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## Worm control in livestock: bringing science to the field

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*Published in:*  
Trends in Parasitology

*DOI:*  
[10.1016/j.pt.2017.05.008](https://doi.org/10.1016/j.pt.2017.05.008)

First published: 21/07/2017

*Document Version*  
Peer reviewed version

[Link to publication](#)

*Citation for published version (APA):*  
Kenyon, F., Hutchings, F., Morgan-Davies, C., van Dijk, J., & Bartley, DJ. (2017). Worm control in livestock: bringing science to the field. *Trends in Parasitology*, 33(9), 669 - 677. <https://doi.org/10.1016/j.pt.2017.05.008>

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1 **Worm control in livestock: bringing science to the field.**

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11

12 **Keywords**

13 Gastrointestinal nematodes, worms, anthelmintic resistance, best practice

14

15 **Abstract**

16 Parasitic roundworm infections are ubiquitous in grazing livestock. Chemical control  
17 through the frequent 'blanket' administration of anthelmintics (wormers) has been,  
18 and remains, the cornerstone in controlling these infections, but this practice is  
19 unsustainable. Alternative strategies are available but, even with the plethora of best  
20 practice advice available, have yet to be integrated into routine farming practice. This  
21 is probably due to a range of factors including contradictory advice from different  
22 sources, changes to advice following increased scientific understanding and top-  
23 down knowledge exchange patterns. In this article, we discuss the worm control  
24 options available, the translation of new best practice advice from science bench to  
25 field and ideas for future work and directions.

26

## 27 **Worm infection limits productivity in grazing livestock**

28 Parasitic roundworms (gastrointestinal nematodes) are ubiquitous on pastures  
29 grazed by livestock. Although infections are generally sub-clinical, they result in  
30 considerable losses in livestock productivity [1 <http://www.discontools.eu/Diseases>].  
31 Estimates of losses of up to 10% of sale value [2] and of around £80 million and  
32 €334 million per annum, respectively, for the UK and EU sheep markets alone [3].

33 Chemical control, through frequent and often indiscriminate use of **anthelmintics**  
34 (wormers, see Glossary), was widely recommended as a strategy to optimise  
35 production, but resistance to these drugs has increasingly been recognised, making  
36 the long-term viability of this approach untenable. The increasing prevalence and  
37 wide-spread dissemination of worms resistant to most of the available anthelmintic  
38 classes has forced the industry as a whole to develop a deeper understanding of  
39 nematode epidemiology and the selection pressures applied to the nematode  
40 community by anthelmintics. Most, but not all, of the principles that are detrimental to  
41 sustainable worm control are well established within the scientific community.  
42 However, many of these messages have failed to be routinely implemented by the  
43 farming community. Therefore, there are two main challenges for the provision of  
44 sustainable nematode control: a holistic understanding of the impacts of various  
45 control options and effective dissemination to, and uptake in, the farming community.  
46 In this opinion article, we summarise the opportunities and challenges that are  
47 present in the translation of new ideas and uptake of best practice advice in  
48 gastrointestinal nematode control options in livestock. We discuss several areas of  
49 worm control, highlighting the evidence present (or if appropriate, knowledge gaps),  
50 the current methods for dissemination of advice, and provide our ideas for the future.

## 51 **A range of different options are available to tackle worm infection**

52 Traditionally, the control of parasitic nematodes on farms included an element of  
53 'evasion', e.g. infection intensity was minimised through carefully planned grazing  
54 strategies (Table 1). For example, in spring, over-wintered larvae of the pathogenic  
55 species *Ostertagia ostertagi* die off rapidly and, therefore, a delay in turnout of calves  
56 until early summer, on pasture already mowed that year, is highly effective [4]. So-  
57 called 'leader-follower' systems were also commonplace on UK farms. These  
58 grazing strategies employ differences in the levels of host resistance, or immunity, of

59 ruminant age groups and host species to limit infective pressure in young,  
60 immunologically naïve, animals. Perhaps the most commonly used method was  
61 alternating cattle and sheep to graze plots, with cattle ‘hoovering up’ the worm  
62 species pathogenic to sheep and *vice versa*. Alternatively, calves and lambs were  
63 allowed to graze pasture first before the older, immune, animals then grazed the  
64 remainder. On pastures thought to be heavily contaminated, the older animals  
65 grazed the plots first thus removing large parts of the infective burden. A third  
66 important ‘evasive’ strategy is rotational grazing; instead of offering a large plot of  
67 land to animals for prolonged periods of time, it is divided into several sub-plots with  
68 animals returning to them only when the larvae have died off. For example, rotating  
69 calves monthly over 4 plots, especially if the plots are mown after they are grazed, is  
70 likely to control worm burdens, while facilitating the build-up of immunity [5].

71 Several concurrent trends in UK ruminant farming have made the evasive control  
72 practices less popular with farmers. Ruminant farms have intensified significantly  
73 over the past decades and, therefore, there has been pressure to both maximise  
74 pasture utilisation and optimise labour costs per animal unit. These modern farms  
75 normally only farm one ruminant species. The ascendance of *Mycobacterium avium*  
76 *paratuberculosis* (Johne’s disease), transmitted from cattle to sheep and from older  
77 cattle to young stock, has further limited the ‘leader-follower’ options. During the  
78 seventies, new, broad-spectrum, anthelmintics came onto the market and these  
79 instilled a feeling that more animals could safely be kept on smaller plots, without  
80 moving them to ‘clean’ pasture, as long as they were wormed regularly. The advice  
81 on worm control therefore made a step change from avoidance of burdens to  
82 acceptance that infective pressure at pasture may be high but that it can be  
83 controlled before becoming overly pathogenic.

84 There have been at least three distinct anthelmintic-based control strategies to date.  
85 Initially, it became commonplace to treat at least all young stock at set intervals, with  
86 the length of the interval between treatments (normally 4-6 weeks) determined by the  
87 residual effect of the drug used. Frequent treatment administrations have been  
88 shown to select heavily for **anthelmintic resistance** [6]. When this started to  
89 emerge, a call for drugs of different classes to be rotated slowed the build-up of  
90 resistance somewhat but could not stop the emergence of multiple-drug resistance  
91 on farms, directly threatening the livelihoods of farmers [7]. A second strategy

92 therefore focuses on lowering drug application frequency by targeting treatments to  
93 periods of high worm abundance levels (**targeted treatment, TT**). Crucially, TT is  
94 applied at group level, e.g., a whole flock of lambs will be treated at the same time.  
95 Given the over-dispersed distribution of parasites in animal populations, a key  
96 challenge to TT has been obtaining, and interpreting, a meaningful monitoring  
97 parameter reflecting the current worm burden [8]. If, the burden of the treatment  
98 group is over-estimated, then the method will result in a higher-than-necessary  
99 dosing frequency, whilst it is designed to do the opposite. However, if the burden is  
100 under-estimated, then disease and associated production losses may be witnessed  
101 when the test indicates a low burden. Moreover, even though doses are given less  
102 frequently, all animals are dosed at the same time and this still gives rise to  
103 bottlenecks in parasite populations which select for anthelmintic resistance. A third  
104 method, **targeted selective treatment (TST)** [9] specifically aims to lower the  
105 proportion of the parasite population exposed to anthelmintic drugs at any given  
106 time, and to lower the frequency of resistant alleles in the population by diluting  
107 these alleles with the offspring of non-resistant worms (e.g., ensuring that a  
108 proportion of worms remains *in refugia*). This is achieved by assessing individual  
109 animal-based patho-physiological parameters, such as weight gain, and identifying  
110 the animals which may benefit from treatment, while leaving animals which achieve  
111 certain parameter thresholds untreated. It has been shown repeatedly that this can  
112 be done without any overall negative effects on productivity [6, 10]. TST also brings  
113 significant savings on anthelmintic drug costs [11]. With farmers moving away from  
114 grazing management-based control strategies and TST currently the key  
115 interpretable anthelmintic-based strategy explicitly focussing on *sustainable* worm  
116 control, it is therefore pertinent to understand why TST has not been implemented on  
117 most farms as yet.

## 118 **Moving towards sustainable control**

119 The change from suppressive worming programmes to refugia-based sustainable  
120 control programmes has been advocated since 1992, with the Sustainable Control of  
121 Parasites in Sheep (SCOPS, [www.scops.org](http://www.scops.org)) industry group, established in 2004  
122 [12, 13], attempting to increase their uptake. The main challenge has been that  
123 suppressive worming regimes are prescriptive, easy to follow and, for many years,  
124 have yielded good productivity. Refugia-based approaches, on the other hand, may

125 not be as straight forward to implement. Initial concerns about reductions in  
126 productivity attached to these approaches were shown to be unfounded [6, 14, 15].

127 For example, dosing groups of animals and moving them to '**clean**' **pastures** at the  
128 same time is valid from a productivity point of view and appeals to common sense as  
129 it lowers the parasite challenge to lambs. However, moving lambs on to clean  
130 pasture where there is little refugia to "dilute out" the resistance worms can be highly  
131 selective for resistance and is therefore no longer recommended [13, 16].

132 Reversion to susceptibility in field studies, where anthelmintic to which resistance is  
133 present is avoided for a period of time, then reintroduced, show that the reversion to  
134 susceptibility is short lived [17, 18]]. It has been hypothesised that, although there is  
135 assumed to be a lack of fitness associated with resistant individuals, as their number  
136 increases, the genes of susceptible and resistant worms co-adapt meaning that  
137 differences in fitness are no longer obvious [17].

138 The dosing of whole-groups, whether lambs or ewes, is still common place, even  
139 though some workers [6] showed that the productivity of lambs did not decrease if  
140 targeted treatments were used. If whole group treatments are carried out, are there  
141 times when this could be acceptable? In cases where there is a high risk of disease,  
142 for example due to infection with *Nematodirus* species, where clinical disease can  
143 occur quickly, or fluke, then whole group treatment would be recommended. Also, if  
144 high levels of refugia are present on pasture, then the impact of whole group  
145 treatment on the development of resistance would be less than if refugia was low.

146 Sometimes, drugs with anthelmintic properties will have to be applied to the whole  
147 flock/herd, for the control of other parasites. For example, macrocyclic lactones are  
148 commonly used for scab control [19]. About 15% of the wormers currently used in  
149 the UK also have endectocidal activity and there is much discussion about the  
150 effects of their use for scab on the development of anthelmintic resistance. Crilly et  
151 al.[19] showed on farms that used macrocyclic lactones for scab control that the  
152 ewes expelled eggs earlier than would be expected but resistance was not  
153 definitively diagnosed. Therefore, more information is required on the effect of off-  
154 target administrations, such as psoroptic mange (scab) treatments on the  
155 development of resistance in nematodes, as the selection pressure will increase as  
156 the level of sheep scab infection continues to rise in the UK.

157 The first, commercially available gastrointestinal nematode vaccine was recently  
158 licensed for use in sheep in Australia and South Africa [20]. Research is on-going for  
159 other species, but are currently in the early stages of testing [21-23]. However, this  
160 approach holds promise as an additional tool in the armoury for sustainable  
161 nematode control.

162

### 163 **Translation of new ideas and knowledge to veterinarians, farmers and farming** 164 **advisors**

165 For mindsets on worm control to be successfully changed, the new control measures  
166 have to be underpinned by sound science and the message from the scientific  
167 community to farming industries has to be a united one; both have proven to be  
168 stumbling blocks in the past. For example, the way in which different anthelmintic  
169 classes should be best employed has been the subject of sustained and continued  
170 debate. Annual rotation of drugs has been advocated by many as a tactic to slow  
171 down the development of resistance. The theory behind this is that resistant worms  
172 pay an ecological fitness cost and so are 'weaker' than the susceptible ones, and  
173 fewer will survive when not exposed to wormer, lowering the number of worms  
174 carrying resistant alleles to a certain anthelmintic in the population. However, little  
175 data are available to support this theory. Within-season rotation is another option  
176 and one study suggested that the effects on slowing the development of resistance  
177 were minimal [24]. Modelling studies have hypothesised within-season rotation may  
178 be beneficial, but the full impact in the field has not yet been assessed [25, 26].

179

180 Historically, information transfer has occurred in a top-down approach, in a  
181 unidirectional fashion, rather than as an exchange of views by all interested parties.  
182 The latter is considered essential to facilitate effective exchange of information.

183

184 Information regarding the control of parasites of sheep is readily available from a  
185 wide range of actors (other farmers, veterinarians, agricultural merchants, farm  
186 advisors, pharmaceutical industry, levy boards, researchers and farming press to  
187 name a few), in an array of formats (journals, internet, social media, books, leaflets,  
188 scientific and popular press articles, newsletters and websites). As an example, the

189 phrase “*control of parasites of sheep*” has 0.5 million hits on Google™, 250,000 hits  
190 on Google scholar™). A number of extension programmes, for example, SCOPS in  
191 the UK and PARABoss ([www.wormboss.com.au](http://www.wormboss.com.au)) in Australia, are also available.  
192 The advent of the digital age has opened up the opportunities to use a wide range of  
193 new platforms including the use of video tuition, animations ([moredun.org.uk/worm-](http://moredun.org.uk/worm-)  
194 [animation](http://moredun.org.uk/worm-)), infographics, electronic-learning tools and decision support systems, but  
195 one area of concern is that the connectivity for many rural areas is still poor  
196 ([www.ofcom.org.uk/research-and-data/infrastructure-research/connected-nations-](http://www.ofcom.org.uk/research-and-data/infrastructure-research/connected-nations-)  
197 [2016](http://www.ofcom.org.uk/research-and-data/infrastructure-research/connected-nations-)), albeit getting better, and many farmer are frustrated by slow download-speed,  
198 potentially leading to poor uptake through these mediums.

199

200 Although information is generally readily available, previous surveys conducted into  
201 farmer behaviour have shown a variable uptake of some advice and  
202 recommendations provided to farmers regarding the treatment and control of gastro-  
203 intestinal nematodes (Bartley, D.J. PhD thesis, Edinburgh University, 2008) [27].  
204 showing that, as scientists, we do need to improve connectivity to the end users and  
205 simplify the messages that we are conveying.

206

207 So, what do we need to do to become more effective at communicating advice? The  
208 answer is likely to be multifaceted and include factors listed in Figure 1 (Key Figure).  
209 Firstly, we need to identify how farmer behaviour is best influenced; for example,  
210 what format would be preferred for the exchange of information? Then, the important  
211 factors are unifying the messages to minimise contradiction and/or ambiguity;  
212 tailoring advice to specific audiences and situations; ensuring guidance is compatible  
213 with farming practices and based on sound data; trying a range of formats be they  
214 theory based or practical, online or hard copy, peer to peer or academic and  
215 providing the appropriate infrastructure for effective knowledge exchange.

216 Workshops, on farm events, or farmer discussion groups can provide valuable  
217 opportunities for producers, researchers and farm veterinarians to get together and  
218 discuss issues and help put across practical applications to encourage farmers to  
219 practice sustainable worm control. One thing is for certain: improved communication  
220 among all parties is essential to ensure the long term sustainability, productivity and  
221 profitability of farming.

222



223

224

## 225 **Looking to the future**

226 Alternative ways of controlling worms of livestock do exist; so, how can the industry  
227 and research move forward? What should be the steps to ensure that uptake is  
228 occurring in the farming community?

229 Uptake of innovation is dependent on many factors, but two are paramount: the  
230 technology itself and the respondent (farmer/practitioner). Both need to be  
231 recognised if innovation is to be adopted. Milne and Paton [29] reviewed barriers to  
232 innovations in livestock systems and the importance of knowledge exchange. They  
233 identified three main areas important to innovation: attributes of the innovation, its  
234 dissemination and adopter characteristics. The lead barriers to adoption were  
235 insufficient information; unrealistic/inaccurate information; and high implementation  
236 and/or operating costs. They argued that “*innovations must ‘fit’ with existing*  
237 *systems*” and that “*realistic assessments of the risks associated with an innovation*  
238 *and how they compare with alternative options are also crucial*”. Accordingly, any  
239 positive or beneficial aspects of sustainable worm control options must be  
240 demonstrated to practitioners, for uptake to take place. TST can be advantageous  
241 for practitioners as the TST approach on a hill farm showed a reduction of wormer  
242 use (~40-50%), without a reduction in production (lamb weights at sales), thus  
243 bringing potential financial advantages to the farmer [30].

244

245 So, how could the implementation of these methods be facilitated? Pecuniary  
246 incentives could certainly help uptake, but often, farmers’ reasons are more than just  
247 financial. In studies of TST and the use of electronic identification (EID) of animals, it  
248 was found that the main barriers for further implementation and use were the  
249 (perceived) cost of the technology, the lack of specific training on how to use the  
250 equipment, and the diversity of systems and type of technology available on the  
251 market [31]. These factors have been confirmed as equally important for farms in  
252 other European countries [32]. There is a clear need for improved tools to help  
253 deliver pen-side worm control treatment options in a user-friendly format, with  
254 appropriate supporting information (impact of decisions; e.g., economically) (Box 1).

255 In addition, further research is required to fully understand the impacts of socio-  
256 economic and psychology factors on farmers' behaviour and their decision making  
257 processes. For instance, Charlier et al. [33] propose looking at economic and social  
258 context to understand factors that drive animal health ("ECONOHEALTH"). Likewise,  
259 Charlier et al. [34] state the importance of better economic impact assessment  
260 combined with non-economic factors for more effective health control strategies in  
261 cattle. Moreover, Van de Velde et al. [35] further argue that it is not just farmers'  
262 behaviour that is important on adoption intentions, but the influence of the significant  
263 others (e.g. family, veterinarian, etc.) [36].

264

265 Additionally, how can we promote the adoption of new strategies/technologies, as  
266 well as ensuring on-farm applicability? There is certainly a role to play for advisory  
267 services and technical consultancy, to help promote these alternative ways in a  
268 format readily understandable and useful for farmers. There is a clear need for  
269 information and training materials to be adapted to the relevant educational levels of  
270 the farmers targeted [32, 37, 38].

271

272 However, measuring success and uptake of any new method remains difficult.  
273 Production parameters within the sheep industry vary greatly, due to the diversity of  
274 sheep systems and practitioners' views. It is thus challenging to benchmark results,  
275 making the assessment of success or failure of new techniques on farms difficult.  
276 Modelling or participatory exercises (e.g. future planning scenarios and techniques),  
277 such as those used by Boden et al. [39], looking at the future of the sheep industry,  
278 and resilience to disease are certainly valuable. These techniques provide a means  
279 to explore "what if" scenarios, and allow forecasting the effects of introducing new  
280 methods on farms, as well as taking into account practitioners' views and attitudes.

281

## 282 **Concluding remarks.**

283 Infection with parasitic roundworms is ubiquitous in grazing livestock. Although  
284 frequent use of anthelmintics was, and in some cases, still is the cornerstone of  
285 control of these infections, this approach is not sustainable in the long-term due to  
286 the development of anthelmintic resistance. Other, alternative approaches are  
287 available but, in general, they have not been adopted into routine farm management.

288 A plethora of information is available, but this is sometimes contradictory, which can  
289 lead to confusion. Co-ordination of information from all sources should be possible,  
290 but may be difficult to achieve. Several questions still need to be answered before  
291 optimised worm control can be a reality for most farmers (see Outstanding questions  
292 box). There is a need for new and improved tools to help farmers and veterinarians  
293 to make optimised worm control treatment decisions. This can be achieved by the  
294 development of pen-side or automated decision support systems, using the cloud for  
295 ease of access and data storage; however, improvements to internet accessibility  
296 will be required to make this reality. Before these systems can be developed, more  
297 information is required on the best methods for knowledge exchange between  
298 interested parties, so that whatever method is identified as most useful can be  
299 applied to the decision support systems developed.

300

301 **Box 1 New tools will improve use of best practices among farmers.**

302 A variety of new tools are required to improve the use or dissemination of best  
303 practice advice among livestock farmers. These can be in several different areas, for  
304 example:

305 Automated performance monitoring and/or treatment decisions with user-friendly  
306 decision support systems. These could be in the form of apps or pen-side 'one-stop  
307 shops' (i.e. multi-purpose, multi-disease treatment indicators).

308 Individualised on-farm risk factor analysis and disease tracking, i.e. which diseases  
309 occurred on which fields and which control measures have been historically applied.  
310 This could be combined with epidemiological knowledge to optimise future control  
311 options

312 Economics of various treatment options. Farmers, veterinarians and their advisors  
313 need to see and understand the costs and benefits of various treatment options,  
314 including comparisons between traditional and sustainable control strategies. These  
315 need to include not only the economics but also effects on parasite populations or  
316 animal performance. Modelling of these and the associated economics would  
317 provide farmers, veterinarians and their advisors with concrete information on which  
318 to base their decisions.

319 As the number of technology driven decision support or recording systems increase,  
 320 so will the demand for secure data storage, which can be reliably accessed from  
 321 remote places where internet connections may be slower than average.

322

323

324

325 **Table 1. Key control options for the management of worm infections in grazing**  
 326 **livestock.**

Option	Strategy	Selection for anthelmintic resistance	Factors preventing uptake
Infection evasion	Late turnout	-	Diminished pasture utilisation, Laborious (care for housed animals) Cost Space
	Leader-follower system	-/+ *	Johne's disease transmission, Move towards mono-species farms
	Rotational grazing	-	Investment needed (fencing), space, Planning for multiple groups / flocks Move towards mono-species farms Johne's disease transmission,
Chemical removal of worm burdens	Dosing all animals at set intervals	+++	None
	Targeted treatment of all animals (TT)	-/+	Interpretation of monitoring data Requires in-depth knowledge of parasite situation on farm Identification of animals to treat
	Targeted selective treatment of individual animals (TST)	-/+	Unclear parameters for identification of animals to treat Investment in monitoring tools

327 \*if worm control is assisted by the application of wormers in one host species, there is potential for resistant worms to be  
328 passed on to the other host species. Key: - = does not select for AR, +/- = minimal contribution to the development of AR, +++  
329 = selects heavily for AR.

330

331

332

333

334

## 335 **Glossary**

336

337 **Anthelmintic:** Chemicals which can be used to control worm infections. Five  
338 different classes are currently available in the UK for use in sheep.

339 **Anthelmintic resistance:** the heritable reduction in the sensitivity of roundworms to  
340 anthelmintics when animals have been administered the correct dose of the drug, in  
341 the correct manner, using drugs that are within date and have been stored correctly.

342 **Clean pastures:** pastures that have no, or very low levels of worms present. This  
343 can occur if grass is newly seeded, if crops have been harvested e.g. hay, or if there  
344 has been drought conditions.

345 **Refugia:** parasite subpopulations from either the stages within the host or free-living  
346 stages on pasture that are not exposed to anthelmintic treatment, and that have the  
347 ability to complete their life cycle and pass on susceptible alleles to the next parasitic  
348 generation [39, reviewed by [10]. This is generally achieved by ensuring that a  
349 proportion of the parasite population remains unexposed to drug, through either TT  
350 or TST (see below).

351

352 **Targeted treatment (TT):** Treatment of a whole group of animals at a time selected  
353 to either minimise the impact on the selection for anthelmintic resistance, or to  
354 maximise animal productivity.

355 **Targeted selective treatment (TST):** The treatment of only some individuals within  
356 a group at one time, instead of the more common 'whole-flock' treatment, where all  
357 animals in the group are treated simultaneously (for review see [10])

358

359

360

361

362 **Figure 1, Key Figure. Factors influencing effective knowledge exchange and**  
363 **uptake/implementation of advice with particular reference to sustainable worm**  
364 **control.** Effective communication of information to producers is complex and likely  
365 to be influenced by a number of internal and external factors. The multifactorial  
366 nature to individual perceptions to advice and the uniqueness of drivers and barriers  
367 to effective knowledge exchange means that we need to develop strategies to  
368 disseminate information effectively. A quote often attributed to Albert Einstein states  
369 that "information is not knowledge. The only source of knowledge is experience"  
370 Veterinarians are often cited as trusted brokers for advice but it is essential that  
371 advice that they receive and ultimately give out is current, implementable and  
372 consistent from different data providers and is borne out of experience in different  
373 situations.

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