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Article

Reduction in Greenhouse Gas Emissions Associated with Worm Control in Lambs

Fiona Kenyon [1], Jan M. Dick [2], Ron I. Smith [2], Drew G. Coulter [2], David McBean [1] and Philip J. Skuce [1,*]

[1] Moredun Research Institute, Pentlands Science Park, Bush Loan, Penicuik, EH26 0PZ, Scotland, UK; E-Mails: fiona.kenyon@moredun.ac.uk (F.K.); dave.mcbean@moredun.ac.uk (D.M.)

[2] SEE360, Bush House, Edinburgh Technopole, Penicuik, Midlothian, EH26 0BB Scotland, UK; E-Mails: jan@cplan.org.uk (J.M.D.); ron@cplan.org.uk (R.I.S.); drew@cplan.org.uk (D.G.C.)

* Author to whom correspondence should be addressed; E-Mail: philip.skuce@moredun.ac.uk; Tel.: +44-(0)131-445-5111 ext.435; Fax: +44-(0)131-445-6111.

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Abstract: There are currently little or no data on the role of endemic disease control in reducing greenhouse gas (GHG) emissions from livestock. In the present study, we have used an Intergovernmental Panel on Climate Change (IPCC)-compliant model to calculate GHG emissions from naturally grazing lambs under four different anthelmintic drug treatment regimes over a 5-year study period. Treatments were either "monthly" (NST), "strategic" (SPT), "targeted" (TST) or based on "clinical signs" (MT). Commercial sheep farming practices were simulated, with lambs reaching a pre-selected target market weight (38 kg) removed from the analysis as they would no longer contribute to the GHG budget of the flock. Results showed there was a significant treatment effect over all years, with lambs in the MT group consistently taking longer to reach market weight, and an extra 10% emission of CO_2e per kg of weight gain over the other treatments. There were no significant differences between the other three treatment strategies (NST, SPT and TST) in terms of production efficiency or cumulated GHG emissions over the experimental period. This study has shown that endemic disease control can contribute to a reduction in GHG emissions from animal agriculture and help reduce the carbon footprint of livestock farming.

Keywords: greenhouse gas emissions; sustainable parasite control; targeted selective treatment; carbon footprint; livestock; anthelmintic

1. Introduction

There is considerable political pressure on many sectors of industry to reduce their carbon footprint to meet ambitious greenhouse gas (GHG) reduction targets in order to mitigate anthropogenic climate change. For example, the UK Government Climate Change Act 2008 [1] requires an 80% GHG reduction by 2050, across the economy, with an 11% reduction from Agriculture by 2020. Globally, agriculture accounts for between 9%–18% of total GHG emissions [2]. Emissions from the agricultural sector in the UK were just over 49 $MtCO_2e$ in 2009, approximately 9% of UK GHG emissions [3], with emissions from livestock calculated to account for approximately 3% of the total [4]. The current UK agricultural inventory primarily implements a basic approach with emission factors, derived from an Intergovernmental Panel on Climate Change (IPCC) international literature review [5], multiplied by national statistics on fertiliser use and livestock numbers to generate emission estimates for the sector. This simple approach is supplemented by more detailed modelling where extra information is available from UK-based research.

Globally, GHG emissions from agriculture are expected to rise, driven by three main factors: (i) increasing global human population, estimated to reach nine billion by 2050, (ii) increased demand for livestock (meat and dairy) products in emerging economies, e.g., China, India and Russia, and (iii) technological changes including increased use of synthetic fertiliser, irrigation and intensification of animal production systems [6]. To meet this global challenge and to secure sufficient safe and nutritious food, agriculture needs to double its output while halving its environmental and waste footprint, so-called "sustainable intensification" [7]. Hence, there is a new requirement for livestock farmers to become more carbon emission efficiency-driven. Animals emitting GHGs whilst not growing or producing efficiently because of sub-clinical illness add significantly to a farm's environmental footprint [4]. Thus combating endemic, production-limiting disease on livestock farms would be considered essential for any improvement in the efficiency of production [8].

There is increasing research effort being focused on calculating the reduction in GHG emissions associated with increased livestock farming efficiency. Previous studies have considered management options such as changing lambing time to coincide with grass growth, mating ewes for the first time as lambs rather than yearlings, feeding lambs to reduce time to slaughter [9], and also feeding strategies such as supplementary fats, application of methane inhibitors [10] and genetic selection for reduced emissions [11]. There has also been considerable interest in improving livestock productivity through breeding and fertility [4]. However, little attention has been paid to the impact of animal health status on GHG emissions from livestock; as a result there are very few quantitative data available, although the role of endemic disease control in this context has been recognised by policy makers in the agricultural sector, e.g., bovine viral diarrhoea (BVD) control in Scotland [12] and Northern Ireland [13]

Parasitic worms, specifically gastrointestinal nematodes (GIN), are responsible for some of the most important production-limiting diseases of farmed livestock globally [14]. For example, in 2005, GIN parasitism was calculated to cost the UK sheep industry in the region of £84 million [15]. Gastrointestinal nematodes typically cause inappetance and poor nutrient utilisation with resultant ill-thrift. It is hypothesized, therefore, that GIN infection may increase the carbon footprint of livestock farming by increasing the time and inputs required for animals to reach final production weight. Routine anthelmintic drug treatment is the mainstay of helminth parasite control worldwide. However, this practice is associated with increased anthelmintic resistance in GIN parasite populations, especially in sheep and goats, and is now recognised as a major issue of concern for livestock farmers throughout the world [16,17]. Recent research has shown that maintaining a parasite population *in refugia i.e.* unexposed to anthelmintic treatment through reduced or targeted treatment, can help slow the development of anthelmintic resistance [18] Treatment strategies which minimise the use of anthelmintics but maximise production efficiency whilst, at the same time, providing effective and sustainable parasite control, would be considered the best options for future worm control.

The aim of the present study is to provide robust and objective data on the role of animal health in the context of GHG emissions from grazing livestock. In this study, we use a 5-year field trial [19] to estimate GHG emissions from naturally grazing lambs treated under one of four anthelmintic regimes aimed at controlling endemic helminth parasites under genuine field/farm conditions in Scotland.

2. Materials and Methods

2.1. Field Study

The experimental design for this study has already been described by Kenyon *et al.* [19]. Briefly, replicated field trials were conducted over five consecutive years (2006–2010) at the Moredun Research Institute farm, near Edinburgh, Scotland. At the beginning of each grazing season (May), 16–24 twin lambs at 5–6 weeks of age, and their dams, were allocated to one of eight groups balanced for lamb weight and sex. Each year, lambs were randomly assigned by group to a paddock on which they grazed from May to October whilst exposed to natural GIN infection. Each of eight one hectare paddocks was randomly assigned to one of four treatment regimes, with each treatment regime replicated once. The anthelmintic treatment given, when required, was ivermectin, administered orally (Oramec, Merial, at manufacturer's recommended dose rate of 0.2 mg per kg liveweight). Each paddock received the same treatment for every consecutive year of the experiment. The treatment regimes tested were as follows:

1. Neo-Suppressive Treatment (NST group), in which all lambs were treated every four weeks throughout the experimental period.
2. Performance-based Targeted Selective Treatment (TST group), where lambs were assessed on their ability to reach individualised target growth rates [16] every two weeks, with those not achieving their set targets being treated.
3. Strategic Prophylactic Treatment (SPT group), in which all lambs were treated at strategically appropriate times based on knowledge of the epidemiology of key GIN species on this farm *i.e.* at weaning and six weeks post-weaning.
4. Metaphylactic/Therapeutic regime (MT group), in which all lambs were treated when individuals within the group exhibited clinical signs of parasitism, including high faecal egg count (FEC), scouring and/or weight loss. The MT group provided a comparison of the potential productivity losses that might occur in the absence of regular chemical intervention.

Liveweights of all lambs were recorded every two weeks throughout the experimental period at which time a decision to treat TST animals based on their ability to reach live weight gain targets was made. The treatment regimes continued until the end of the grazing season at day 154 when all lambs were removed and the pastures left fallow until the trial resumed with a fresh batch of lambs the following spring.

2.2. Greenhouse Gas Emission Model

An IPCC-compliant model (CPLANv2) was modified to focus on the growing period of the lambs in the study, from about 5–18 weeks of age, and was used to model the GHG emissions over the 154 days of the field trial for each of five years. The model is designed to use the default IPCC sheep equations [5] with parameterisation for Western Europe. This relies on the weight of the animal driving a set of energy requirement equations and includes assumptions about the available nutrition and the waste products produced by the animal. There are both direct emissions of GHGs by the animal and further indirect emissions from the consequences of manure being in storage and being spread on the soil. In this experiment, all manure is assumed to be deposited on the pasture.

The model to calculate GHG emissions operates on a daily time step, so calculations are done for each lamb's growth over the successive 14 day periods. The parameters for calculating the net energy used for maintenance and growth are different for female, male and castrated lambs, so for simplicity the model assumed 50% female and 50% male lambs in the composition of all the flocks. The balance of nutrition between milk and grass feed also affects the GHG emissions, and the timing of changeover from mainly milk to mainly grass-fed is required for more detailed modelling; as these data were not available for individual lambs in this experiment, it is assumed that lambs in all treatments were grass-fed throughout the experimental period, which will introduce an upward bias in the calculated GHG emissions. In accordance with IPCC guidelines, the estimated emission of GHGs from the lambs included emissions of methane from enteric fermentation in the digestive system and emissions of both methane and nitrous oxide from manure decomposition on pasture. With the above simplifying assumptions, the model was used to give comparative estimates of GHG emissions across the treatment strategies employed in the study, with the biases in estimates expected to be similar for all treatments.

To simulate what would happen on a commercial farm, a target slaughter weight of 38 kg was set for all years in the experiment. A slaughter weight of 38 kg equates to a dead weight of 17–19 kg, depending on a killing-out percentage (45%–50%), this is a standard weight for the UK supermarket trade [20]. Total cumulative GHG emissions were calculated for all animals in the respective treatment groups until they had reached the pre-selected slaughter weight of 38 kg, at which time they were removed from subsequent GHG calculations.

3. Results

3.1. Proportion of Lambs Reaching Target Slaughter Weight

From a total of 830 lambs in the experiment over the five years, 338 lambs reached the target weight of 38 kg, with 286 lambs of these reaching this target and being removed from their respective treatment group before the end of the experimental period. Table 1 shows the proportion of lambs that reached the target slaughter weight of 38 kg in each year in each treatment group. The statistical analysis, using a generalised linear model with a binomial error function and logit link, shows that effect of Treatment is significant ($P < 0.05$) as is the effect of Year ($P < 0.01$). Across the five years, only 24% of lambs in the

MT treatment group reached their target slaughter weight, significantly fewer compared with 44%, 44% and 51% for the SPT, TST and NST treatment groups, respectively. 2010 had significantly more lambs reaching 38 kg live weight than the other years, and 2008 had significantly fewer than 2006, 2009 and 2010. The interaction Year x Treatment is not statistically significant. The standard errors vary and are approximately 5% for overall treatment, 6% for overall year, and 12% for the interaction.

Table 1. Percentages of lambs that reached slaughter weight of 38 kg in each year following treatment under one of four different anthelmintic regimes.

Treatment	2006	2007	2008	2009	2010	Overall Treatment
MT	12.5	16.7	3.1	25.0	60.0	23.6 a
NST	62.5	43.7	21.9	40.0	82.5	51.4 b
SPT	33.3	33.3	32.3	50.0	70.0	43.5 b
TST	36.2	33.3	28.1	45.0	80.0	44.4 b
Overall Year [1]	36.1 a	31.8 a	21.3 a	40.0 a	73.1 b	40.7

[1] Different letters associated with overall treatment and overall year means on the column and row margins signify statistically significant differences ($P < 0.05$).

3.2. GHG Emissions Associated with Anthelmintic Treatment Group

The cumulative GHG emissions reflect the differences in weight and weight gain between the animals at the end of the experiment (Figure 1). The GHG emissions for lambs reaching their target slaughter weight of 38 kg ranged from 20 kgCO_2e for an individual in 2010 in the SPT group, which reached its target weight on day 56 of the experiment, compared with 58 kgCO_2e for an individual lamb in the SPT group of 2006, which did not reach its target weight until the end of the experimental period on day 154. The relationship between live weight gain and GHG emissions, however, was not linear, as is apparent from the scatter between weight gain of a lamb and the associated estimated cumulative GHG emissions for the period either until it reached its target slaughter weight or until the end of the experiment.

The detail of this relationship was explored by calculating the cumulative GHG emissions per kg live weight gained (Table 2). Lambs in the MT treatment group commonly had the highest GHG emissions per kg live weight gained, reflecting the fact that many had not reached their target slaughter weight and, hence, a greater number of lambs were continuing to contribute to the cumulative GHG emissions throughout the experimental period as they grew at a slower rate. The standard errors vary and for overall treatment and overall year means are approximately 0.07 and 0.08, respectively, and 0.14 for the individual cell means.

Figure 1. Cumulative GHG emissions associated with the weight gain of 830 lambs treated under the four anthelmintic regimes from 2006 to 2010, inclusive (with lambs either reaching the target slaughter weight or the end of the experimental period at 154 days).

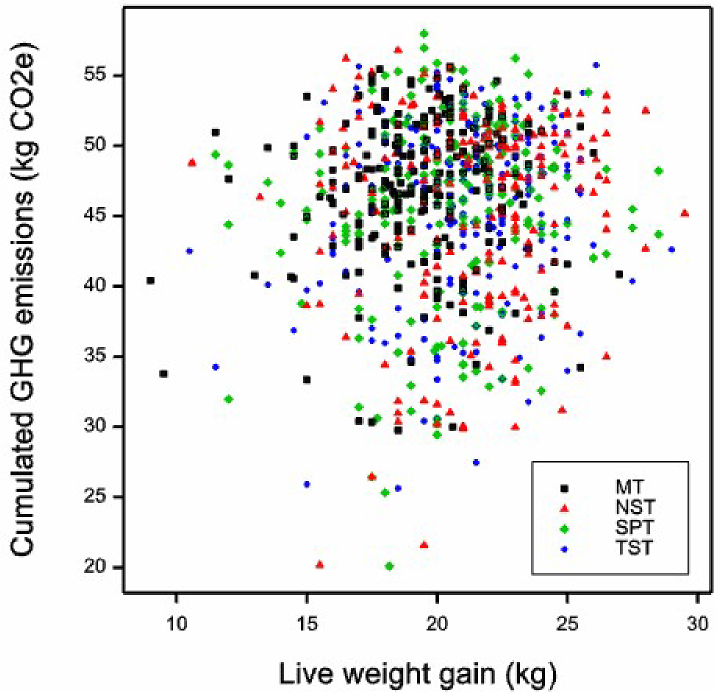


Table 2. Estimated average GHG emissions (kg CO_2e per kg live weight gain) assuming lambs removed from the treatment group at slaughter weight of 38 kg [1].

Treatment	2006	2007	2008	2009	2010	Overall Treatment
MT	2.51	2.53	2.42	2.67	2.25	2.48 b
NST	1.99	2.31	2.19	2.40	1.97	2.17 a
SPT	2.27	2.31	2.13	2.37	2.23	2.27 a
TST	2.16	2.29	2.16	2.31	2.14	2.22 a
Overall Year	2.23 ab	2.36 bc	2.23 ab	2.44 c	2.15 a	2.29

[1] Different letters associated with overall treatment means on the column margins signify statistically significant differences ($P < 0.05$), and with overall year means on the row margins ($P < 0.05$).

The difference between treatments was analysed using analysis of variance. This analysis revealed that the cumulative GHGs emitted over the experimental period by each animal, standardised for its weight gain (kg CO_2e emitted per kg of weight gain until the individual was removed at the target slaughter weight of 38 kg or until the end of the experiment, *i.e.* over 154 days of growth starting at approximately four to six weeks old depending on year), shows a significant effect for Treatment ($P < 0.01$) and for Year ($P < 0.05$) with the Treatment x Year interactions not statistically significant. The MT treatment produces significantly higher GHG emissions than the other three treatments (Table 2), and this is consistent for all years. However, analysing the cumulative GHGs emitted over the experimental period by each animal without standardisation (Table 3) showed only a statistically significant effect of Year ($P < 0.01$), with 2010 lower and 2007 higher than the remaining three years.

The standard errors vary and for overall treatment and overall year means are approximately 0.5 and 0.6, respectively, and 1.2 for the individual cell means.

Table 3. Estimated cumulated GHG emissions for the season (kg CO_2e per lamb) assuming lambs removed from the treatment group at slaughter weight of 38 kg.

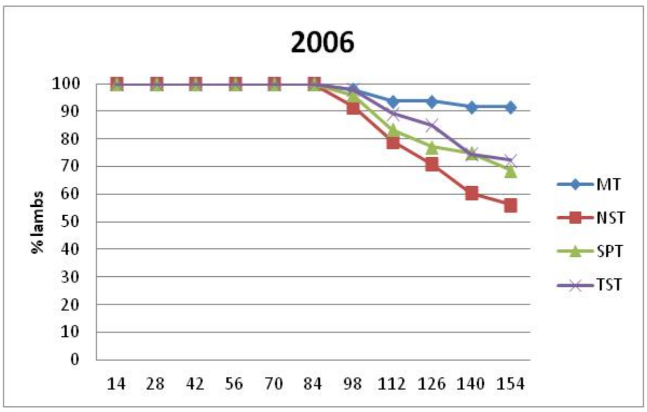
Treatment	2006	2007	2008	2009	2010	Overall Treatment
MT	46.43	48.59	46.25	48.9	43.76	46.86
NST	44.65	47.96	46.78	45.99	41.32	45.36
SPT	45.22	48.45	46.6	46.02	41.59	45.63
TST	45.8	48.71	45.41	46.03	41.77	45.68
Overall Year [1]	45.52 b	48.43 c	46.26 b	46.73 b	42.11 a	45.88

[1] Different letters associated with overall year means on the row margins signify statistically significant differences ($P < 0.05$).

3.3. Variation in Greenhouse Gas Emissions within and between Years

There was considerable variation between years in the proportion of lambs reaching the selected target weight of 38 kg and a consequential influence on their estimated GHG footprint (Figure 2). In all years, the MT group became separated from the SPT, TST and NST groups as animals were removed upon reaching their target weight. The overall GHG emissions were highest in 2007 and lowest in 2010 (Table 3).

Figure 2. Pairs of plots for each of the years 2006 to 2010 showing for the four treatments (on left) the % of lambs remaining in the experiment over the 154 days (*i.e.* those not yet reached the selected target weight of 38 kg) and (on right) the estimated greenhouse gas footprint (average kgCO_2e per lamb) for each successive 14 day period.



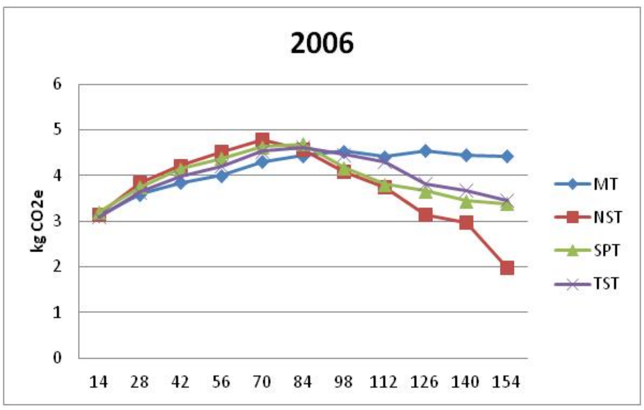
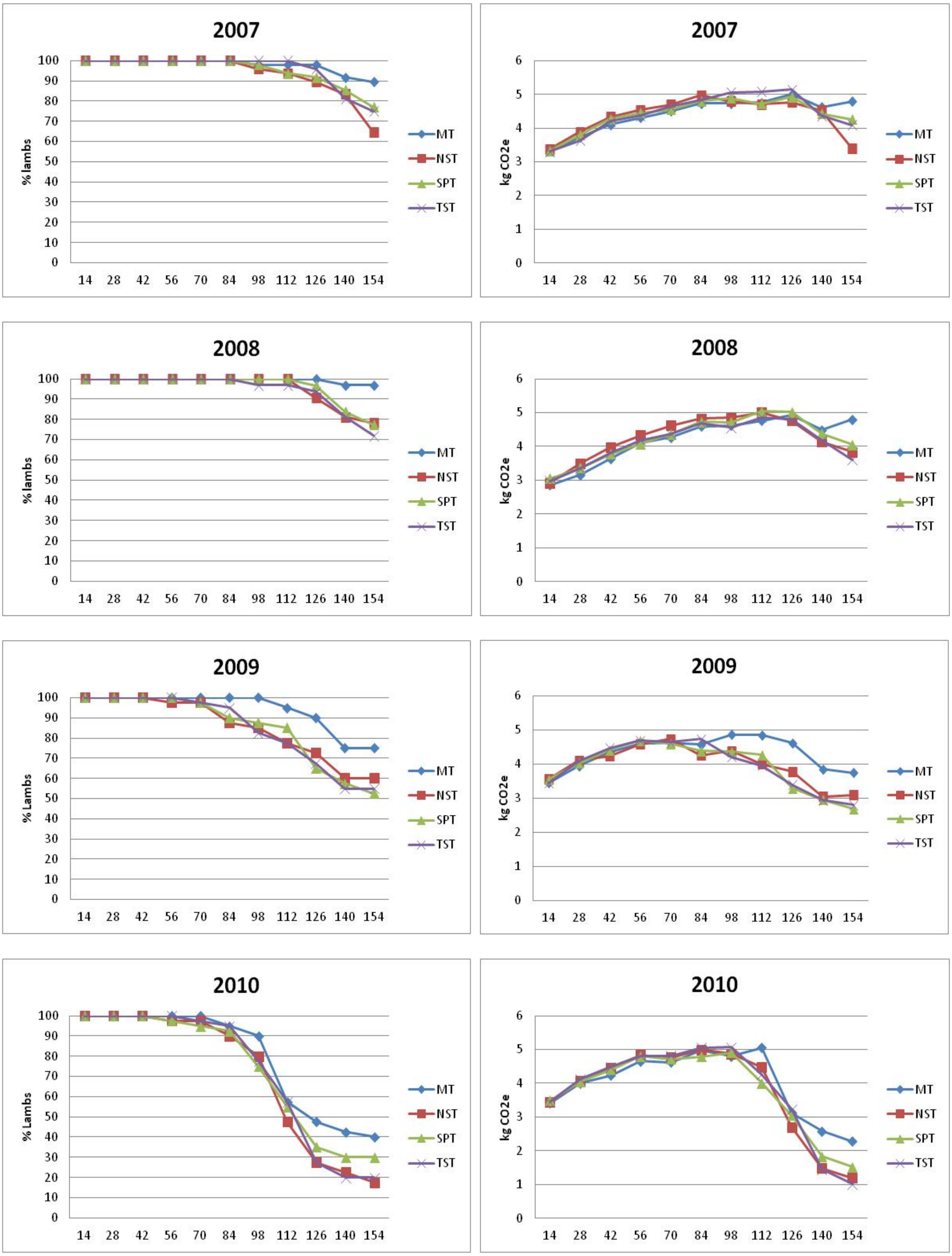


Figure 2. *Cont.*



4. Discussion

This study aimed to quantify the GHG emissions associated with naturally grazing lambs under one of four different anthelmintic treatment regimes aimed at controlling endemic gastrointestinal parasites. The analysis revealed that the anthelmintic regime adopted by the farmer to control GIN parasites can have a significant influence on the time it takes lambs to reach their desired slaughter weight and, as a consequence, the animal's carbon footprint.

Across the five years of the study, only 23.6% of lambs in the MT group reached their target slaughter weight compared with 43.5%, 44.4% and 51.4% for the SPT, TST and NST groups, respectively. Lambs in the MT group consequently, had a larger GHG footprint, with an extra 10% emission of CO2e per kg of weight gain over the other treatments. On average, over the whole study, the lambs in the MT treatment group had slightly higher total GHG emissions compared with the other anthelmintic regimes tested, but this was not statistically significant. They also received the fewest anthelmintic treatments, averaging approximately one treatment per year throughout the study [19]. There was no significant difference in GHG emissions between the SPT, TST and NST treatments indicating that the increased use of anthelmintic in the NST group did not improve performance and, essentially, represented wasted expense and effort. This was also reflected in the mean weight gain from these groups, as Kenyon *et al.* [19] reported no significant differences in mean bodyweight of lambs in these groups throughout the five year study.

There was considerable variability across the years in terms of lamb liveweight gain with, for example, only 3% of lambs in the MT group reaching their target weight in 2008 compared with 60% in 2010. This extreme difference was attributed to an outbreak of nematodirosis in spring 2008, lambs in the MT group being particularly vulnerable as they would have had no anthelmintic treatment up until that point [19]. There was more subtle variation in lamb liveweight gain between years, most likely due to variation in climatic conditions and environmental factors such as pasture growth and, hence, nutrient availability. The sex of the lambs will also influence liveweight gain and associated emissions, with the model assuming ~12% higher GHG emissions for male lambs compared to female lambs for any given weight or growth rate. The proportions of male and female lambs were not significantly different across the treatments within any given year, yet the MT group consistently diverged from the other three treatment groups over all five years. Year-to-year variability was balanced out by the time taken or proportion of the respective male and female lambs to reach the target weight and is not considered an important effect by comparison to the other model assumptions. It was also not deemed to be a contributory factor in the associated TST study [19]. There were also changes in the genetic make-up of the study flock over time. The breed of sheep varied across the 5-year study period as a result of a farm management decision to move from stocking Scottish Blackface to more commercial Texel breeds. In Year 1 (2006), Scottish Blackface x Leicester lambs were used but, in subsequent years, mule x Texel were used, with the genetic influence of the latter breed increasing year on year [19]. While this change may account for some of the increase in proportion of lambs reaching target market weight over time, this change applied equally across all treatment groups and there was still a significant difference in liveweight gain and associated GHG emissions between the MT and the other three treatment groups.

Very few, if any, studies have considered the annual variation in the GHG budgets of farms. While this study was not designed to do so, it is clear that, without taking such variation into account, regulatory mechanisms to monitor or control GHG emissions from farms could be both restrictive in terms of limiting a farmer's management choices, although excluding inefficient options should be beneficial overall. Such mechanisms could also involve climatic factors beyond the farmer's control. Policy-making related to GHG reduction strategies for food and agricultural production is a relatively recent activity [21], but the strong coupling of economic and GHG efficiency shown in this study leads to common strategies thus simplifying the process. It could be argued that farmers might increase stocking density as a result of these earlier finishing times for the lambs, but as this study is restricted to the grass-fed element within the full lamb production life-cycle and as the costs associated with the ewe are not altered, it seems unlikely that this management change alone would lead to increased flock numbers.

Although there were no significant differences in cumulative GHG emissions from the NST, SPT and TST groups, from a parasitological perspective, NST would not be considered to represent best practice as frequent treatment has been consistently shown to select strongly for anthelmintic resistance [17]. In this study, monthly neo-suppressive treatment (NST) throughout the study period, resulted in a reduction in ivermectin efficacy of 33.4% over the 5 years of the trial, compared to reductions of 9.0%, 11.6 and 14.4% for the TST, SPT and MT groups, respectively [19]. The NST regime, therefore, is associated with rapid selection for ivermectin resistance, yet it brings no significant production or GHG emissions advantage. It is worth noting that the SPT regime employed here was based on considerable experience and a sound understanding of the epidemiology of the parasite population on this property, it remains to be seen how applicable this approach is to other farm systems. Similarly, the TST regime used in this study requires an element of investment in equipment and labour input e.g., fortnightly weighing of lambs, but the advent of electronic identification systems, automated weighcrates and drafting systems with built-in decision support will help facilitate its use in practice [19]. Lambs in the TST group could conceivably have received more treatments than their NST counterparts, but this proved never to be the case; the average number of treatments ranged from 1.6–2.2 per year in the TST group against the standard four treatments in the NST group [19]. Considering all factors together e.g., lamb performance, drug usage, development of resistance and GHG emissions, then TST or SPT approaches would offer the best options for sustainable parasite control.

There are some small differences in the equations and parameter values used in a UK-specific model as against this IPCC version based on their 2006 reports [5]. For this particular experiment, there is a direct linear relationship between the two estimates with the UK model estimate being 21% greater than the IPCC model estimate, so raising the 2.5 kg CO_2e per kilogram liveweight gain for the lambs in this study to 3.0 kg CO_2e per kilogram liveweight gain if UK-specific parameters were used. The appropriateness of the particular assumptions for specific applications has to be further tested for a good on-farm estimate of GHG emissions, but these differences in assumptions do not change the relative performance of the treatments in this study.

In the present study, we only considered the growth of the lamb and did not include GHG emissions associated with the ewe or grass production, as these were considered standard across all treatments. The E-CO2 carbon dioxide equivalent calculator takes a Life Cycle Analysis approach, modelling GHG fluxes from birth to the farm gate, utilising conversion factors and economic allocation to establish annual GHG emissions per kilogram of live and deadweight for each enterprise [22]. On average, across 30 sheep enterprises in England, it has been estimated that the GHG budget of sheep meat is 11.95 kg

CO_2e per kilogram liveweight or 23.9 kg CO_2e per kilogram of carcase weight, with an estimated range of 9.57–12.87 kg CO_2e per kilogram liveweight for lowland flocks, equivalent to the production system in this study.

A recent carbon audit of 131 English beef and 57 English sheep enterprises [23], identified traits associated with low and high carbon livestock farms. Low carbon livestock farms were typified by, amongst other factors, (i) achieving optimum daily liveweight gains and (ii) achieving the best finishing weight as early as possible. Production-efficiency-based strategies such as TST, by definition, exemplify some of the key requirements of low carbon livestock farming. Several studies have highlighted the dominance of biological processes in contributing to the GHG budget of livestock farming systems [24,25]. Booth [26] surveyed 16 farms in Scotland on similar land types to the present study and estimated that livestock contributed over 70% of the total farm GHG emissions with the remainder being associated with energy and fuel (18.7%), fertilizer (7.6%), and emissions associated with crop residue in fields increasing soil emissions (<1%). In order to reduce the GHG footprint of livestock farms, mitigation options that target biological processes are, therefore, likely to be most effective. Management strategies aimed at maximising economic gain to the farmer and consequently the supply chain are increasingly being recognised as also reducing GHG emissions [9]. It has been estimated, for example, that every 1 kg CO_2e reduction per kg liveweight in GHG emissions is associated with a £0.28 improvement in English sheep enterprise margins [22]. Such economic benefits would also be more likely to encourage farmer uptake of appropriate GHG mitigation measures.

There are very little, if any, data available on the role of animal health and endemic disease on GHG emissions from livestock. The present study revealed differences in GHG emissions associated with four different anthelmintic treatment strategies in lambs, which are sufficiently large that they could have an impact on a farm's GHG budget. The differences relate to the weights of the animal but also reflect the length of time the animal is contributing to overall emissions from the farm. Although this study concentrates on gastrointestinal nematode control in sheep, these findings could have wider implications for livestock farming *i.e.* that sustainable control of other endemic, production-limiting diseases could help reduce the carbon footprint of livestock farming. In addition to gastrointestinal nematode parasitism in sheep and cattle [14,15], there are numerous studies in the scientific literature describing production losses due to disease in food-producing animals. Examples include (i) fewer units of product e.g., kg beef, produced per day due to paratuberculosis [27], (ii) animals taking more days to reach their target weight as a result of liver fluke infection [28], (iii) delayed onset, reduced yield and quality of production e.g., for milk due to mastitis [29], (iv) lost production *i.e.* lambs or calves aborted due to infection with *Chlamydia* or *Neospora*, for example, during pregnancy [30,31] and (v) premature culling, common in dairy cattle due to lameness or mastitis [32]. These studies tend to have an economic focus but they could equally be translated into emissions estimates, using GHG per unit product as the readout.

This study demonstrates that sustainable control of endemic, production-limiting disease represents a potential win-win situation, both from an economic and environmental standpoint. Such information will allow policy makers to make informed decisions about the mitigation options available for reducing GHG emissions from animal agriculture, balanced against the contribution of livestock products to local and global food security.

5. Conclusions

The present study has shown that effective management of endemic production-limiting disease, in this case, gastrointestinal parasites, can reduce the farm's GHG budget under simulated commercial farming conditions. Waiting for animals to show clinical signs before treatment had a production and GHG emissions penalty. There was little difference between the monthly, strategic and targeted treatment approaches in terms of performance efficiency and GHG emissions. However, monthly anthelmintic treatment is not sustainable as it selects strongly for resistance. Strategic treatment would be a better option but requires a sound understanding of the epidemiology of the gastrointestinal parasites on a given farm to be fully effective. Targeted (selective) treatment represents the best and most practical option for sustainable parasite control and reducing GHG emissions as it, by default, optimises daily liveweight gain, reduces the selection pressure for resistance and reduces the amount of anthelmintic used overall

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