank Correlation in the JMP model platform was used to test the direction and strength of the relationship between DWG and DISCO, and between DWG and BCS. The significance level was always set to $p < 0.05$.

3. Results

3.1. Parasite status of the animals

As shown in Fig. 1A–C, FEC exhibited similar, highly repeatable stereotypical patterns in all groups every year. In all years the highest FEC levels were observed in the TST and untreated NT calves approximately 4–5 weeks post turn-out, and there was never any significant difference between these two groups. Similarly, the proportions of *O. ostertagi* and *C. oncophora* were very similar in the NT and TST groups, with a slightly increasing proportion of *O. ostertagi* towards the end of the grazing period (data not shown). In contrast, FEC in the calves from the doramectin-treated SP group was almost negligible in both 2008 and

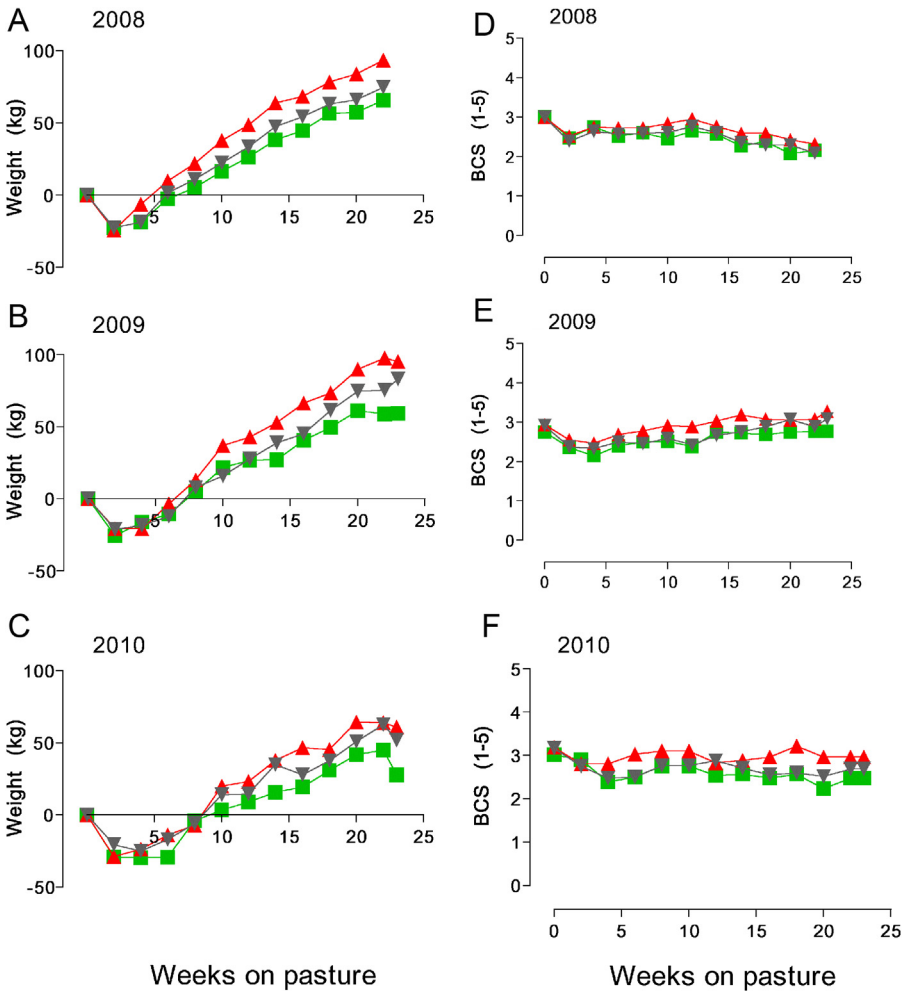

Fig. 1. (A)–(C) Mean nematode egg counts in faeces (FEC) and (D)–(F) level of serum pepsinogen concentration in blood (SPC) from turn-out until housing in first-season grazing calves. NT = no parasite control (squares and green), SP = repeated doramectin (Dectomax®) injections (upward triangles and red), TST = targeted selective weight gain-based anthelmintic treatments of individual calves (downward triangles and black).

2009, while there were no parasite eggs at all in 2010. As shown in Fig. 2B, there were no significant differences in the cumulative FEC between groups NT and TST. The average cumulative FEC in group NT at housing was in the range 1271–1953 epg and in TST in the range 1221–1968 epg. In contrast, parasite eggs were rarely detected in group SP and then only during the first two years (an average of 12 and 38 epg, respectively).

The SPC values in calf blood are shown in Fig. 1C–E. As with FEC, a consistent and repeatable pattern was observed every year, with a gradual increase until mid-summer, followed by a slight decline towards the end of the grazing season. In general, the lowest SPCs were seen in the regularly treated calves in group SP, intermediate levels in group TST and the highest levels in the untreated group NT. The mean concentration at housing in NT varied from 1.7 to 3.0 Utyr, in SP from 1.0 to 2.0 Utyr, and in TST from 1.2 to 3.2 Utyr. In contrast to FEC, there were highly significant differences in SPC ($p < 0.001$) between the experimental groups, which also persisted during the last two years when the calves in group NT were excluded from the analyses (2008 $p = 0.0061$; 2009 $p = 0.027$; 2010 $p < 0.001$). No anti-lungworm antibodies were found.

3.2. Animal performance

As shown in Fig. 3A–C, weight followed a highly predictable pattern, initially decreasing until about four weeks after turn-out and then increasing linearly throughout the grazing period. However, during the last two years a reduction in weight was seen, particularly in the NT group, between the penultimate sampling and the final sampling in conjunction with housing. The minimum weight observed four weeks after turn-out decreased continuously in the three consecutive years, as did the subsequent growth increase. In 2008, the average weight decrease at four weeks after turn-out was −10 kg, in 2009 it was −18 kg, and in 2010 −26 kg. In all years the disparity in animal performance differed significantly between the groups (2008 $p = 0.0396$; 2009 $p = 0.0021$; 2010 $p = 0.0012$). The

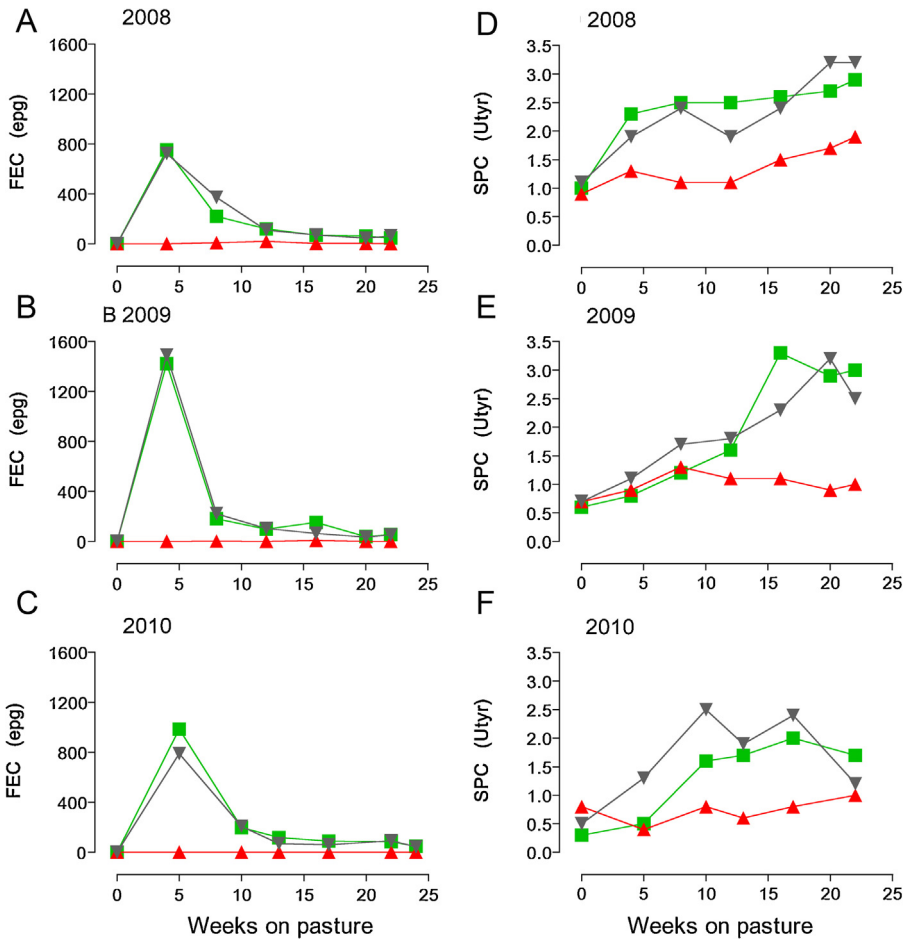

Fig. 2. (A) Average daily liveweight gain (DWG, kg) from September until housing in first-season grazing calves in treatments and (B) cumulative faecal nematode egg counts (Cum FEC, epg) at housing on a logarithmic scale. NT = no parasite control, SP = repeated doramectin (Dectomax®) injections, TST = targeted selective weight gain-based anthelmintic treatments of individual calves. Different letters above the bars indicate statistically significant differences.

total weight gain for the grazing period for each respective year was: 94, 97 and 63 kg in SP; 66, 59 and 36 kg in NT; and 75, 79 and 57 kg in TST. The highest weight gains were observed in 2008, intermediate in 2009 and the lowest in 2010. The pattern at housing for the regularly dewormed calves in group SP was to have a higher daily weight gain (DWG) (0.39–0.61 kg/day) than those in the TST group (0.36–0.50 kg/day), which in turn always exceeded the untreated NT group (0.23–0.39 kg/day) (Fig. 2A). Pairwise comparisons at housing also showed that the total DWG in the NT group was significantly lower than that in the TST group the last two years (2009 and 2010), when the groups were grazing different enclosures (Fig. 2A).

The BCS of the calves is shown in Fig. 3D–E. In general, BCS was higher in the dewormed calves in group SP (mean 2.7–3.3) than those in TST (2.5–3.1), which in turn was higher than in the untreated calves in group NT (2.3–2.9). These differences were significant in every year (2008 $p < 0.001$; 2009 $p = 0.012$; 2010 $p < 0.001$). Furthermore, although the trend for BCS was similar in all groups every year, there were also differences between years. For example, in 2008 BCS decreased in all groups over time within the grazing season, while in 2009 there was a tendency for an increase in all groups after an initial dip. There was a highly significant positive correlation between BCS and DWG (Sperman's rho = 0.42), however, that shows that only 16% of the variation in DWG is explained by BSC.

Although faeces consistency and signs of diarrhoea expressed as DISCO were correlated, they exhibited no consistent pattern (data not shown). In addition, they were never significantly different between calves in the different experimental groups. DISCO was also uncorrelated with DWG (Spearman's rho = 0.06).

3.3. *Chemical composition and parasite status of the pasture*

The chemical composition of the herbage from the three enclosures was similar (Table 1). During 2009 and 2010, when the three treatments were allocated to different enclosures, average sward height, NDF and ME concentration did not differ by more than 9%, 5% and 7%, respectively, among enclosures within years (Table 1).

Table 1
Description of three treatments (NT = no parasite control, SP = repeated doramectin (Dectomax®) injections, TST = targeted selective weight-gain-based anthelmintic treatments of individual calves starting eight weeks after turn, but only when their accumulated weight gain from turn-out was inferior to the average of the poorer 50% of those in the SP group), animals used in the experimental groups, acreage, sward height and chemical composition of the three experimental enclosures (standard deviations in parenthesis). During 2008 calves of the three treatments were mixed in the three enclosures, whereas calves of the three treatments were kept separately in 2009 and 2010 with NT in enclosure 1, SP in enclosure 2 and TST in enclosure 3.

Year	2008			2009			2010		
Treatment	NT	SP	TST	NT	SP	TST	NT	SP	TST
Animals									
Calves, *n*	22	22	22	24	18	24	24	18	24
Pre-exp. gain of calves, kg/day	0.79 (0.11)	0.76 (0.12)	0.76 (0.12)	0.90 (0.09)	0.89 (0.11)	0.87 (0.07)	0.95 (0.07)	0.93 (0.09)	0.93 (0.10)
Initial weight of calves, kg	238 (36)	235 (44)	235 (40)	252 (23)	254 (28)	250 (21)	271(18)	273 (18)	267 (21)
Initial age of calves, months	8.3 (0.7)	8.5 (0.9)	8.5 (0.7)	7.9 (0.4)	8.0 (0.7)	8.1 (0.7)	8.1 (0.5)	8.4 (0.8)	8.1 (0.4)
Year	2008			2009			2010		
Enclosure	1	2	3	1	2	3	1	2	3
Pasture									
Acreage, ha.	9	9	10	9	9	10	9	9	10
Sward height, cm	5.1 (2.7)	5.2 (2.4)	4.2 (2.1)	5.4 (3.4)	5.4 (2.6)	4.9 (2.4)	5.1 (2.5)	4.9 (2.3)	5.1 (2.3)
Dry matter, %	26 (6)	27 (8)	29 (6)	28 (3)	27 (3)	29 (4)	41 (5)	42 (6)	41 (7)
Crude protein, g kg DM^{-1}	155 (29)	141(21)	129 (14)	154 (17)	146 (17)	147 (21)	183 (82)	139 (25)	147 (41)
Neutral detergent fibre, g kg DM^{-1}	566 (43)	594 (36)	592 (41)	526 (9)	535 (20)	555 (32)	515 (39)	539 (36)	525 (40)
Metabolisable energy, g kg DM^{-1}	9.9 (1.2)	9.5 (1.0)	9.3 (1.2)	10.2 (0.6)	10.1 (1.2)	10.9 (0.7)	10.0 (1.2)	9.5 (1.2)	9.9 (0.9)

The worm burdens for the tracers calves were *O. ostertagi* and *C. oncophora*, with an overall ratio varying from 24 to 27%. The two pairs of tracer animals that grazed enclosure 1 (with a history of NT calves in 2008) harboured a mean of 81,625 ± 4419 (SD) worms in 2009 and 10,125 ± 4773 worms in 2010. The tracers in enclosure 2 (grazed by TST calves in 2008) had a mean of 36,000 ± 25,456 worms in 2009 and 25,375 ± 7248 worms in 2010. In contrast, the tracers in enclosure 3 (with a history of SP animals in 2008) harboured a mean of only 673 ± 817 worms in 2009, and 3750 ± 5303 worms in 2010, and the majority of these were inhibited stages, predominantly of *C. oncophora*. Because of the limited number of observations, further statistical treatment of the data was not possible.

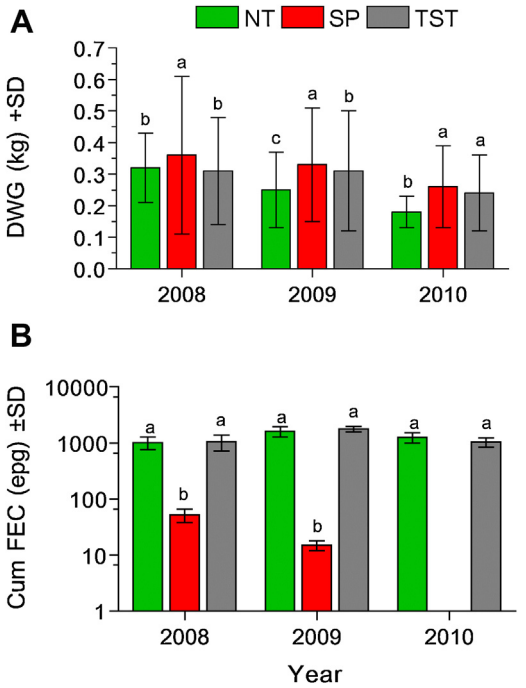

Fig. 3. (A)–(C) Mean liveweight gain (LWG, kg) from the start of the grazing season and (D)–(F) body condition score (BCS), ranging from 1 (thin) to 5 (fat) from turn-out until housing in first-season grazing calves. NT = no parasite control (squares and green), SP = repeated doramectin (Dectomax®) injections (upward triangles and red), TST = targeted selective weight gain-based anthelmintic treatments of individual calves (downward triangles and black).

3.4. Use of anthelmintics

The proportion of calves in group TST actually dewormed was 62%, 54% and 50% in 2008, 2009 and 2010, respectively. Most (92%) of these calves were treated 8 weeks after turn-out and with one animal each after 10 weeks and 12 weeks, respectively. No animal was treated more than once. On average, the TST group received 0.5 doses per animal and year, whereas the SP group received 7 doses per animal per year.

4. Discussion

The principle of TST is to restrict anthelmintic use to only a proportion of animals in the herd, without compromising animal health and productivity or exerting selective pressure leading to development of AR (Van Wyk, 2001). So far, different TST strategies have proven to be effective against GIN in goats and sheep (*e.g.* Gallidis et al., 2009; Kenyon et al., 2009a). A weight gain-based TST has also been tested before with some success in a commercial cattle herd in New Zealand (Greer et al., 2010). However, to our knowledge no previous study has allowed the weight gain in TST animals to be compared with both positive (suppressive treated) and negative (untreated) control groups

grazing for three consecutive grazing seasons alongside TST animals in neighbouring enclosures on the same pasture.

The present study showed that the weight-based TST strategy tested herein in FSG calves was acceptable from a productivity point of view. Still, our TST approach obviously failed to prevent differences in FEC between TST and NT animals. Our results show that pasture infectivity was high in the enclosure grazed by the TST group during the last two years, and with FEC values comparable to those in untreated (NT) animals in a neighbouring enclosure. This confirms experiences from a similar TST approach to GIN infection in sheep (Greer et al., 2009). Interestingly, the FEC results in the experimental animals declined every year, and there was only a few surviving *Cooperia* in the SP tracers. Although we did not test the actual level of AR with the faecal egg count reduction test (FECRT) or by any other method (*e.g. in vitro* and/or genetic tests), there was no indication of selection for AR parasites in the SP group. This is consistent with a previous study in which animals treated with doramectin at monthly intervals grazed the same enclosure for two consecutive years without showing signs of AR (Höglund et al., 2008).

Taking into account the relatively few treatments applied, the infection levels in the enclosure used by the TST group during the final two years resulted in a DWG that was intermediate between that observed in the untreated (NT) and regularly dewormed (SP) groups. The lower DWG in the groups with higher levels of GIN (NT and TST) was not due to deficiency in herbage quantity or quality. In fact, during the years when the treatment groups were kept in separate enclosures (2009 and 2010), the NT calves, with the lowest weight gain, were offered the numerically most abundant herbage with the highest energy concentration, combined with the lowest concentration of feed intake limiting NDF.

The use of weight gain-based TST is, in theory, a practical and efficient approach to controlling GIN in FSG cattle (Höglund et al., 2009). However, with the TST strategy used in the present study the threshold for when treatment should be initiated was not fixed, as it was calculated from the performance of the animals in the protected SP group. It therefore fluctuated somewhat between different sampling occasions and years. In fact, the treatment thresholds identified in the present study were always lower than the theoretical threshold of 0.75 kg DWG calculated by Höglund et al. (2009) from archived historical data collected from FSG primarily on cultivated leys. There is no doubt that the deviations from this theoretical threshold was related to the fact that the FSG calves in this study were kept in enclosures on a meagre semi-natural pasture containing low-nutrient herbage. On the other hand, this is the type of pasture where it can be expected that an increasing proportion of grazing cattle will be kept, due to nature preservation incitements, and therefore the TST strategy examined will be used.

In addition to adjusting the treatment threshold according to pasture type, the accuracy of this TST approach may be improved by knowledge of the DWG during the preceding indoor period and, hence, the level of animal compensatory growth on pasture. In fact, this DWG was lowest in 2008 and highest in 2010, most likely contributing to the reversed levels during the grazing periods, with the highest DWG when the animals were on pasture in 2008 and the lowest in 2010. Another complicating factor was that the threshold for when treatment should be applied varied somewhat between the different weighing occasions. As discussed earlier, this can be partly explained by the growth potential of the animals varying between different years, mainly due to differences in compensatory growth, as both the biomass and chemical composition of the pasture herbage were fairly similar between years. Thus, consideration should be given to compensatory growth from the preceding indoor period in future TST trials.

It was also realised that our TST method entails a significant amount of fieldwork, as it involves repeated weighing of the animals when they are on pasture. This illustrates the importance of finding alternative ways to determine the threshold for weight gain-based treatments that can be applied in diverse environments. Thus, in order to improve the TST approach and to make it more applicable under practical farming conditions, it is necessary to take advantage of automated weighing systems, and this aspect requires more attention in future studies.

With any parasite control programme based on the usage of anthelmintics, it is important to achieve a balance in the extent to which animals are dewormed, both to reduce the risk of transmission of that parasite proceeding unchecked and to avoid development of AR. The use of anthelmintics in the TST calves was only 8% of that in the SP group, which received suppressive whole-herd prophylactic treatment at monthly intervals throughout the grazing period (mean 7 per year). Although the treatment frequency in the SP group is not a viable and realistic alternative in Swedish herds, with this TST strategy the total number of doramectin treatments was reduced considerably compared with the SP group.

Data were also collected on BCS, which is a performance-based criterion that has been used with some success as an indicator for deworming in the control of GIN in different breeds of goats and sheep (Gallidis et al., 2009), but not by Ouzir et al. (2011). In the present study, no clear trend was observed in terms of BCS. Although BCS was positively correlated to DWG, according to our results it does not seem sufficiently robust and/or sensitive to be used as a marker of GIN infection in FSG cattle. Unlike in the study by Ouzir et al. (2011), we observed problems with DISCO, which was uncorrelated to DWG. This was partly explained by the fact that the faeces did not adhere to the hair on the rear end of the animals in calves with spouting watery diarrhoea. In summary, unlike the situation in small ruminants, according to the present study both BCS and DISCO appear to have limited or no value as TST markers in cattle.

5. Conclusion

The TST approach tested here significantly decreased the number of anthelmintic treatments applied (by 92% compared to the regulary dewormed animals). At the same time, the LWG and DWG in animals subjected to TST were significantly lower than in the SP group, while they were higher than in the NT group the last two years when the

animals in the different group were in separate enclosures. In contrast, FEC in the TST group was as high as in the NT group, whereas they were close to zero in SP group throughout this study. However, in this study we compared a TST strategy with two treatments that would themselves not be recommended under practical field conditions. To this extent, this TST strategy has not been compared with current practices. Thus, further studies are required comparing TST with present worm control recommendations, to indicate whether effective control can be achieved with a reduction in anthelmintic use compared to programmes presently required to give adequate control.

Acknowledgements

The study was funded by Formas (220-2007-1616), the 7th framework programme of the EU (GLOWORM, Project FP7-KBBE-2012-288975), and the Swedish University of Agricultural Sciences. We thank Jonas Dahl and David Johansson at Götala Research Station for carrying out the daily work with the animals.

References

Andersson, R.C., 1992. Nematode parasites of vertebrates. CAB International, University Press Cambridge, Cambridge578.

Borgsteede, F.H., Hendriks, J., 1974. Identification of infective larvae of gastrointestinal nematodes in cattle. Tijdschr. Diergeneeskd. 99, 103–113.

Demeler, J., van Zeveren, A.M.J., Kleinschmidt, N., Vercruysse, J., Höglund, J., Koopmann, R., Cabaret, J., Claerebout, E., Areskog, M., von Samson-Himmelstjerna, G., 2009. Monitoring the efficacy of ivermectin and albendazole against gastro intestinal nematodes of cattle in Northern Europe. Vet. Parasitol. 160, 109–115.

Demeler, J., Kuttler, U., von Samson-Himmelstjerna, G., 2010. Adaptation and evaluation of three different *in vitro tests* for the detection of resistance to anthelmintics in gastro intestinal nematodes of cattle. Vet. Parasitol. 170, 61–70.

Dorny, P., Vercruysse, J., 1998. Evaluation of a micro method for the routine determination of serum pepsinogen in cattle. Res. Vet. Sci. 65, 259–262.

Edmonson, A.J., Lean, I.J., Weaver, L.D., Farver, T., Webster, G., 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72, 68–78.

Frame, J., 1993. Herbage mass. In: Davis, A., Baker, R.D., Grant, S.A., Laidlaw, A.S. (Eds.), Sward Measurement Handbook. British Grassland Society, UK, pp. 39–67.

Gallidis, E., Papadopoulos, E., Ptochos, S., Arsenos, G., 2009. The use of targeted selective treatments against gastrointestinal nematodes in milking sheep and goats in Greece based on parasitological and performance criteria. Vet. Parasitol. 164, 53–58.

Goździk, K., Engström, A., Höglund, J., 2012. Optimization of in-house ELISA based on recombinant major sperm protein (rMSP) of *Dictyocaulus viviparus* for the detection of lungworm infection in cattle. Res. Vet. Sci. 93, 813–818.

Goering, H.K., van Soest, P.J., 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). In: Agricultural Handbook No. 379. USDA Department20.

Greer, A.W., Kenyon, F., Bartley, D.J., Jackson, E.B., Gordon, Y., Donnan, A.A., McBean, D.W., Jackson, F., 2009. Development and field evaluation of a decision support model for anthelmintic treatments as part of a targeted selective treatment (TST) regime in lambs. Vet. Parasitol. 164, 12–20.

Greer, A.W., McAnulty, R.W., Gibbs, S.J., 2010. Performance-based targeted selective anthelmintic treatment regime for grazing dairy calves. In: Proceedings of the 4th Australasian Dairy Science Symposium, pp. 385–389.

Höglund, J., 2010. Parasite surveillance and novel use of anthelmintics in cattle. Acta Vet. Scand. 52, 2–5.

Höglund, J., Morrison, D.A., Charlier, J., Dimander, S.O., Larsson, A., 2009. Assessing the feasibility of targeted selective treatments for gastrointestinal nematodes in first-season grazing cattle based on mid-season daily weight gains. Vet. Parasitol. 164, 80–86.

Höglund, J., Törnqvist, M., Rydzik, A., Ljungström, B., 2008. Best use of doramectin in first season grazing calves. Swed. Vet. J. 4, 11–18.

Kenyon, F., Greer, A.W., Coles, G.C., Cringoli, G., Papadopoulos, E., Cabaret, J., Berrag, B., Varady, M., Van Wyk, J.A., Thomas, E., Vercruysse, J., Jackson, F., 2009a. Refugia based approaches to the control of gastrointestinal nematodes of small ruminants. Vet. Parasitol. 164, 3–11.

Kenyon, F., Sargison, N.D., Skuce, P.J., Jackson, F., 2009b. Sheep helminth parasitic disease in south eastern Scotland arising as a possible consequence of climate change. Vet. Parasitol. 163, 293–297.

Lindgren, E., 1979. The nutritional value of roughages determined in vivo and by laboratory methods. Report No. 45. Department of Animal Nutrition, Swedish University of Agricultural Sciences, Uppsala, Sweden (in Swedish).

Ouzir, M., Berrag, B., Benjouad, A., Cabaret, J., 2011. Use of pathophysiological indicators for individual decision of anthelmintic treatment of ewes against gastro-intestinal nematodes in Morocco. Vet. Parasitol. 180, 372–377.

Van Dijk, J., Sargison, N.D., Kenyon, F., Skuce, P.J., 2010. Climate change and infectious disease: helminthological challenges to farmed ruminants in temperate regions. Animal 4, 377–392.

Van Wyk, J.A., 2001. Refugia – overlooked as possibly the most potent factor concerning the development of anthelmintic resistance. Onderstepoort J. Vet. Res. 68, 55.